Accidents:
Failures to Re-frame

Dr. Randy Mumaw

International Symposium on
Pilot Training for Startle and Surprise Management

Soesterberg, Netherlands

September 26, 2019

SAN JOSÉ STATE UNIVERSITY
RESEARCH FOUNDATION

Overview

Surprises; but Larger Theme is Understanding

- Accidents can occur when system operators fail to understand system or airplane state

  . . . although misunderstandings also happen without accidents

- The design of the system interface, procedures, and training do not always support understanding

  . . . in fact, they can make it harder

- There is a tension between design and the interests of the operators

  . . . largely due to the evolution of system design

- I will offer several ideas for better supporting operator understanding

Making Sense of a Complex World

Challenges: Complex systems and unfamiliar forces

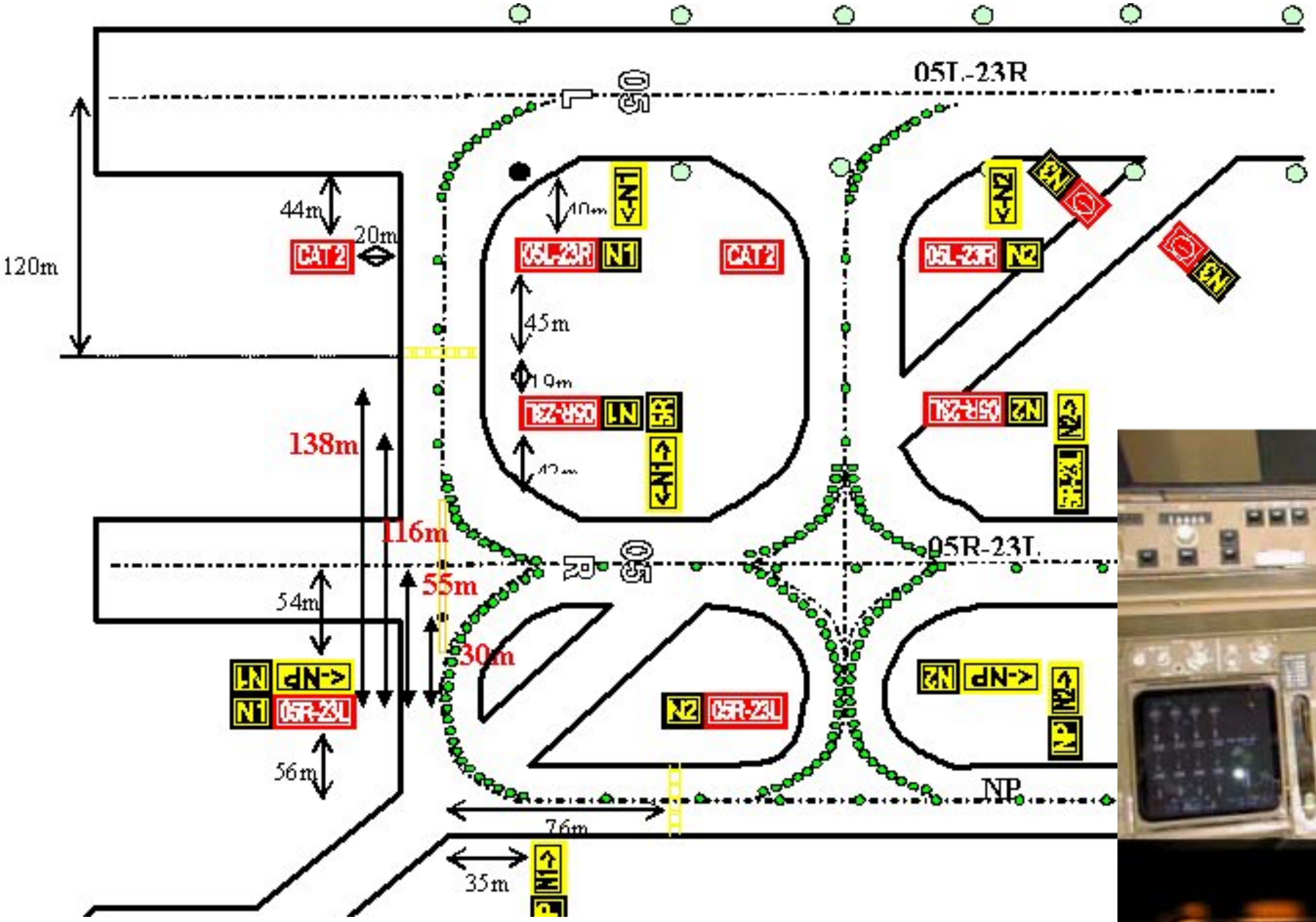
What are common reasons for surprise?

- Knowledge: Inadequate understanding of systems
  - Singapore 006
  - Spanair 5022
- False perception: Spatial disorientation
  - Flash Air 604

