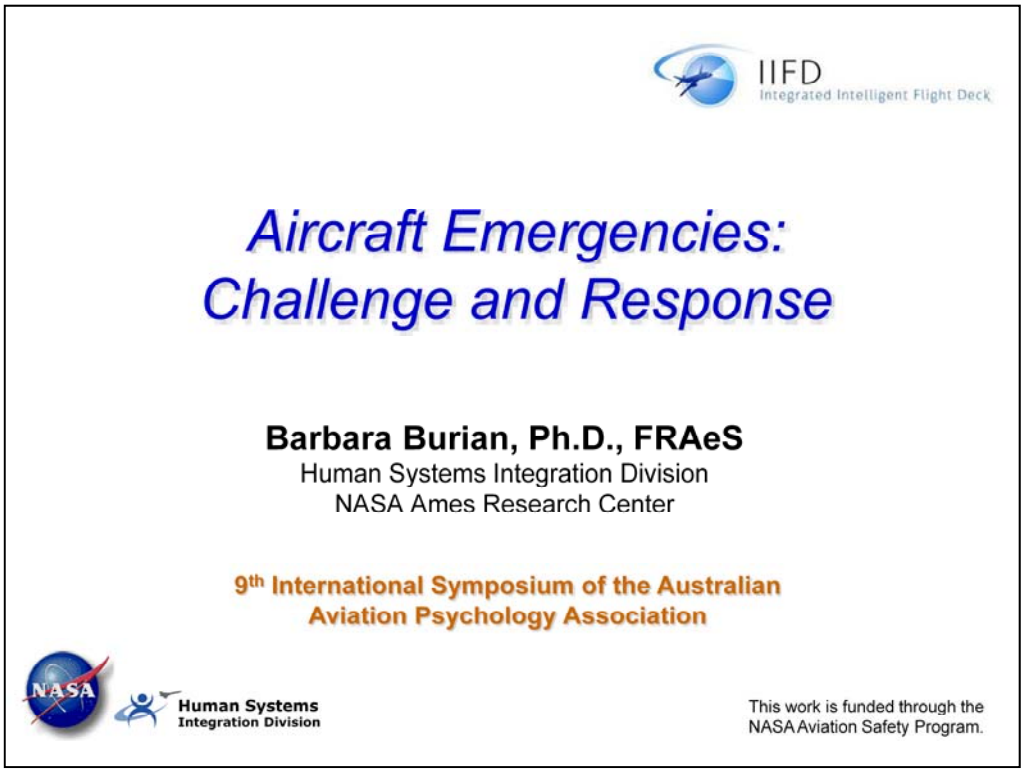

To get an idea of the scope of what we are talking about, I will begin with review of 5 different emergency or abnormal situations

Air Canada 797 - DC-9 In-flight Fire, Covington, Kentucky June 2,1983

- **1851:14** three cb for aft left lav. toilet flush motor trip
- 00:13 CA resets cb (elapsed time from cb trip)
- 08:31 CA resets cbs again (elapsed time from 1st reset)
- **1902:40** FA reports fire in back washroom to flight crew and that other FAs are fighting it
- 00:30 FO goes back to assess
- 01:47 FO "…I can't go back now, it's too heavy, I think we'd better go down"
- 00:09 FA "…You don't have to worry I think its gonna be easing up"
- 00:07 FO "OK it is starting to clear now"
- 00:28 FO goes back to assess a second time
- 00:45 FA "..put a big discharge of CO_2 in the washroom, it seems to be subsiding, all right"
- 00:36 CA calls Indy Center, reports electrical problem, may be off radios soon, stand by
- 00:23 FA "Getting much better, okay"
- 00:17 FA "CO_2 it was almost half a bottle and it now almost cleared"
- 00:19 FO returns, "I don't like what's happening, I think we better go down, okay?"
- **05:30** (approx.) **elapsed between first report of fire and initiation of emergency descent**

- Dallas Text to Toronto, Ontario, Canada – 5 crew members and 41 passengers – in cruise at FL330
- CA reset cbs twice – thought the flush motor was overheated
- CA did not appear to refer to procedure for resetting cbs in abnormal section of AOM – no reference to this procedure on CVR
- FO and FA didn't clearly communicate that they could not see the source of the fire
- FA's discharge of CO2 completely ineffective – fire was behind the lavatory wall
- Lost left AC and DC left electrical systems so CA made report to Indy Center
- NTSB estimated that fire had been burning up to 15 minutes before detected by passenger and flight attendants

Air Canada 797 - DC-9 In-flight Fire, Covington, Kentucky June 2,1983

- 1907:41 Emergency AC and DC busses lost power, CA & FO attitude indicators tumbled
- ATC offered landing at Cincinnati-Covington Airport
- CA accepted; heading 060° and 20 miles
- Declared emergency, squawked 7700 but transponder inoperative due to power loss
- 1909:33 Handoff from Indy Center to TRACON

- TRACON unaware of 797's electrical problems identified the wrong target on radar scope
- ATC planned for landing rwy 36; aircraft not positioned well for rwy 36 when identified as correct target; eventually landed rwy 27L

- ATC asked for "fuel and souls" twice, FO declined
- Though not required by procedure, FO turned off the air conditioning & pressurization packs "because the smoke was getting bad at that point and my reasoning was I have to do something…"
- Toxic fumes and gases built up, a flash fire occurred soon after landing and opening doors for evacuation; 23 passengers died.

Pack Trip

- Master Caution Alert sounds
- Crew Identifies that Pack has tripped off
- Crew completes 4 step procedure
- Flight proceeds normally

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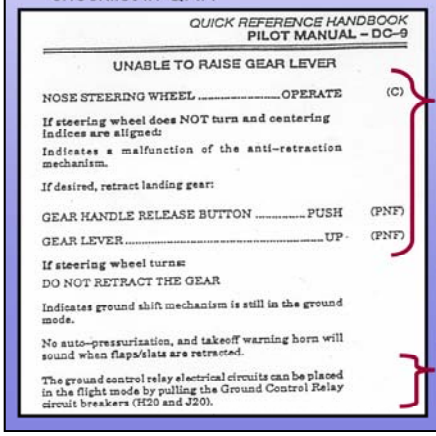
Illustration of range of situations – a pack trip is generally pretty benign and easily handled – not much increase in stress or workload – some pack trip checklists may have more than 4 items

ValuJet 558 - DC-9 Ground Spoiler Activation In-flight, Nashville, TN January 7,1996

- CA performed preflight walk around, all looked normal
- Ice and snow on taxiways, concern about contamination
- FO was PF, on Take off called "positive rate, gear up"
- CA unable able to move gear lever to retract position
- CA consulted UNABLE TO RAISE GEAR LEVER checklist in QRH



QUICK REFERENCE HANDBOOK
PILOT MANUAL – DC–9

UNABLE TO RAISE GEAR LEVER

NOSE STEERING WHEEL ..... OPERATE (C)

If steering wheel does NOT turn and centering indices are aligned:

Indicates a malfunction of the anti–retraction mechanism.

If desired, retract landing gear:

GEAR HANDLE RELEASE BUTTON ..... PUSH (PNF)

GEAR LEVER ..... UP (PNF)

If steering wheel turns:

DO NOT RETRACT THE GEAR

Indicates ground shift mechanism is still in the ground mode.

No auto–pressurization, and takeoff warning horn will sound when flaps/slats are retracted.

The ground control relay electrical circuits can be placed in the flight mode by pulling the Ground Control Relay circuit breakers (H20 and J20).

- CA determined malfunction of the anti-retraction mechanism & completed appropriate checklist steps
- CA took over as PF; FO confirmed checklist complete
- CA advanced throttle to climb power, TO warning horn sounded, cabin not pressurizing
- Decided that ground shift mechanism must have also malfunctioned
- To place ground control electrical relay circuits in flight mode, FO pulled the Ground Control Circuit cbs as per checklist.

