Reducing the Risk of Smoke and Fire in Transport Airplanes: Past History, Current Risk, and Recommended Mitigations

Regulating, Training and Equipping for the Unthinkable

By:

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Smoke, Fire and Fumes in Transport Aircraft

Past History, Current Risk and Recommended Mitigations

A Specialist Paper prepared by
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With original Appendices material by the Reviewing team of the
RAeS Flight Operations Group (FOG) Committee

The Appendices must be read in conjunction with the Main Paper.
They are complementary corollaries and an important part of this Specialist Paper

THE AUTHOR
A veteran major airline, corporate and general aviation pilot, Captain Cox has flown over 14,000 hours
with over 10,000 in command of jet airliners. Additionally, he has flown as an instructor, check pilot, and
test pilot in addition to extensive involvement in global safety. He holds an Air Line Transport Pilot Certificate
with type ratings in the Airbus A320 family, the Boeing 737 family, the Fokker F28 and the
Cessna Citation. He is an experienced accident investigator having been involved in six major NTSB
investigations (the best known being the US Air 427 accident in Pittsburgh in 1994) and numerous
smaller investigations. He holds an Air Safety Certificate from the University of California, Berkeley.
The International Federation of Airline Pilots Association (FALPA) certified him as an international accident
investigator. For over twenty years he served as an Air Safety Representative for the Air Line Pilots
Association rising to the position of Executive Air Safety Chairman, ALPA’s top safety job, ALPA awarded
him their highest safety award in 1997. A Fellow of the Royal Aeronautical Society, he was awarded a
Master Air Pilot Certificate by the Guild of Air Pilots and Air Navigators in October 2004. In December
2004 he retired from airline flying after 25 years to found Safety Operating Systems a Washington, DC,
based aviation safety consulting firm.

THE ROYAL AERONAUTICAL SOCIETY FLIGHT OPERATIONS GROUP
The Flight Operations Group committee consists of 30 members from both the civilian airline and
military transport & flying training sectors, with Flight Safety and the Quality of Training throughout the
Public Transport Industry being its primary objectives. The FOG is a discussion group that focuses on
issues which primarily concern civil aviation, although it touches upon aviation safety in the armed
forces, specifically where the safety issues could also be applicable to civilian operations. Its
membership is highly respected within the civil aviation operations area and brings together a team with
many years of experience in the field of aviation.

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This Paper represents the views of the Specialist Group of the Society and of the Guild committee that was Involved with its
preparation. It has not been discussed outside the Learned Society Board or the Guild’s Secretariat. As such, it does not
necessarily represent the views of the Society or the Guild as a whole, or any other Specialist Group or Committee.
Risk, Perception, and Probability of Smoke, Fire and Fumes

What are the odds?
In-flight fire is the 4\textsuperscript{th} leading cause of fatalities in commercial jet aircraft accidents 1987 – 2004 (Boeing Study)

- Loss of Control (LOC)
- Controlled Flight into Terrain (CFIT)
- Specific Component failure (non-powerplant)

Probability is > 1 in 10,000
IATA STEADES DATA

36 months: Jan. 2002 to Dec. 2004

Total Air Safety Reports (ASRs) = 2,596

1701 of the 2596 events were in-flight occurrences of smoke
Probability

- > 1000 in-flight smoke events occur annually
- Resulting in >350 unscheduled or precautionary landings
- In-flight smoke rate is 1 in 5000 flights
- In-flight smoke diversion rate is 1 in 15,000 flights

IATA Data
Fatalities by CAST/ICAO Taxonomy Accident Category*

Number of on board fatalities

<table>
<thead>
<tr>
<th>Category</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFIT</td>
<td>3735</td>
</tr>
<tr>
<td>LOC-I</td>
<td>2830</td>
</tr>
<tr>
<td>SDF-NP</td>
<td>662</td>
</tr>
<tr>
<td>SDF-PP</td>
<td>618</td>
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<tr>
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<td>489</td>
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<tr>
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<td>1</td>
</tr>
<tr>
<td>LOC-Q</td>
<td>1</td>
</tr>
<tr>
<td>RAMP</td>
<td>1</td>
</tr>
<tr>
<td>EVAG</td>
<td>1</td>
</tr>
</tbody>
</table>

Number of fatal accidents
237 total

* See page 19 for the CAST/ICAO category definitions
Decreasing trends - technology

Worldwide Airline Fatalities, By Accident Type, 1995–2004

Total Fatalities: 5,828
CFIT and LOC Fatalities: 3,598 (62%)