Let’s look at some missed opportunities to re-frame

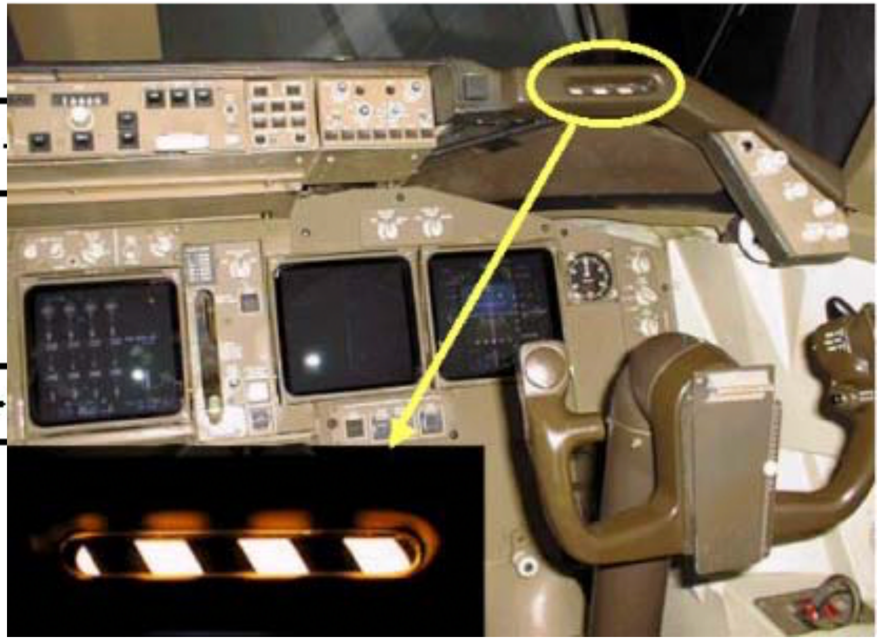
Singapore Airlines 006

Taipei, October 2000 / 747-400



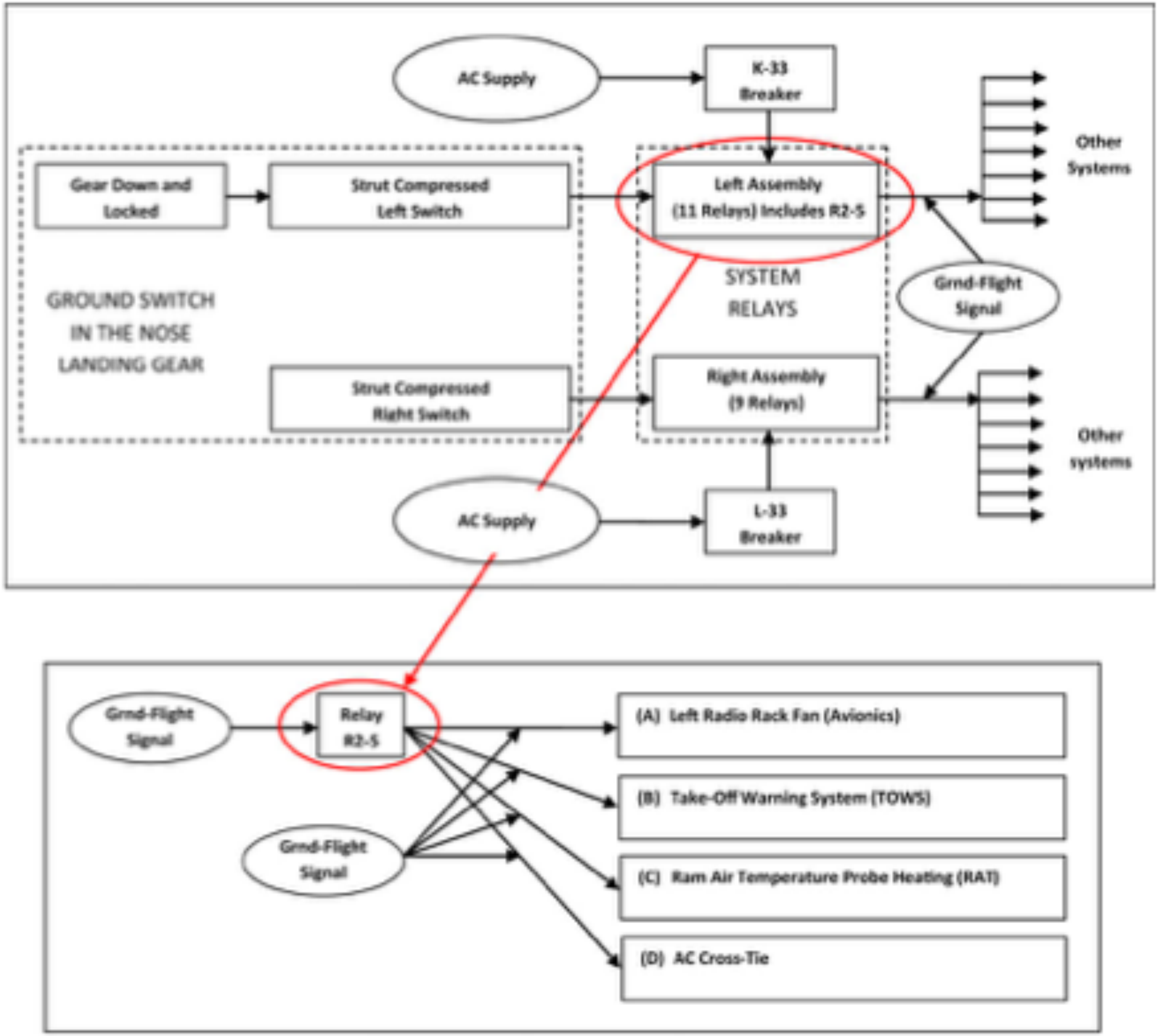
Surprise: PVD did not activate

Response (Capt): Not on yet er PVD huh never mind we can see the runway, not so bad. Ok, I am going to put it to high first.



Spanair 5022

Madrid, August 2008 / MD-82



Full airplane sitting on the runway on a hot day in August.

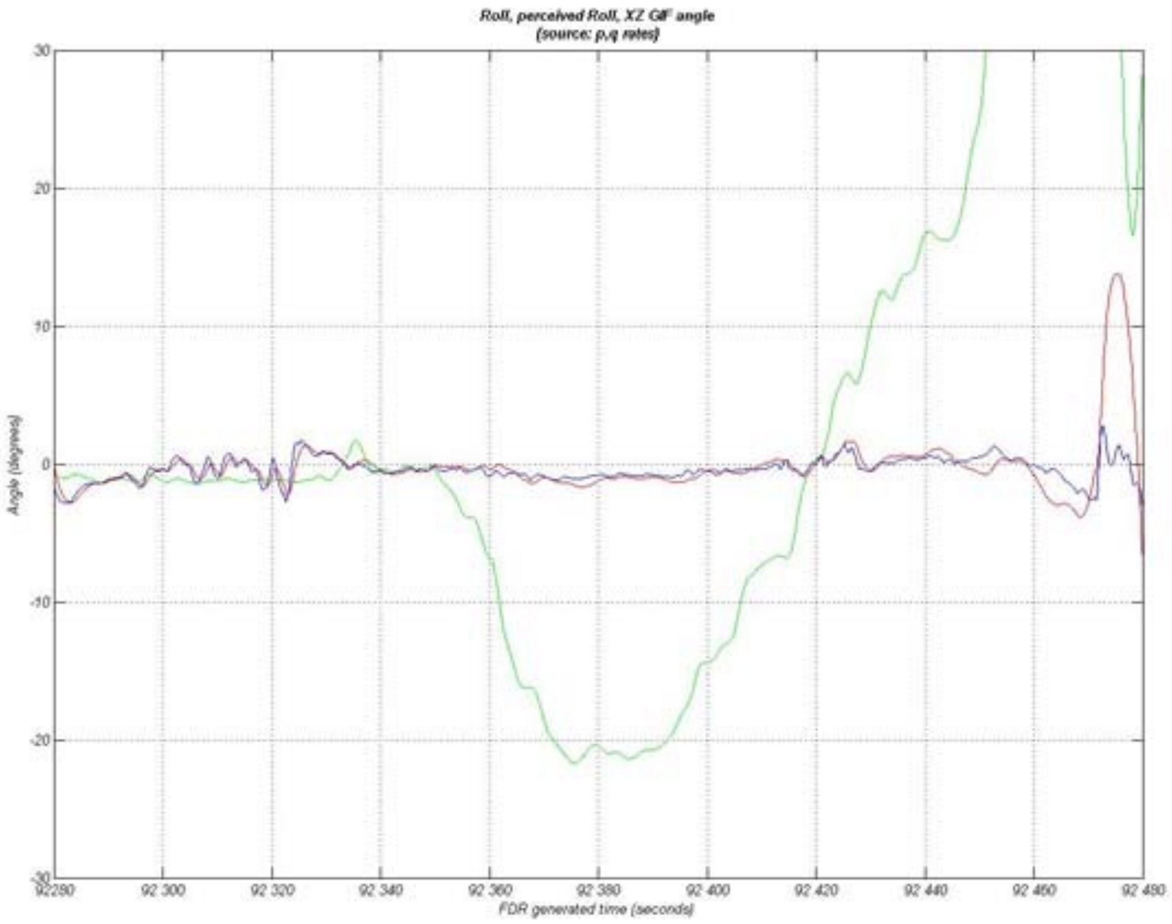
Surprise: Ram Air Turbine probe heat is on and its temperature is increasing.