- Atlanta, GA to Nashville, TN – 5 crew members and 88 passengers

ValuJet 558 - DC-9 Ground Spoiler Activation In-flight, Nashville, TN January 7,1996

- Crew did not contact dispatch as per SOPs because they thought the problem was resolved
- During landing brief, consulted QRH, decided to depressurize aircraft on approach
- Around 100' AGL, CA verified zero psi differential and the reset cbs as per QRH checklist
- Aircraft went into ground mode and ground spoilers deployed
- Aircraft hit hard in approach light area short of runway 2R, lost nose wheel and radios, bounced, went around and landed on runway 31
- Information about when to reset ground control circuit breakers missing from QRH but included in AOM

The ground control relay electrical circuits can be placed in the flight mode by pulling the Ground Control Relay circuit breakers (H20 and J20).

Do not exceed VLE (300 kts/M.70).

Approach and landing:

If landing gear was not retracted prior to landing, ground spoilers must be operated manually.

AIRPLANE	DEPRESSURIZE	(PNF)
ANTI-SKID SWITCH (before 30 kts)	OFF	(PNF)
GROUND CONTROL RELAY C/Bs (if pulled) (H20 and J20)	RESET	(C or FO)

AOM

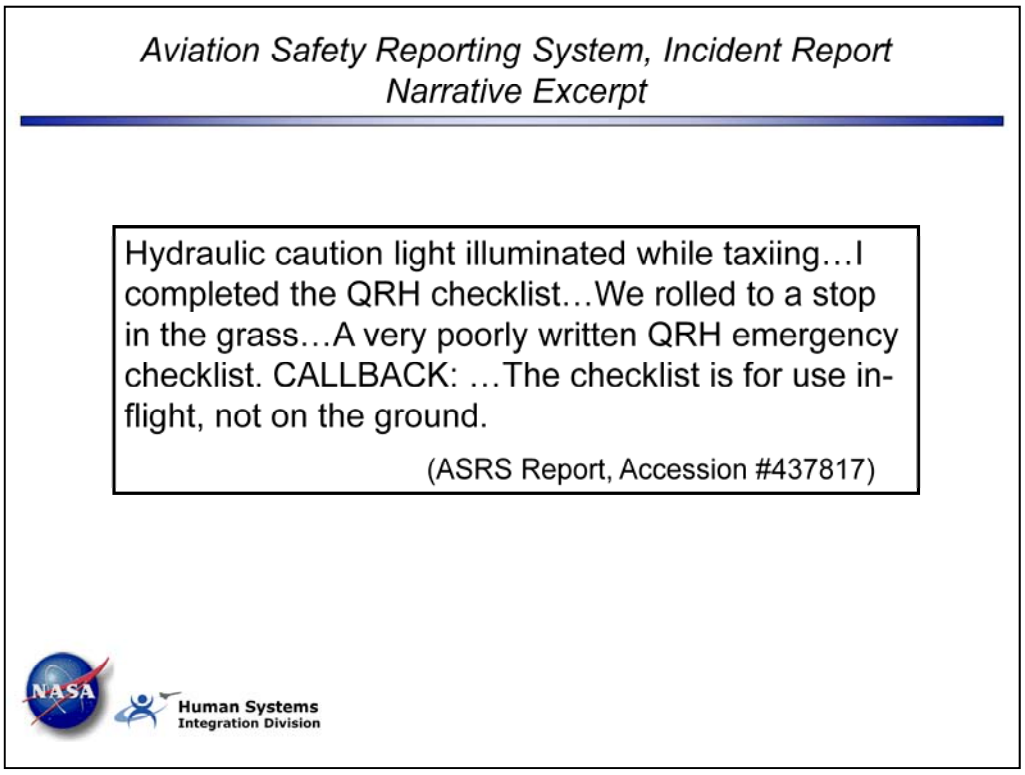
Approach and landing:

If landing gear was not retracted prior to landing, ground spoilers must be operated manually.

AIRPLANE ..... DEPRESSURIZE (PNF)
- Ensure airplane is depressurized prior to landing.

ANTI-SKID SWITCH (before 30 kts) ..... OFF (PNF)
- During landing rollout and prior to 30 kts, momentarily release brakes and place Anti-skid switch to OFF.

GROUND CONTROL RELAY C/Bs (if pulled) (H20 and J20) ..... RESET (C or FO)
- Reset Ground Control Relay circuit breakers during taxi and verify that circuits are in the ground mode.



Example where checklist is inappropriate for the situation – designers did not consider variety of situations in which the checklist would be needed

Aloha 243 - B737 Rapid Decompression, Maui, Hawaii April 28,1988

- 1345:43 As aircraft is leveling off at cruise altitude of FL240, sound of increased wind noise is heard on Cockpit Area Microphone
- CA, FO, and Jumpseat rider don oxygen masks
- CA takes over a PF and begins emergency descent, FO dials in 7700 on transponder
- Attempt to contact FAs is unsuccessful
- FO attempts multiple radio calls to Honolulu Center, Maui Approach, and Maui Tower

- 1348:34 FO hears Maui Tower ATC respond and declares emergency
- Initial ATC confusion about aircraft flight number – multiple radio calls, FO requests ambulance
- Left engine was lost, CA could not transmit over radios, no nose gear down indication
- FO attempts two manual gear extensions, advises ATC they have no nose gear
- ATC:"OK, if you need assistance keep me advised" FO:"We'll need all the equipment you got."
- CA lands flaps 5, 170 kts. on runway 2 Maui, aircraft visibly bows up and down on rollout
- **FO estimates all or parts of 17 different checklists completed in 13 min. almost all from memory. QRH consulted only for flaps 5 landing speed and passenger evacuation**

- Hilo to Honolulu, HI – 5 crew members and 41 passengers – leveling off at 24,000 ft. when decompression occurred
- FO reached for oxygen mask and it wasn't there – had been pulled out of storage compartment by decompression and was flopping in the wind behind her seat, still attached by its tubing to the oxygen system
- FO and CA could see blue sky and tail of the aircraft through the open cockpit door
- One flight attendant lost, one knocked unconscious, the third was crawling up and down the isle on hands and knees assisting passengers put on life vests
- Multiple serious injuries for passengers
- FO and CA helped passengers evacuate, some were so bloody that they slipped through hands of FO, CA and ARFF when trying to help them up

Situational and Operational Demands of Emergencies

- **Wide range of conditions:**
  - Straight forward and clear cut – ambiguous, misleading cues
  - Common, highly trained – uncommon, never trained or anticipated
  - Relatively benign, minimal time pressure – potentially catastrophic, highly time critical
  - Characteristic: static – dynamic and/or cascading failures
  - Checklists: exist for exact situation – don't exist at all, not pertinent, no time to access and consult
- **Communication and coordination is a challenge**
  - Between / among / with flight crew, flight attendants, ATC, dispatch, maintenance, passengers, ARFF