Number of Fatalities

- Controlled Flight Into Terrain: 1,999
- Loss of Control in Flight: 1,599
- Midair Collision: 420
- In-flight Fire: 339
- Fuel Tank Explosion: 231
- Structure: 225
- Landing: 136

Number of Fatal Accidents (78 Total)

- Controlled Flight Into Terrain: 22
- Loss of Control in Flight: 21
- Midair Collision: 2
- In-flight Fire: 2
- Fuel Tank Explosion: 2
- Structure: 1
- Landing: 15

Source: Boeing

Flight Safety Foundation Aviation Safety World July 2006
Terms

- AC 25-1309 1A
  - Catastrophic (not all fires are, but potential)
  - Extremely improbable
    - $1 \times 10^{-9}$ or less

- Probability of diversion due to cockpit smoke could be a reasonably probable event and within the range of remote (Halfpenny)
History

- July 1785, Jean-François Pilâtre de Rozier’s hydrogen balloon ignited and burned over the English Channel.

- Aviation’s first fatal accident was an in-flight fire.

Credits - 2001 National Air and Space Museum, Smithsonian Institution (SI Neg. No. A-4691)
1973 and B707 fires

Varig Flight 860, July 11, 1973

Cabin fire with heavy smoke

Landed in a field 70 second from Paris Orly

Crew and Passenger smoke inhalation

Open Flight Deck Windows did not provide sufficient visibility
Varig Flight 860
Pan Am Flight 160

- November 3, 1973
- Cargo Flight - Hazardous Material Fire
- Smoke overwhelmed Flight Deck
  - Continuous Smoke Generation
- Flight Deck Window Opened - Not Successful Landing
Air Canada Flight 797

- June 2, 1983 – DC-9-30
- Fire began in Aft Lavatory – Spread
  - Cause believed to be electrical near flush motor
- Smoke filled Cabin and Flight Deck
- Flight Deck Door Broken
Air Canada Flight 797

- F/A and Passengers Smell Smoke
- Pilots Hear Circuit Breaker Trip
  - Reset once
- Smoke Increases
- CO₂ Fire Extinguisher Discharged into Lavatory
  - Not effective
  - Not applied directly at base of fire
Air Canada Flight 797

- Fire and Smoke Spread
- First Officer Went Aft to Investigate
- Flight Deck Door Left Open
- First Officer Switched Off Air-conditioning Packs
  - Ventilation flow aft stopped
- Flight Deck Windows Opened and Closed
  - Reversed
  - High Noise
Changes

- Lavatory Fire Detection
- Full Face Masks Portable Crew Oxygen
- Protective Breathing Equipment
- Fire Blocking Seats (650,000)
- Halon Fire Extinguisher (2 – 2.5 lb)
- AC 25-9
  - Smoke Testing
Single Failure – Multiple Results
Single Failure – Multiple Results

- RAF Nimrod Example
  - #1 Engine DC Wire Loom Failure
  - Uncommanded Opening of #4 Engine Starter
  - Starter Turbine Valve Over Speeds
    - Air from operating engine
  - Starter Turbine Disintegrates
  - Turbine Escapes Housing
  - Turbine Punctures Fuel Tank
  - Severe Fuel Tank Fire
  - Ditching in the North Sea – All Survived
Single Failure – Multiple Results

- Swiss Air 111
  - In-Flight Entertainment Systems Wiring
    - Likely initial location of arcing and/or fire
  - Spread to Nearby Wiring
    - Multiple system failure
    - Flight instruments failed
  - Unrelated Systems Affected by Initial Event
Location, Location, Location

- Inaccessible Areas Contain
  - Wiring
  - Thermal Acoustic Blankets
  - Contaminates
    - Conductive
    - Non-Conductive
  - Liquids
  - Corrosion Block
  - Lubricants
Unprotected Area of Aircraft

- Examples were all unprotected areas
  - No Detection
  - No Suppression

- Most in-flight fires are in unprotected areas
Wiring

- 2/3 In-Flight Fires are Electrical

- 2003 MITRE Report
  - 81 Large Transports Inspected
    - 40 wiring anomalies PER airplane average
  - 39 Small Transports Inspected
    - 58 wiring anomalies PER airplane average
Wiring

- FAA Report 1995 to 2002
  - 397 Wiring Failures
    - 84% burned, loose, damaged, shorted, failed, chafed or broken wires