Response (Capt): Reset breaker several times; after 30 minutes saw that MEL said “the airplane could be dispatched with the probe heating inoperative as long as icing conditions were not forecast for the flight”; so, disconnect power to RAT probe and depart.

Flash Air 604

Sharm el-Sheikh, January 2004

Sub-threshold Roll



Surprise 1 (with a Startle): Due to force on the column, the autopilot does not engage in the expected mode; the FD roll bar is lost.
Response (Capt): A shocked exclamation; distraction.

Surprise 2: The distracted Captain continues to make roll inputs to the right, ending up at 20º right instead of 20º left.
Response (Capt):

FO: Turning right, sir

Captain: What?

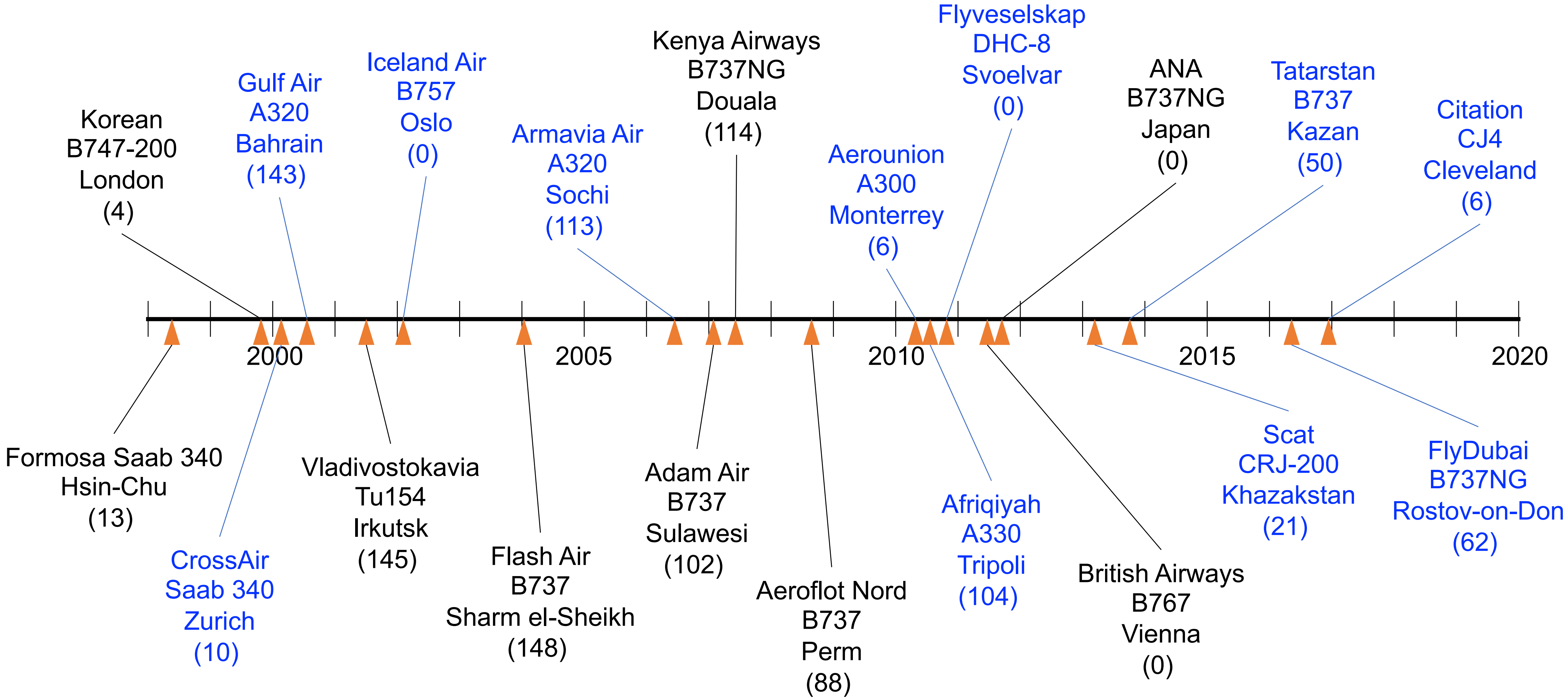
FO: Aircraft turning right

Captain: Turning right? How turning right?

The airplane eventually rolled to about 110° to the right before substantial control inputs in the opposite direction were made, which was too late to avoid the crash into the Red Sea.

SD in Commercial Aviation

SD is a Likely Contributor to a Significant Percentage of LOC Events



Blue = Likely somatogravic illusion
Black = Other form of SD

Autoflight Surprises (aka Mode Confusion)

16 Incidents and 26 Accidents

- The autopilot is off or failed, and the pilot thought it was engaged
  - Eastern L1011, near Miami, 1972; an inadvertent touch of the control column disengaged the A/P, and the airplane started a gradual, undetected descent into the ground
- The autopilot goes into an alternate control law and the autoflight behavior is changed
  - Air Asia A320, Indonesia, 2014; due to pilot actions, drop into Alternate Law mode. Unlike in normal operations, the airplane can stall in Alternate Law, and inappropriate pilot actions led to a stall.
- The autopilot takes actions that the pilot is not aware of
  - Aeroflot Nord 737, Perm, Russia, 2008; thrust levers were mis-calibrated but A/P was engaged and managing thrust. Pilot was unaware of A/P actions. When A/P was disengaged, pilot failed to handle thrust difference.
- The autopilot (or autothrottle) mode reverts to another mode
  - Flash Air 737, Sharm-el-Sheikh, Egypt, 2004; pilot engaged A/P but it engaged in control wheel steering (CWS-R) mode, and FD roll bar disappeared. Pilot exclaims from surprise by this reversion.
- The pilot does not understand the mode's behavior
  - Asiana 777, San Francisco, 2013; on approach, pilot selected FLCH mode for descent, and the airplane started climbing to the MCP altitude.
- The pilot failed to put the airplane into the correct mode or autoflight state
  - Air Inter A320, near Strasbourg France, 1992; on approach, the crew intended to program the autopilot for a 3.3-degree flight path, but inadvertently selected vertical speed mode (resulting in 3300 ft/min descent).