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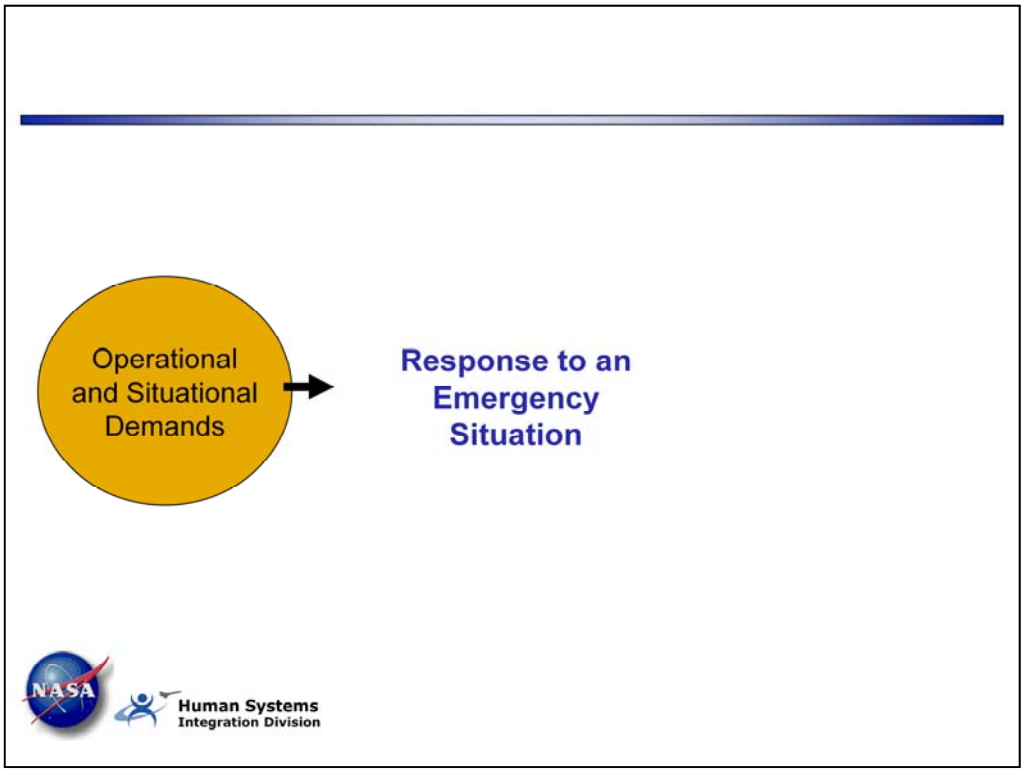
Situational and Operational Demands of Emergencies

- Workload:
  - Manage increased workload
  - Distribute workload effectively
  - Ask for assistance as appropriate
  - Handle interruptions, distractions
  - Interleave concurrent task demands appropriately
  - Accomplish normal flying tasks
  - Shed tasks appropriately
  - Make accurate diagnosis, determine appropriate response, estimate time available accurately
  - Maintain “big picture” and update mental model as situation unfolds


Operational and Situational Demands
Response to an Emergency Situation
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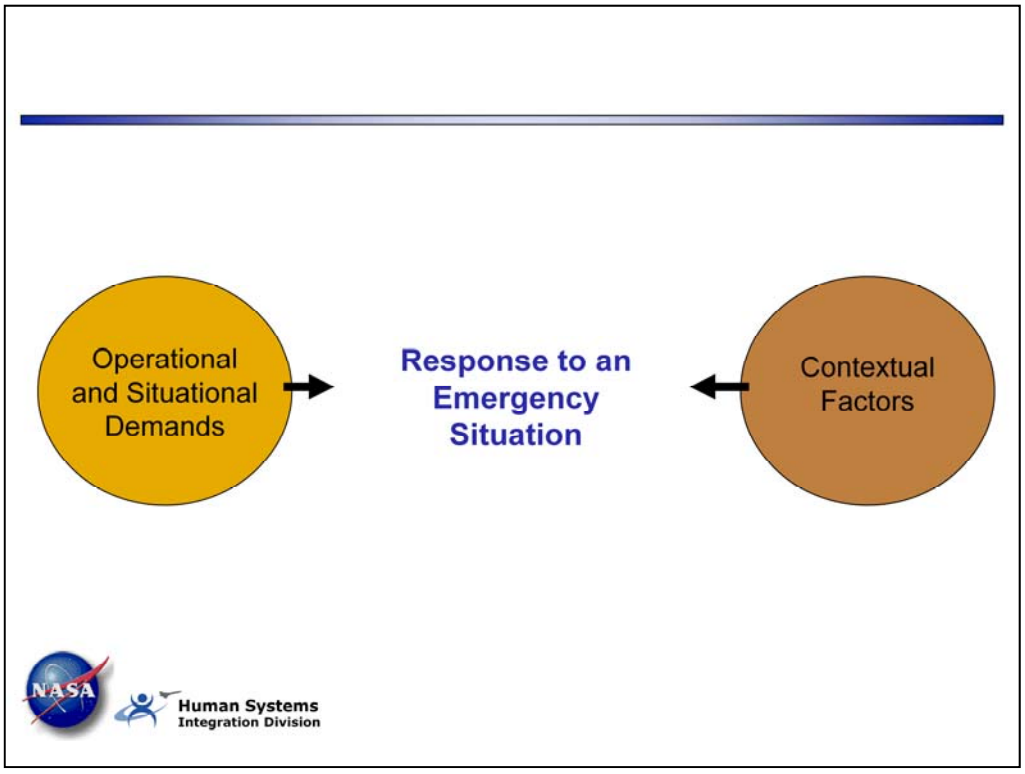
Contextual Factors

- Environmental – night, day, angle of sunlight, weather and precipitation, winds, haze (visibility), ice, amount of other aviation traffic
- Geographic – altitude, terrain, water, mountains, plains, roads/highways, city/suburban/rural, familiarity with area
- Aviation infrastructure, external – numbers and kinds of navaids, location of airports, location of maintenance bases/dispatch support, availability of ARFF and hospitals
- Aviation infrastructure, internal – types and kinds of automation, aircraft equipage, types and kinds of checklists and procedures, single-pilot, crew ops
- Historical – other recent similar emergencies/accidents, issues emphasized during training, known historical problems for type of aircraft
- Personal and Interpersonal – exposure to/experience with similar situations in the past, crew pairing history (first day, last day, previous trip), personality, fatigue, health status, knowledge, skill, single-pilot vs. crew background, culture


Operational and Situational Demands
Response to an Emergency Situation
Contextual Factors
NASA
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Human Performance Capabilities under Stress

Well-learned motor skills

- remain robust and relatively unaffected by stress

> Our simulator training really paid off. This was my first engine shutdown in 20 years of flying and it felt like I had done it a thousand times before!
>
> (ASRS Report, Accession #466167)

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Human Performance Capabilities under Stress

Cognitive Performance

- Reduced Cognitive Processing Speed
- Tunneling
  - narrowing of human attention
  - restricts scanning of environmental cues
  - narrow focus on most salient or threatening cues (positive and negative aspects)
  - yields poor differential diagnosis of situation
- Working Memory
  - capacity and length of time information can be held decreases
  - when exceeded – difficulty performing mental calculations, problem solving, making sense of disparate pieces of information, shifting mental sets
- Tendency to Rush
- Altered Sense of Time
- When overwhelmed, tend to be reactive, cannot see the “big picture”

Human Performance Capabilities under Stress

We did find communication difficult and the use of oxygen masks, intercom, trying to talk to ATC was a handful.

At night made it that much harder to read/accomplish checklist items. Turning cockpit lights on sooner would have helped.

(ASRS Report, Accession #472755)

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*Crew Performance under Stress**

- Effective teams tend to shift strategies from explicit to implicit coordination
  - this only works if roles are well understood and all share the same mental model of situation and needed response
- Telegraphic speech, incomplete communication, greater reliance on body language is common
- Level of cooperation tends to increase
- Lower status crew members are more likely to rely on leader's decisions and defer, less likely to speak up or confront
- Under high stress, leaders tend to be more open to input from lower status crew members

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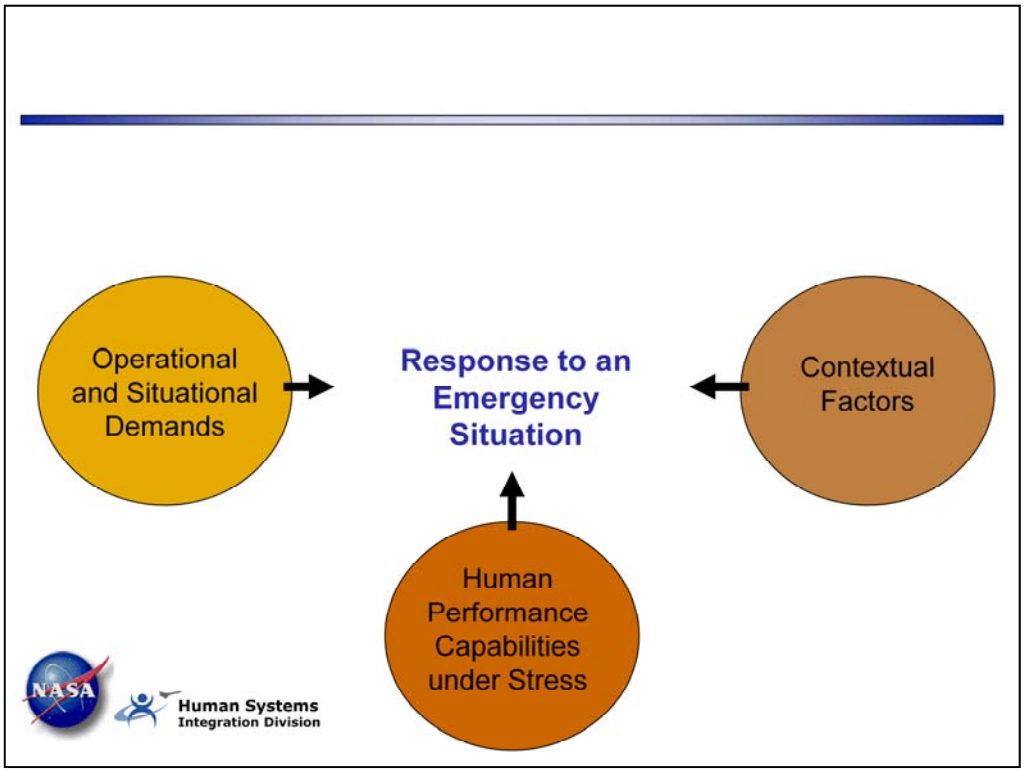
* Findings primarily from laboratory studies with subjects from Western Cultures


Operational and Situational Demands
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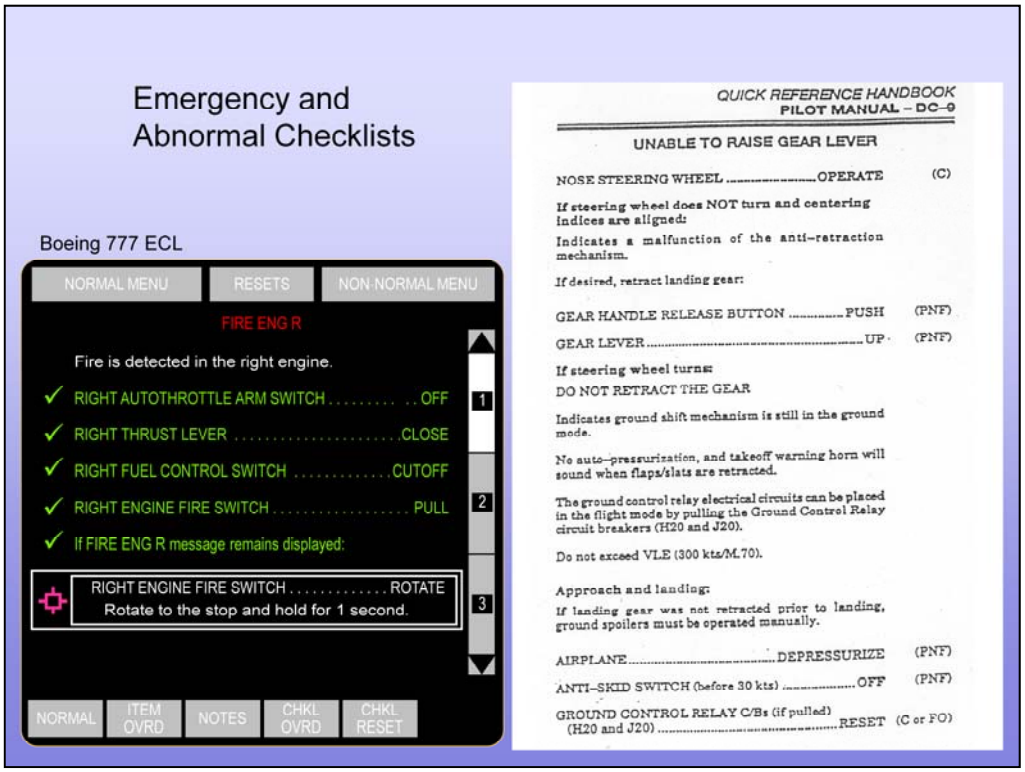
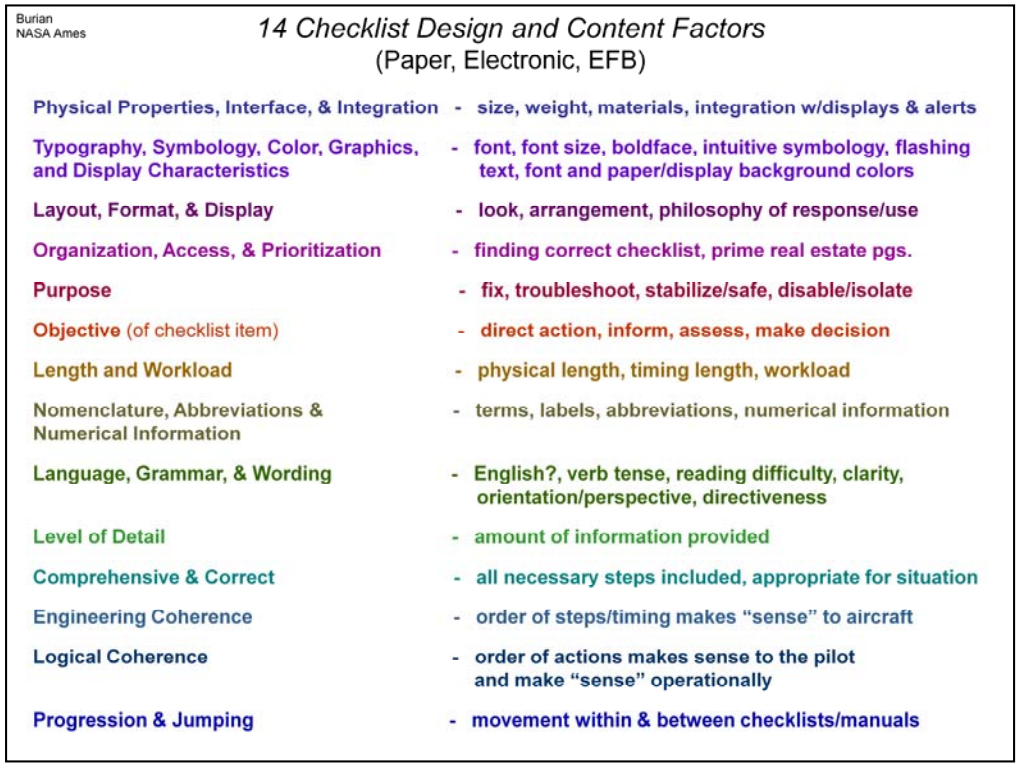
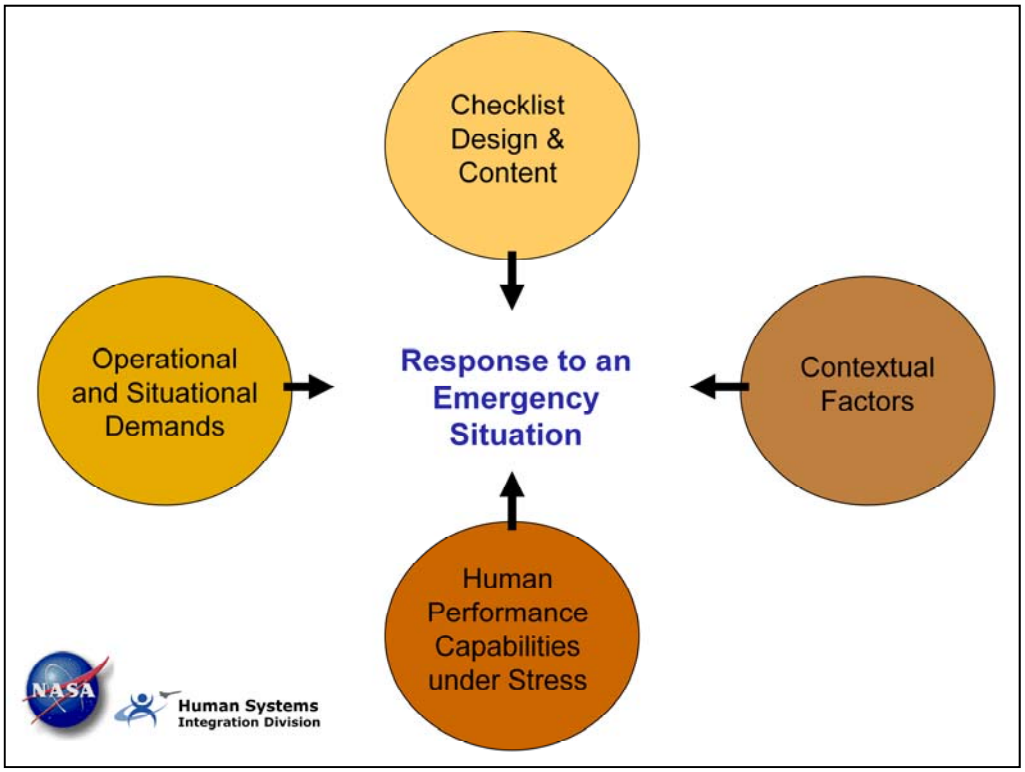