Barriers to Understanding

(and some proposals to remove the barriers)

- System interface
  - single-sensor, single indicator
  - autoflight: hidden rules, states, targets, and more
- Operational procedures
  - no accommodation for knowledge-based performance
  - not oriented to operational decisions
- Operator training
  - equipment-oriented
  - a reluctance to dissect expertise (“airmanship”)

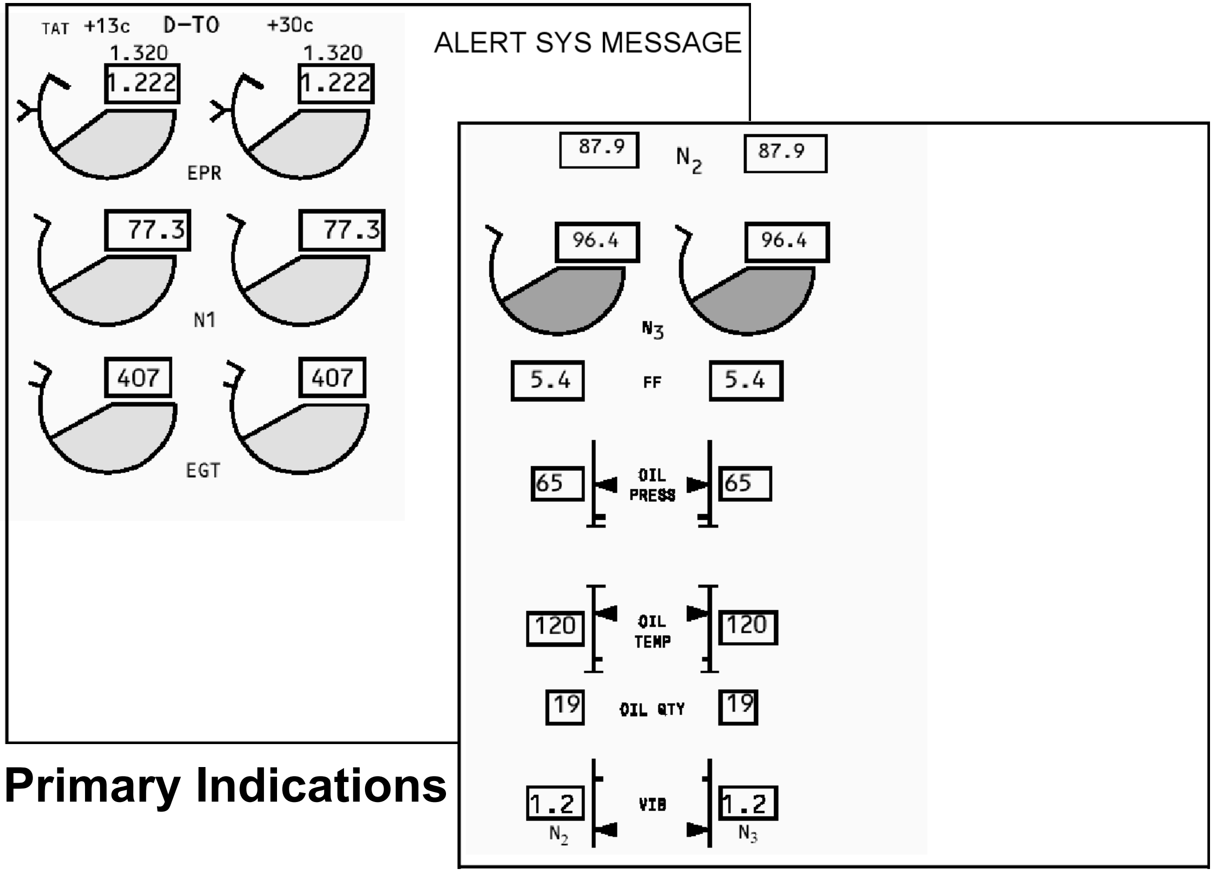
Single-sensor; single-indicator architecture

There is a burden on the operator to
- allocate attention appropriately
- add context
- understand system state
- identify developing problems