Checklists are essential tools that crews use to help them respond appropriately to emergency and abnormal situations. Two examples of checklists – B777 ECL and a paper checklist (paper checklists can look very different from this one – this is just one example and I used it because it is already in the public domain (included in an NTSB accident report).



List of checklist design and content areas


Checklist Design & Content
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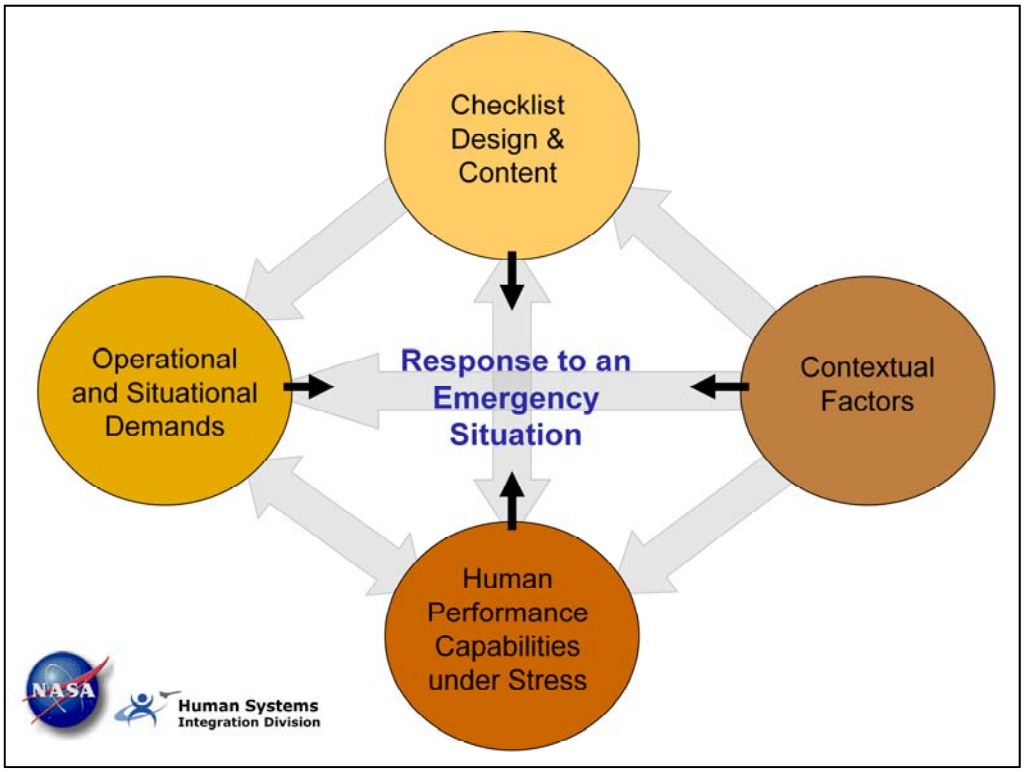


Of course, much more complicated picture – a number of interactions

US Airways 1549 - A320 Dual Engine Failure, Hudson River, NY January 15, 2009

- During climb out from LGA the aircraft hit a flock of geese and lost the thrust in both engine
- CA took over as PF and called for the ENG DUAL FAILURE checklist
- This is a paper checklist (ECAM Exception)

- FO tries several time to start the engines - unsuccessful
- Approx. 3 min. after hitting the birds, CA performs a forced landing into the Hudson River

Analysis:

- Daylight, good visibility, crew saw the birds right before hitting them
- Assessment: Knew immediately what their problem was and why, amount of time
- Division of workload clear – CA took over as PF and called for checklist
- FO recently completed training, recognized the checklist as an ECAM exception and knew to go to QRH for the checklist

US Airways 1549 - A320 Dual Engine Failure, Hudson River, NY January 15, 2009

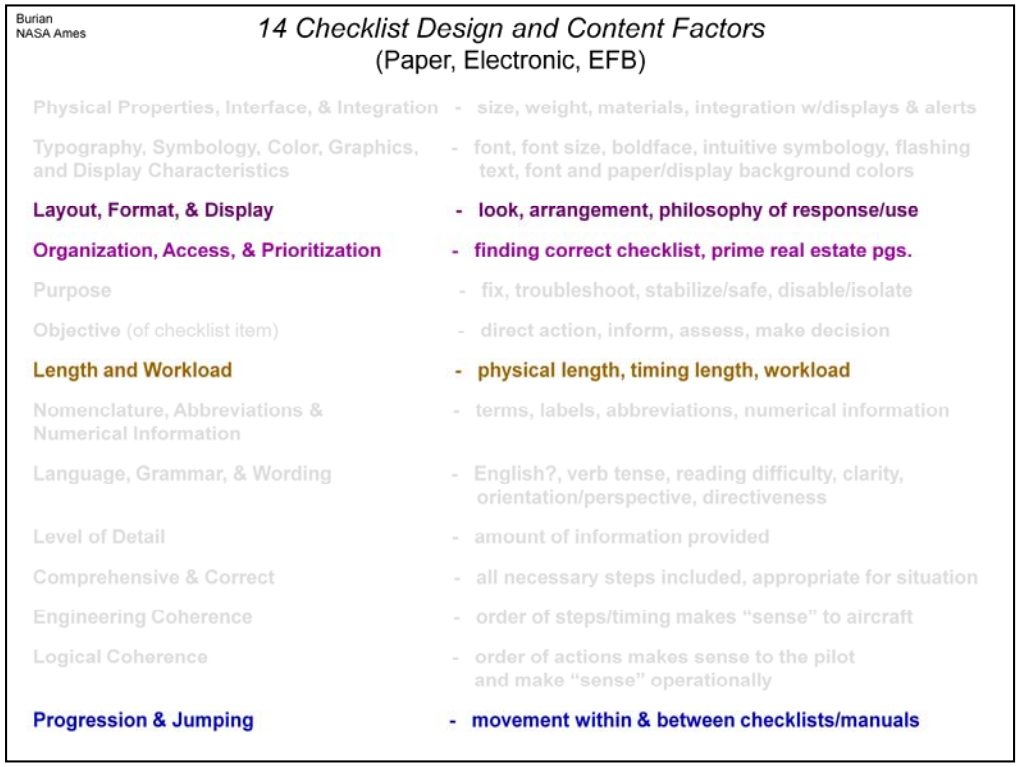
Below 15000':
c. RAM AIR ..... ON
d. BARO ..... Set
Below 10000':
e. CREW OXYGEN MASKS ..... OFF
f. OXYGEN CREW SUPPLY ..... OFF
g. V_{APP} ..... Determine
Note: A319/320 V_{REF} + 25/150 kts minimum
A321 V_{REF} + 30/160 kts minimum

3. ▶**If Forced Landing is anticipated:**
Prior to 3000' AGL:
a. FLAPS ..... Configure for Landing
Note: Final Descent slope when configured (CONF 3 and Gear Down) will be approximately 800-900 feet per minute with no wind.
When in CONF 3 and at V_{APP}:
b. GRAVITY GEAR EXTEN ..... PULL & TURN
Note: Disregard "USE MAN PITCH TRIM" on the PFD. The stabilizer is frozen due to insufficient hydraulic power.
When L/G downlocked:
c. L/G Lever ..... DOWN
or
d. GND SPOILER ..... ARM
e. Max Brake Press ..... 1000 psi
[Brakes on Accumulator only]
At 500'AGL:
f. Brace Signal ..... Command
At touchdown:
g. ENG MASTER 1 and 2 ..... OFF
h. APU MASTER SW ..... OFF
i. ENG DUAL FAILURE Checklist complete, and
☛ If required, go to "Evacuation" Checklist, on page i.

▶**If Ditching is anticipated:**
Prior to 3000' AGL:
a. FLAPS ..... Configure for Landing
b. L/G Lever ..... Check Up
At 2000' AGL:
c. Ditching pb ..... ON
Note: In case of strong crosswind, ditch facing into the wind. In the absence of strong crosswind, ditch parallel to the swell. Touchdown with approximately 11 degrees of pitch and minimum vertical speed.
At 500'AGL:
d. Brace Signal ..... Command
At touchdown:
e. ENG MASTER 1 and 2 ..... OFF
f. APU MASTER SW ..... OFF
g. ENG DUAL FAILURE Checklist complete, and
☛ If required, go to "Evacuation" Checklist, on page i.

Analysis, continued:

- ENG DUAL FAILURE checklist is three pages long
- Divided into three parts:
  - No fuel remaining vs. fuel remaining
  - Steps if restart is successful vs. unsuccessful
  - Forced landing or ditching anticipated
- Organized for dual engine failure at altitude
- Items expected to be completed in order presented
- Flaps configuration item at bottom of page 2 (For landing…Use FLAPS 3)
- Expectation that configuration for ditching will occur above 3,000 ft.
- "Ditching pb……ON" item near the end of the checklist



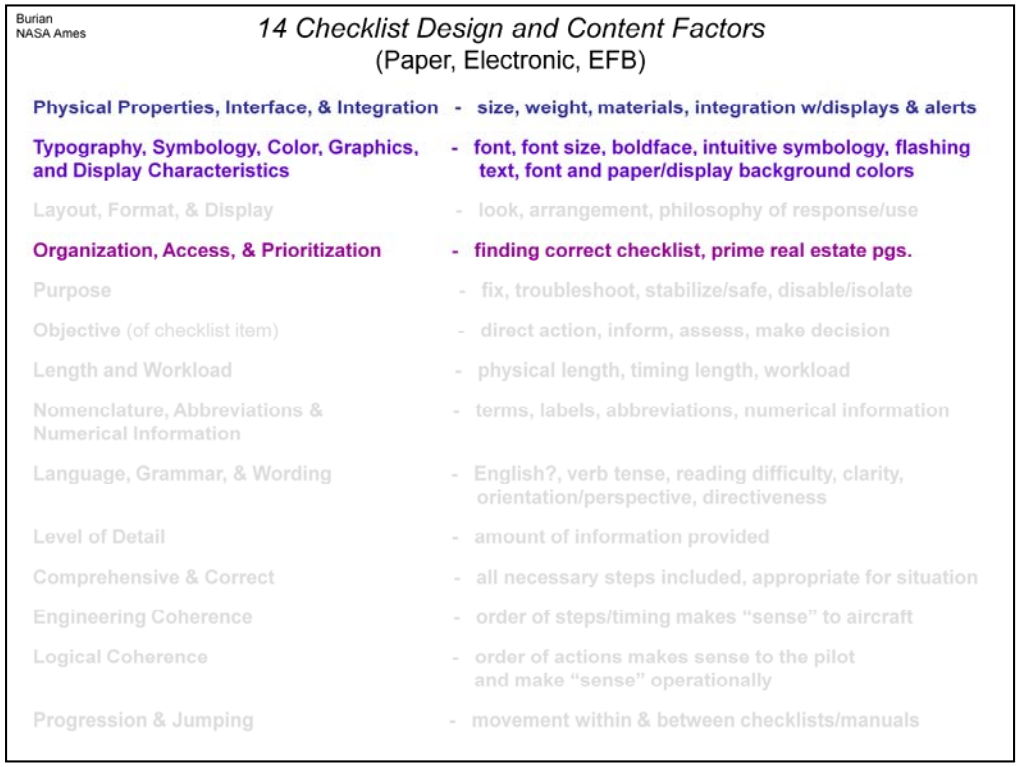
List of checklist design and content areas pertinent to this accident

Saudi Arabian 163 - L1011 Cargo Fire, Riyadh, Saudi Arabia August 19, 1980

- 7 minutes after takeoff, climbing through 15,000 ft. crew given visual and aural alerts of smoke in aft cargo compartment
- 4 minutes spent trying to confirm warnings & locate procedure in QRH – never found
- CA attempted to fly aircraft, assess situation, and remedy problem himself
- FO inexperienced, did not assist with radio communication or monitoring systems; SO spent most of event looking through AOM repeating "No Problem" to himself; FAs not informed
- No. 2 engine thrust level became stuck during return to airport, engine shut down
- Aircraft stopped on taxiway 2 min. 40 sec. after touchdown, 3 min. 15 seconds later engines shut down, evacuation never initiated, doors remained closed, all 301 on board perished

Analysis:

- Night flight, crew unsure if alerts were accurate or false alarms
- Very poor CRM and distribution of workload, CA attempted to do it all
- Crew were looking for checklist in "Abnormal" section of QRH, it was located in the "Emergency" section