Airplane Interface Started the Same Way

The Airplane Interface has some Vestiges of SS-SI

Engine Indications



Primary Indications

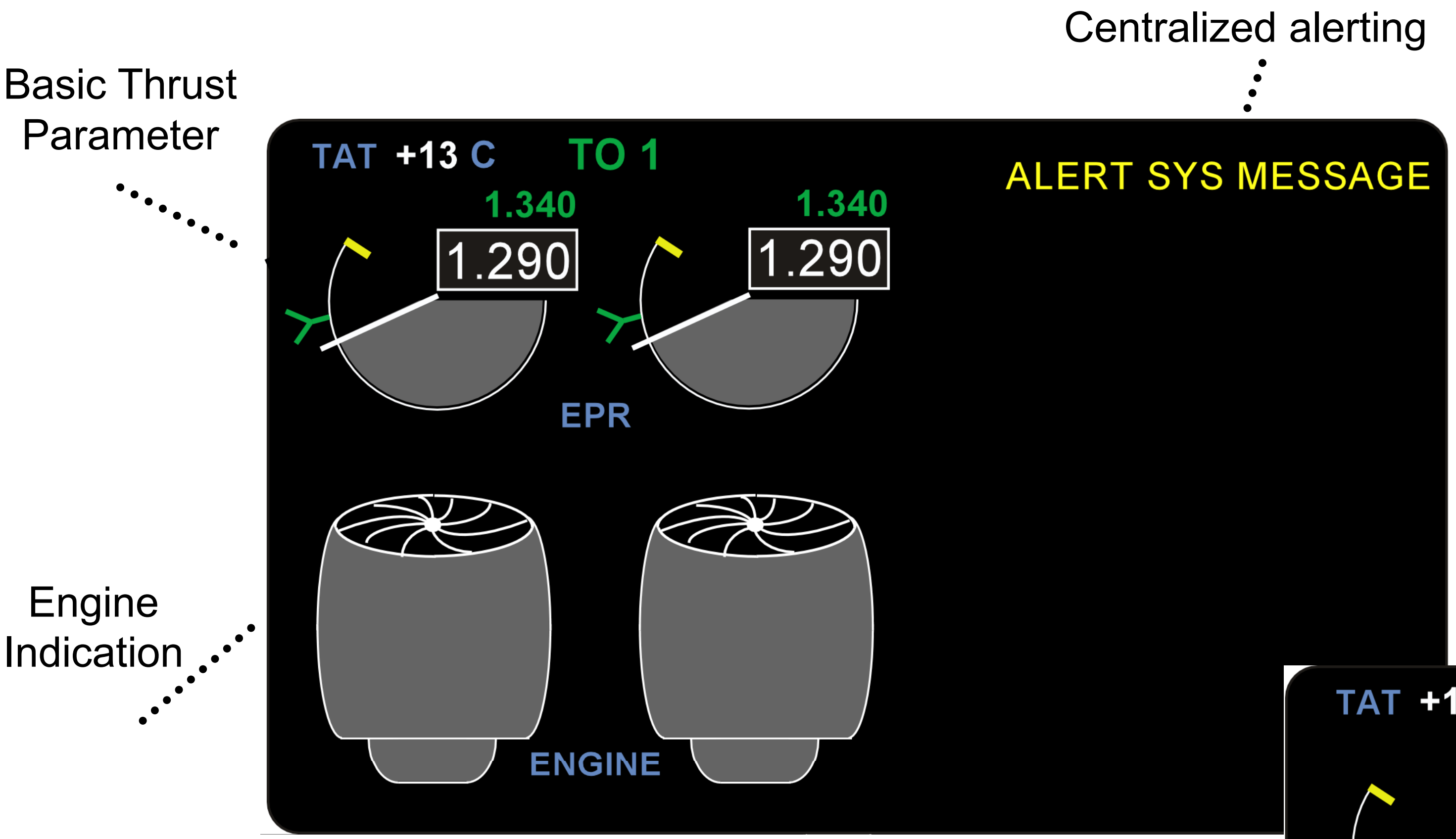
Secondary Indications

The Regulations require all of these parameters

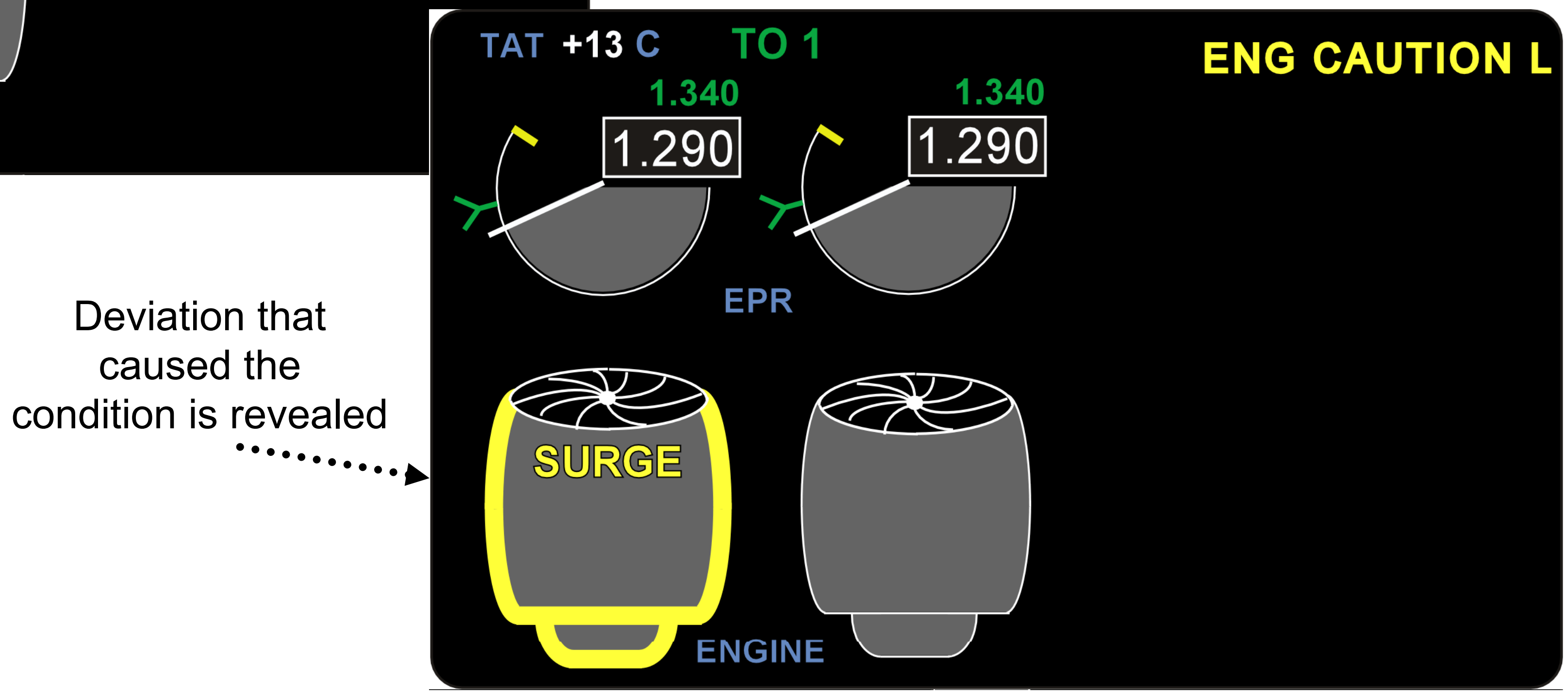
Important engine states must be inferred

- engine surge
- engine damage / severe engine damage
- significant degradation or vibration

There have been cases of confusion about which engine is affected



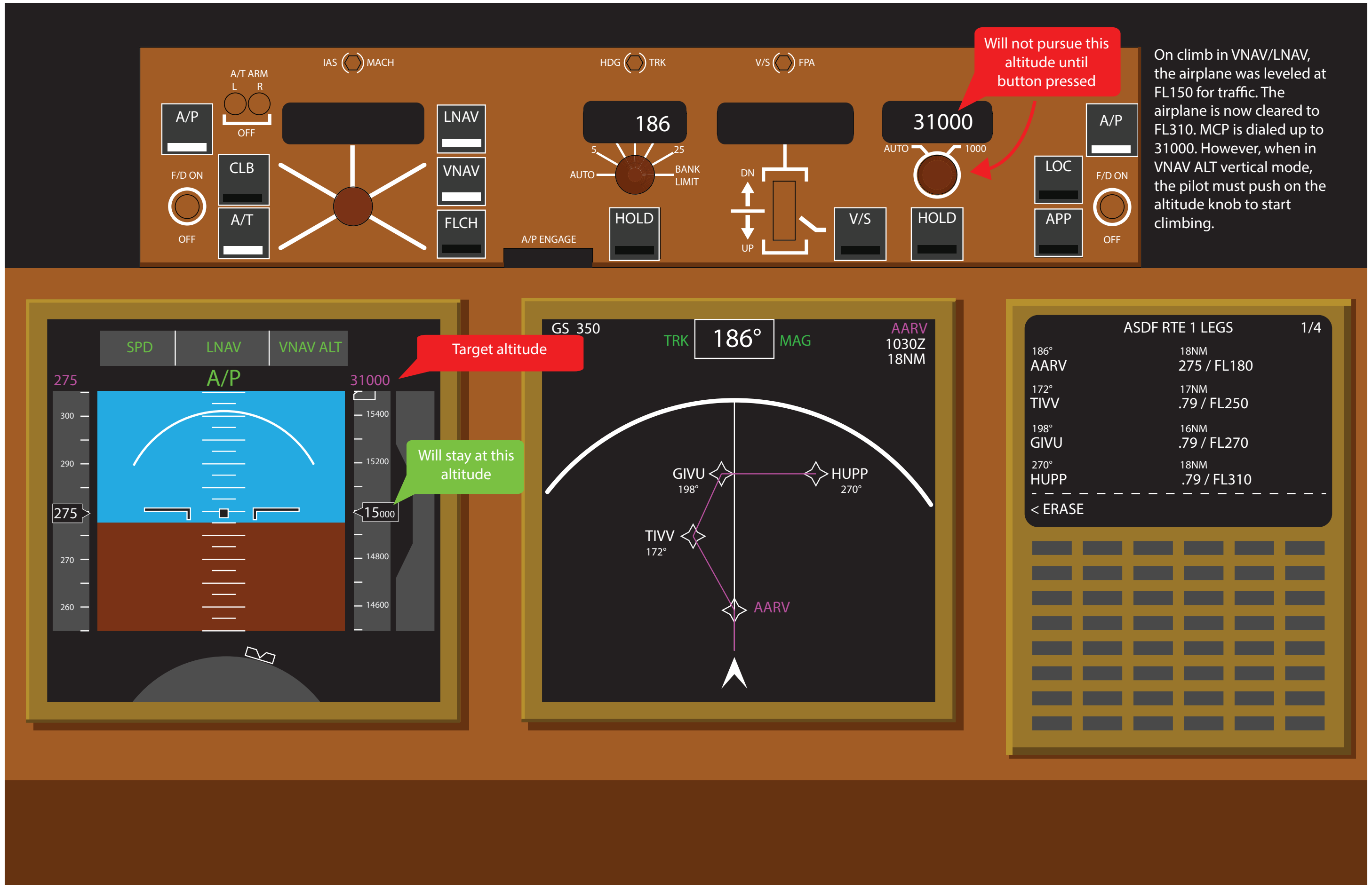
- Operating State (Engine Availability)
  - engine running
  - engine not running
    - failed
    - shut down
    - engine starting (and status)
- Non-Normal State
  - which engine is affected?
  - what is the required action?
    - reduce throttle
    - shut down engine
  - why? what condition is present?