List of checklist design and content areas pertinent to this accident

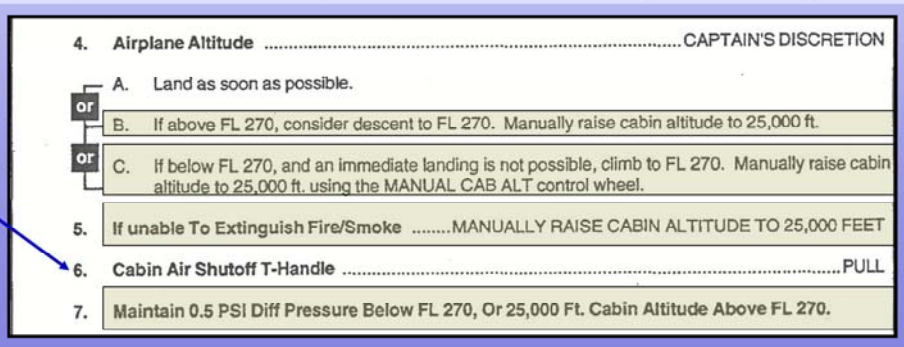
Federal Express 1406 - DC-10 In-flight Fire, Stewart, NY September 5, 1996

- 0536:23, Flight was in cruise, FL330, cabin cargo smoke light illuminated
- CA and FE donned smoke goggles, FE removed them after noting no smoke, CA removed them prior to landing so he could put his glasses back on
- CA spent a few minutes determining that alert was real
- 3 min. 44 sec. after first light illuminated, CA called for emergency descent, emergency descent checklist items completed from memory
- FO continue as PF, CA handle radios and work with FE in completing checklists – "Fire and Smoke" and "Cabin Cargo Smoke Light Illuminated"
- FO slowed to 250 kts. CA told him to keep his speed up
- CA broadcast internal cockpit communication over the ATC frequency.
- FE asked for and was told identifier for diversion airport three times – he never got it
- FE confused by one step and missed two checklist items by mistake; the evacuation checklist was never called for or completed
- Aircraft was still partially pressurized upon landing.

Federal Express 1406 - DC-10 In-flight Fire, Stewart, NY September 5, 1996

Analysis:

- Some delay in descent; focus on monitoring progression of smoke and fire
- High level of stress and workload for all three crew members
- FE knew that first checklist to complete was "Smoke and Fire" checklist (gateway)
- CA engaged in multiple tasks, did not monitor FE workload closely
- Multiple checklists not completed; FE made errors during checklist completion



4. **Airplane Altitude** ..... CAPTAIN'S DISCRETION

   A. Land as soon as possible.

   or

   B. If above FL 270, consider descent to FL 270. Manually raise cabin altitude to 25,000 ft.

   or

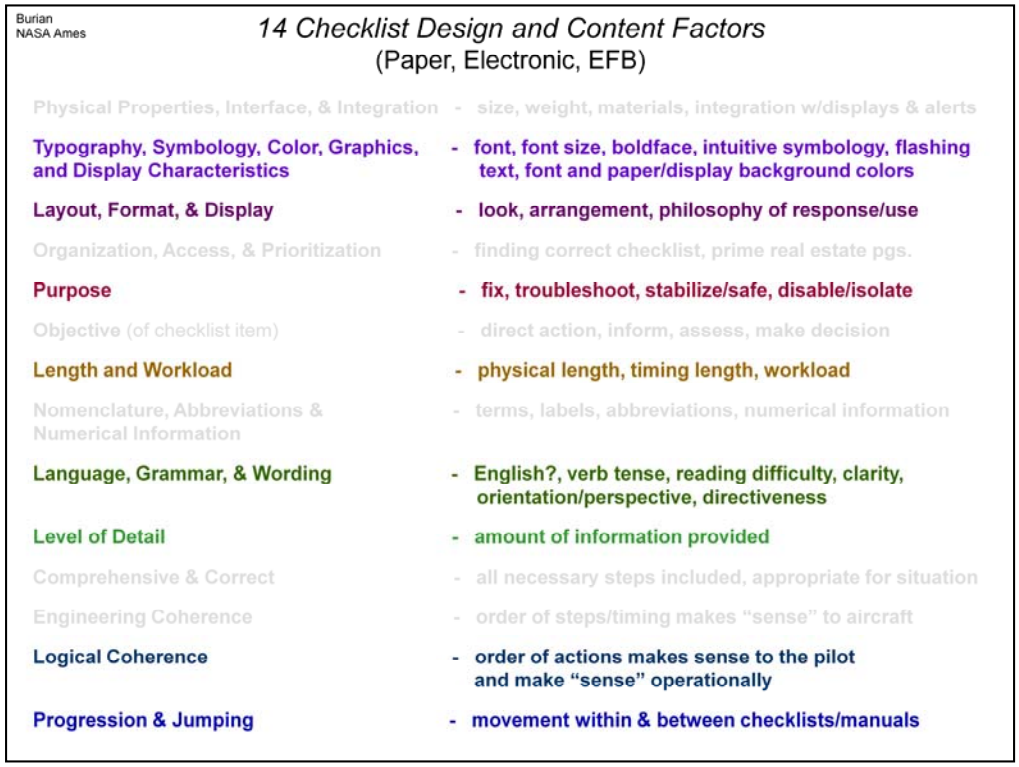
   C. If below FL 270, and an immediate landing is not possible, climb to FL 270. Manually raise cabin altitude to 25,000 ft. using the MANUAL CAB ALT control wheel.

5. **If unable To Extinguish Fire/Smoke** ..... MANUALLY RAISE CABIN ALTITUDE TO 25,000 FEET

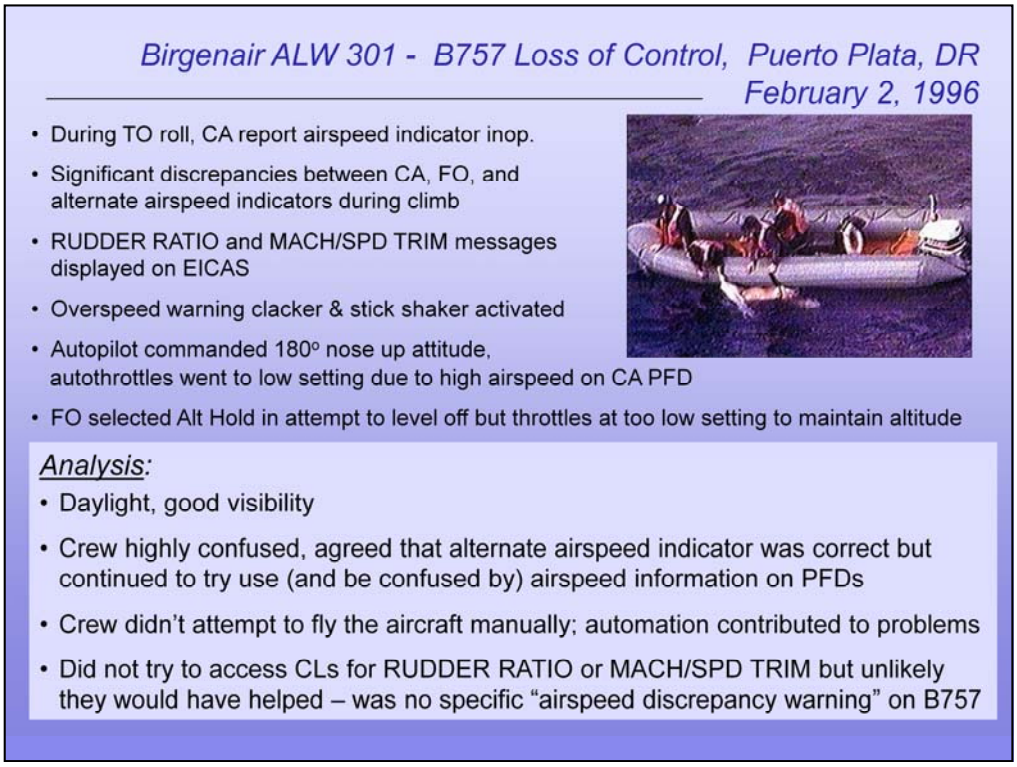
6. **Cabin Air Shutoff T-Handle** ..... PULL

7. **Maintain 0.5 PSI Diff Pressure Below FL 270, Or 25,000 Ft. Cabin Altitude Above FL 270.**

- Section of Cabin Cargo Smoke Light Illuminated Checklist
- Multiple items make reference to cabin altitude and FL270 – logical coherence issues
- Inconsistencies in amount of information provided re: identical actions
- "MANUAL CAB ALT" control wheel – FE "cranked it open a couple of times" – NTSB determined it would have needed 16 cranks to fully open – difference between simulator and real life



List of checklist design and content areas pertinent to this accident



Events:

•During the takeoff roll the CA indicated that his airspeed indicator was not working

•It appeared to start working properly once the aircraft began to climb but significant discrepancies existed between the CA's, FO's, and alternate airspeed indicators

•A few seconds later two advisory messages appeared on the EICAS display: RUDDER RATIO and MACH/SPD TRIM

•The overspeed warning clacker sounded

•The center autopilot commanded an 18 degree nose up attitude and the autothrottles went to a very low power setting in response to very high airspeeds as indicated on the CA's PFD

•The autopilot and autothrottles disengaged and the stall warning "stick shaker" activated

•Great confusion reigned; power was applied and then removed more than once

•The FO selected Altitude Hold in an attempt to level off and give them time to sort out what was going on. However, the throttles were at too low of a power setting to maintain altitude

Findings:

•Investigators determined that a pitot tube that provided information to the left Air Data Computer (ADC) was most likely completely blocked. The left ADC provided information to the CA's airspeed indicator and the center autopilot

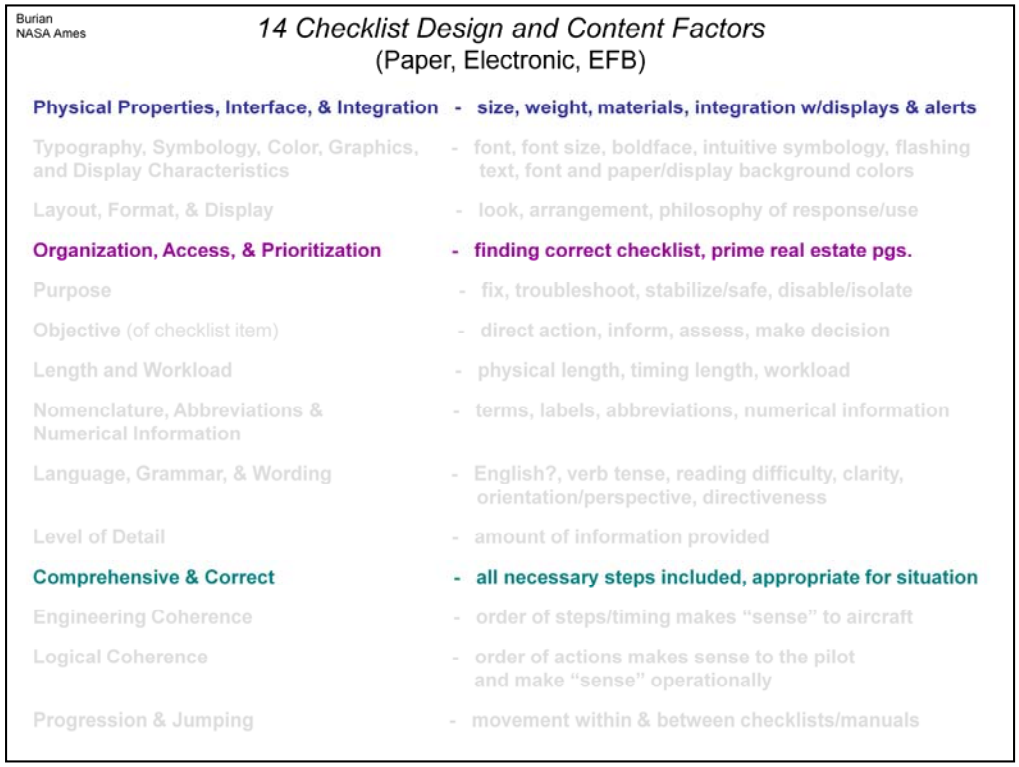
•There was no specific airspeed discrepancy warning on the B757

•The crew did not attempt to clarify the RUDDER RATIO or MACH/SPD TRIM advisories but it is unlikely that any related checklists would have proved useful

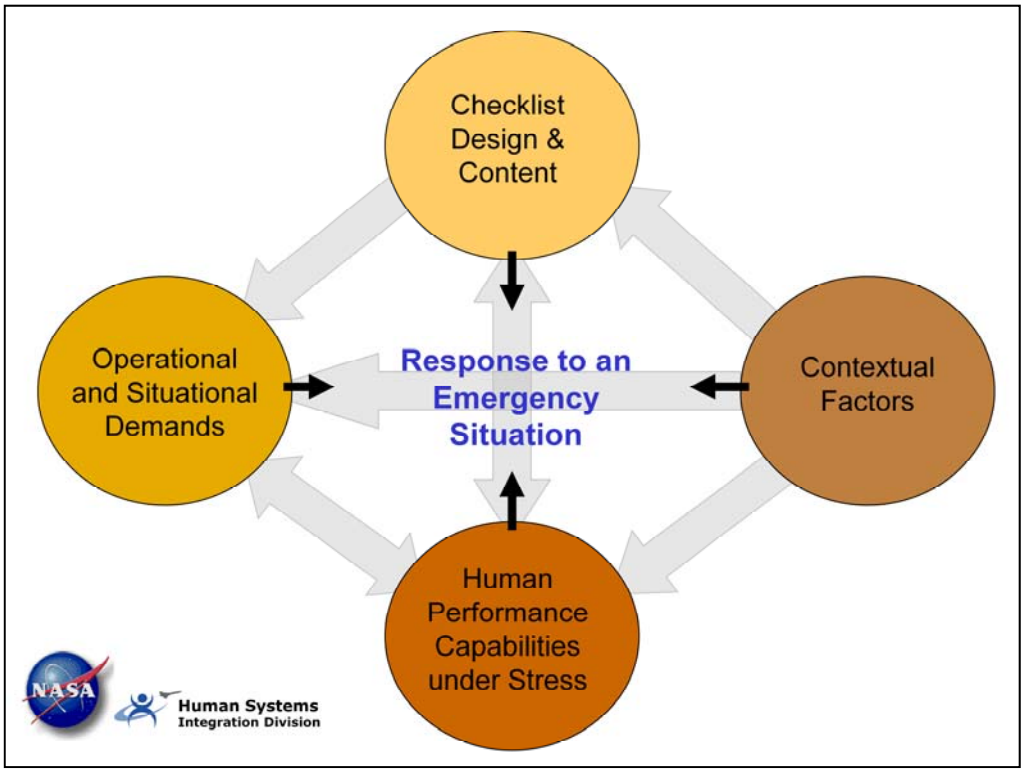
•Although the crew agreed that the alternate airspeed indicator was correct they continued to try to use (and be confused by) airspeed information on the PFDs

•The contradictory warnings and indicators were confusing and the center autopilot and autothrottles contributed greatly to their problems at least initially

•The crew did not attempt to fly the aircraft manually and continued to try use automation that did not help them (i.e., Altitude Hold)



List of checklist design and content areas pertinent to this accident


Checklist Design & Content
Operational and Situational Demands
Response to an Emergency Situation
Contextual Factors
Human Performance Capabilities under Stress
NASA
Human Systems Integration Division

Upcoming Publication

Burian, B. K. (in press). *Emergency and Abnormal Situations and the Checklist: Construction, Content, Context and Cognition.* NASA Technical Memorandum.

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Emergency and Abnormal Situations Study

http://human-factors.arc.nasa.gov/eas