Sikora, J. & Mumaw, R. (2004). Making engine displays more meaningful to flight crews. Proceedings of the International Conference on Human-Computer Interaction in Aeronautics, Toulouse, France.

Autoflight Interface

Scattered Indicators and Hidden Rules



Target confusion

Multi-function buttons

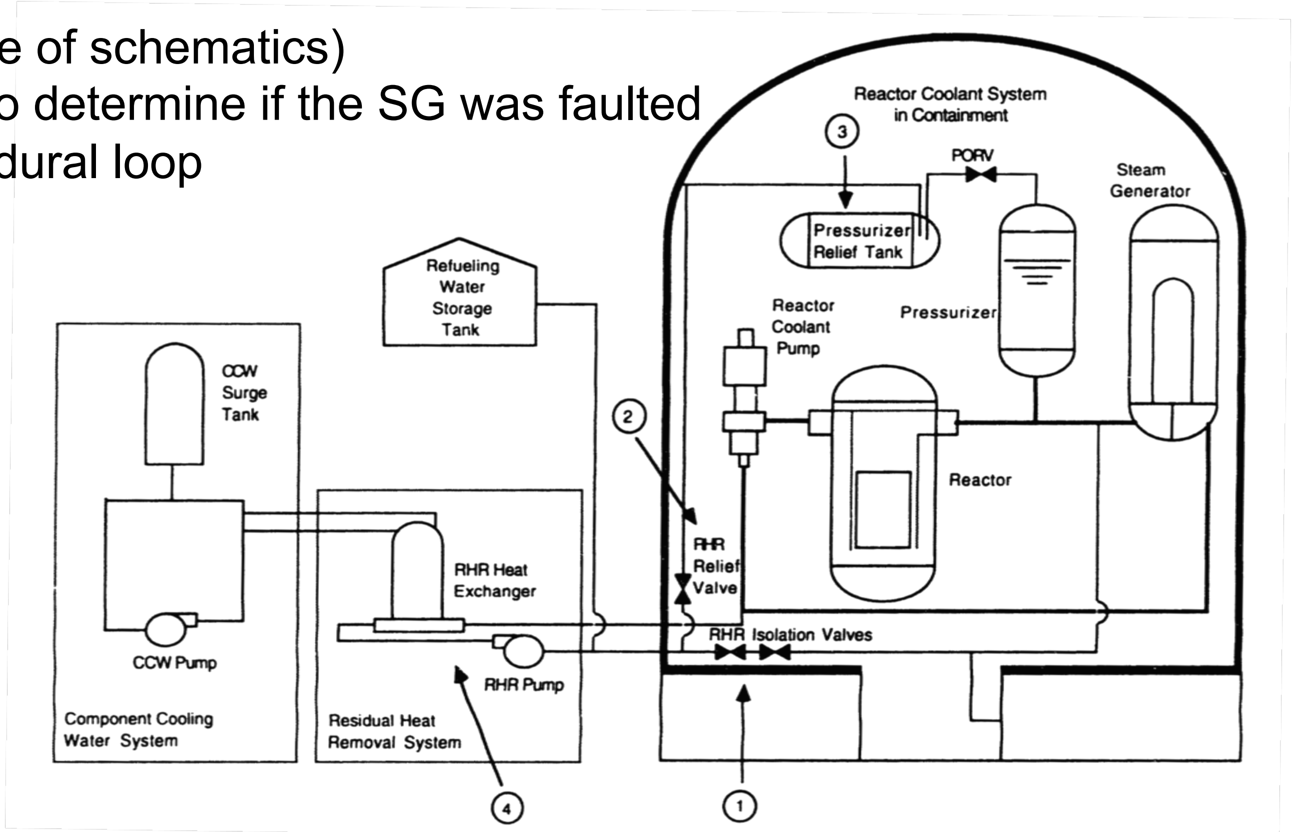
Hidden VNAV behaviors

Early descent zone

Procedure Use for a Cognitively Demanding Fault

Solving the Problem

- Problem: Reactor coolant leak in an unusual place (distributed symptoms);
  Solution requires a transition between separate Emergency Operating Procedures (EOPs)
- Key EOP step: if Steam Generator (SG) pressure NOT stable or increasing return to step 1
  [and, SG pressure is decreasing]
- Key to solving:
  - A focus on other inputs to SG pressure (use of schematics)
  - Understood that the point of the step was to determine if the SG was faulted
  - Awareness that they were stuck in a procedural loop



Roth, E.M., Mumaw, R.J., & Lewis, P.M. (1994). An empirical investigation of operator performance in cognitively demanding simulated emergencies. (NUREG/CR-6208). Washington, DC: Nuclear Regulatory Commission.

The Struggle between Understanding and Following Procedures

Compliance >> Solving the Problem

- Nuclear power plant operators in a training exercise
  - They understand the limitations of the procedure
  - They understand that they are not addressing the problem

Malicious Procedural Compliance

Explosion of Alert Messages

Managing Non-Normals

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; many additional later (> 80 total)
- 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*

Qantas 32 (QF 32) Uncontained Engine Failure

2:01:08	ENG 2 TURBINE OVERHEAT
2:01:09	ENG 2 STALL
	ENG 2 OIL TEMP HI
	ENG 2 EGT OVER LIMIT
2:01:13	F/CTL SLAT SYS 1+2 FAULT
	HYD G RSVR PRESS LO
	HYD Y ENG 4 PMP A PRESS LO
	HYD Y ENG 4 PMP B PRESS LO
	L/G CTL 1 FAULT
	AIR L OUTR WING LEAK
	AIR L INR WING LEAK
	AIR ENG 2 BLEED LEAK
2:01:14	F/CTL PART SPLRS FAULT
	F/CTL ALTN LAW (PROT LOST)
	L/G CTL 2 FAULT
	BRAKES A-SKID FAULT ON WING LG
2:01:15	ELEC DRIVE 1 DISCONNECTED
	F/CTL AILERON ACUATOR FAULT
	F/CTL AILERON ELEC ACTUATOR FAULT
	HYD G RSVR LEVEL LO
2:01:16	ELEC C/B TRIPPED
	ELEC DRIVE 2 DISCONNECTED
2:01:17	F/CTL L MID AILERON FAULT
2:01:18	ELEC AC BUS 2 FAULT
	ENG 2 NORM MODE FAULT

2:01:23	A-ICE WING VLV
	A-ICE ENG 1 VLV
	A-ICE ENG 2 VLV
2:01:24	AIR L OUTR WIN
	AIR L INR WING
	AIR ENG 2 BLEED
2:01:25	FUEL JETTISON V
	ENG 1 NORM+AL
	ENG 2 NORM+AL
	ENG 4 NORM+AL
2:01:28	F/CTL AILERON A

2:02:18	ENG 2 TURBINE OVERHEAT
	ENG 2 OIL PRESSURE LOW
2:02:41	ENG 2 FIRE
2:03:00ish	ENG 2 FAIL (flight crew sh
2:03:30ish	VENT COOLG SYS OVHT
2:06:29	ENG 2 SHUTDOWN
2:06:40	AUTO FLT A/THR OFF
2:06:45ish	F/CTL SLAT SYS 1+2 FAUL
2:07:19	HYD G RSVR LEVEL LO
2:07:40ish	HYD G RSVR AIR PRESS LO
2:11:30ish	HYD G SYS PRESS LO
2:12:45ish	HYD Y ENG PMP A PRESS LO
	HYD Y ENG PMP B PRESS LO
2:16:20	ELEC AC BUS 2 FAULT
2:16:29	FUEL JETTISON VLV NOT CLOSED
2:16:45	ENG 1 NORM+ALTN MODE FAULT
	ENG 2 NORM+ALTN MODE FAULT
	ENG 4 NORM+ALTN MODE FAULT
2:16:50ish	LOW OIL QUANTITY ENG 2
2:18:43	AIR L INR WING LEAK
	AIR L OUTR WING LEAK
	AIR ENG 2 BLEED LEAK

2:19:33	FUEL NORM+ALTN MODE FAULT
2:21:50ish	FUEL FEED TK2 MAIN+STBY PMPS FAULT
	FUEL NORM+ALTN XFR FAULT
	FUEL JETTISON VLV NOT CLOSED
2:21:56	F/CTL PART SPLRS FAULT
2:22:06	ELEC AC BUS 2 FAULT
2:22:30ish	FUEL JETTISON VLV NOT CLOSED
2:22:42	FUEL NORM+ALTN XFR FAULT

2:29:00ish	FUEL L INR TK FWD+AFT PMPS FAULT
	FUEL R INR TK FWD+AFT PMPS FAULT
2:31:07	F/CTL ALTN LAW (PROT LOST)
2:31:35	LOW OIL QUANTITY ENG 2
2:31:46	FUEL FEED TK 2 MAIN+STBY PMPS FAULT
2:33:08	LOW OIL QUANTITY ENG 2
2:33:18	A-ICE ENG VLV 1 OPEN
2:33:22	FUEL WINGS NOT BALANCED
	FUEL L INR TK FWD+AFT PMPS FAULT
	FUEL R INR TK FWD+AFT PMPS FAULT
2:34:18	LOW OIL QUANTITY ENG 2
2:34:46	ELEC C/B TRIPPED
2:35:01	F/CTL L OUTR AILERON FAULT
	F/CTL R OUTR AILERON FAULT
	F/CTL L MID AILERON FAULT
	F/CTL AILERON ACTUATOR FAULT
2:35:51	LOW OIL QUANTITY ENG 2
2:36:10	L/G CTL 2 FAULT
2:36:26	COND FWD CARGO VENT FAULT
2:37:20	A-ICE WING VLV OPEN

86 ECAM messages (over 36 minutes)

The crew later reported that they had begun to understand the effect of the engine failure on the aircraft and its systems. (after 1 hr 10 min)

New Approach for Managing Non-normals

Airplane system failure → Mission Compatibility

↳ Airplane Capabilities

Maneuver Envelope

Changes to Operational Limitations (phase of flight)

↳ Diversion Decision Making (if needed)

Mumaw, R.J., Feary, M., Fucke, L., Stewart, M., Ritprasert, R., Popovici, A., & Deshmukh, R. (2018). Managing complex airplane system failures through a structured assessment of airplane capabilities. NASA/TM-2018-291775. Moffett Field, CA: NASA Ames Research Center.

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

↓

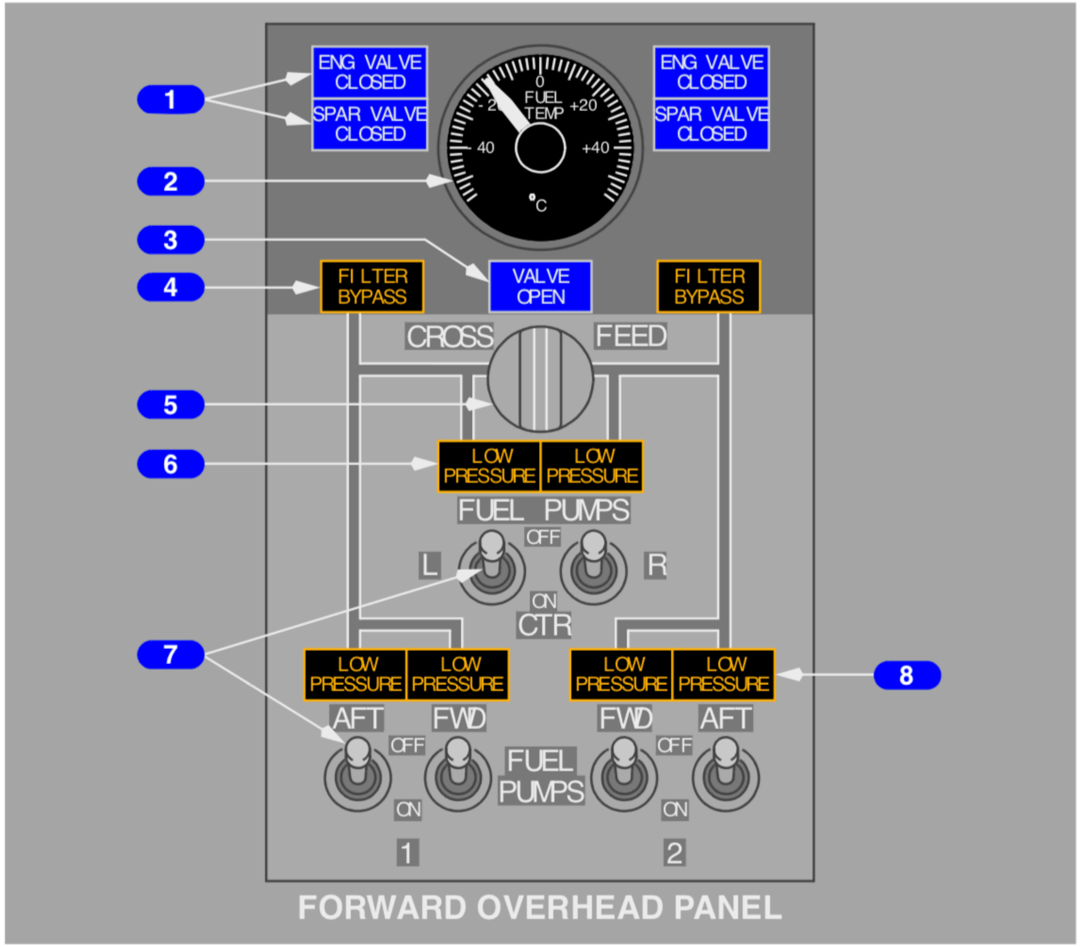
What can I do?
Where can I go?

Standard Approach to Systems Training

Knobology

- Training on the interface to the flight deck interface is typically a tour of the physical features.
- Operational relevance is less of a focus

Fuel Control Panel



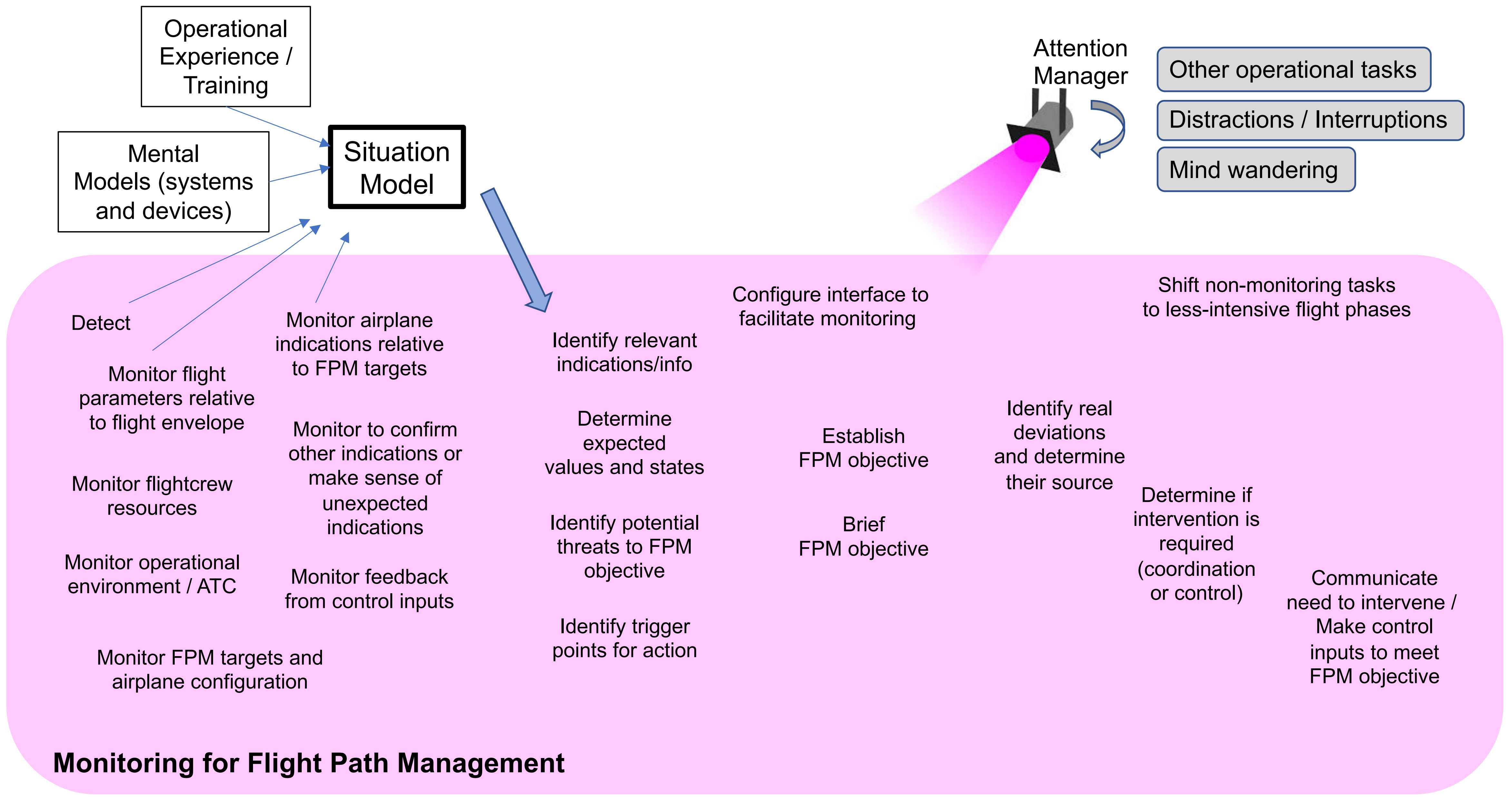
A Reluctance to Treat "Airmanship" as Trainable

Situation: The airplane is held at cruise altitude past the Top of Descent point, and there is a waypoint altitude constraint that may be hard to make.
Example: Held in CRZ at FL310; using the BDEGA3 arrival (LEGGS transition) into SFO. The waypoint LOZIT has an 'at or below' restriction at 16000.

Situation Model	Expected Values & Decision Gates	Actions	Display Elements
Nearing ToD; prior to new clearance Flight path is programmed in the FMS; A/P will descend aircraft on the arrival as programmed. LOZIT to BDEGA leg is steep (known from experience) →	Should cross LOZIT below 16000 due to geometry of FMS flight path	Verbalize current plan and any inconsistencies	
		Monitor winds and update FMS	NAV Display wind vector
		Identify difficult FPM segments	FMS LEGS page
		Identify traffic that might cause a late descent	Nav display, Radio chatter

At this point, the flight crew is expecting a normal descent on the FMS flight path. However, the flight crew is also looking ahead for potential threats to the plan, such as changes to the wind or traffic. Also, the flight crew has determined that one of the flight plan legs is pretty steep, and they know it can be flown more easily if they cross LOZIT well below 16,000 ft (rather than simply making the restriction at 16,000 ft).

Situation Model	Expected Values & Decision Gates	Actions	Display Elements
ATC requests delaying descent until notified Airplane will now go above FMS flight path; Eventual flown path will need to be steeper; Use 3-to-1 to determine: What is latest position where I can still make LOZIT at 16000? →	Generate a GATE on current path at FL310 where it is too late to get down to LOZIT at 16000	Estimate how long you will be held high	Radio Traffic
		CNTRL: slow down, as possible, to preserve options and decrease energy	NAV Display wind vector



Operational Experience / Training
Mental Models (systems and devices)
Situation Model
Attention Manager
Other operational tasks
Distractions / Interruptions
Mind wandering
Detect
Monitor flight parameters relative to flight envelope
Monitor flightcrew resources
Monitor operational environment / ATC
Monitor FPM targets and airplane configuration
Monitor airplane indications relative to FPM targets
Monitor to confirm other indications or make sense of unexpected indications
Monitor feedback from control inputs
Identify relevant indications/info
Determine expected values and states
Identify potential threats to FPM objective
Identify trigger points for action
Configure interface to facilitate monitoring
Establish FPM objective
Brief FPM objective
Identify real deviations and determine their source
Shift non-monitoring tasks to less-intensive flight phases
Determine if intervention is required (coordination or control)
Communicate need to intervene / Make control inputs to meet FPM objective
Monitoring for Flight Path Management

Points to Take Away

- Operator surprises are not uncommon for jet transport pilots. System complexity and lack of transparency is a major contributor. For various reasons, re-framing can fail.
- Operators strive for system understanding; the interface, procedures, and training can create barriers to understanding. Designing to support understanding runs counter to early design ideas.
- The interface needs to integrate information to support operational decision making.
- Procedures need to find a way to remove limitations and support knowledge-based performance.
- Training also needs to be more operationally oriented and find a way to expose expertise.
- Operator communication is another significant method for supporting understanding.

Thanks for your time!

Making Sense of a Complex World

Understanding relies on each individual's experience and knowledge

Seattle, home of Boeing, has many airplane-savvy people.

LOOK!!
It's a beaver !!

????
No, Jimmy, that's
an airplane.