- TWA 800 NTSB Report
  - Examined 25 Transport Aircraft
    - 24 had metal shavings in wiring bundles
    - 5 showed evidence of heat or fire damage
Wiring

- **Supplemental Type Certificate**
  - FAA Study of 316 Circuit Breakers
    - Many lugs contained two different size wires
    - Violation of 14 CFR Part 25.1357

- **Swiss Air 111 IFE**
  - No wiring routing drawings
  - By-Passed Cabin Bus Switch
Wiring

Video Deleted

Arc Fault Circuit Breaker
Vision Assurance

- Vision to Maintain Control
- Navigate
- Accomplish Checklist
- Land
Full Face Masks

- Better protection
- Better ability to purge
- Eliminates ability to only use mask
  - FedEx 1406

Sufficient Oxygen Supply for Landing
- MEL does not consider Smoke/Fire/Fumes
Halon Fire Extinguishers

- FAA Tests
  - 2 ½ lb did not extinguish fire
  - 5 lb could have extinguish fire
Training

Video Deleted

FAA Tech Center
Training

- FAA Tests
  - Line Flight Attendants
    - With 2 ½ lb Halon – Fire was not extinguished
    - PBE problems
    - Smoke Migration
  - Training was not adequate
Training

- Smoke
  - Toxicity
    - Improved but still a serious consideration
  - Location
    - Access
      - Remove panel or “ax it”
      - Collateral Damage
  - Amount
    - Continuous
      - Combustion ongoing
Training

- Use of the Ax
- When?
- Where?
- How?
CAN =

[Images of a crowbar, a bundle of wires, and a spark]
Checklists

- Various manufacturers – various checklists
  - e.g. Testing with a smoke filled simulator required 25 minutes to complete electrical smoke checklist

- Confusion
  - Most complex checklist for use in the highest stress time.
Flight Safety Foundation Template

INDUSTRY TEMPLATE

Emergency/Escape Checklist: Skyscapes and Rationales

The following items comprise the industry template for an integrated, non-linear SPP checklist. The accompanying rationale includes the purpose of each step and the reason for each step's sequential placement within the checklist.

Protect the flight crew from severe loss of oxygen.

1. Oxygen masks may be required.
   - Rationale: Some aircraft models require the flight crew to wear oxygen masks during flight. Oxygen masks are typically provided to flight crew to ensure a safe and comfortable flight experience.
   - Action: Provide oxygen masks and ensure that the flight crew is aware of their availability.

2. Oxygen masks (if required)...
   - Rationale: Oxygen masks are required to prevent the flight crew from suffering from hypoxia due to low oxygen levels in the cabin.
   - Action: Provide and fit oxygen masks to the flight crew.

3. Smoke detection equipment...
   - Rationale: Smoke detection equipment is critical to identify and mitigate potential fire hazards.
   - Action: Ensure that the smoke detection equipment is functioning properly.

4. Close & Sealed Compartments...
   - Rationale: Close and sealed compartments are essential for maintaining cabin pressure and preventing smoke from entering.
   - Action: Ensure that all compartments are closed and sealed.

5. Source elimination steps...
   - Rationale: Source elimination steps are crucial to prevent the spread of smoke.
   - Action: Identify and eliminate the source of smoke.

6. Course is immediate and can be quickly extinguished...
   - Rationale: The course is immediate and can be quickly extinguished if detected early.
   - Action: Implement immediate action to extinguish the fire.

7. Extinguish the source...
   - Rationale: Extinguish the source to prevent further spread.
   - Action: Use available fire extinguishing equipment to extinguish the fire.
## Flight Safety Foundation Template

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td><strong>Flight Safety Foundation Template</strong></td>
</tr>
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<tr>
<td>16</td>
<td><strong>Flight Safety Foundation Template</strong></td>
</tr>
</tbody>
</table>

### Additional Source Identification/Extermination Steps

- **Warning:** If the SPP situation becomes unmanageable consider an immediate landing.
- **Rationale:** The purpose of this warning is to remind the crew an immediate landing may be required if the situation deteriorates. The step is placed here after the initial probable source elimination steps have been accomplished, and before the additional source elimination steps which may be lengthy.

### Follow-up Actions

- **Rationale:** Additional source identification and isolation guidance may be required when the airplane is far from a suitable landing site. Initial system steps are presented here to prevent catastrophic system failure. These steps are taken in the absence of a detailed and isolated source because they may take time. The sequence of these steps is determined by the greatest damage they pose to the airplane.

- **Rationale:** This is the final assessment step in the checklist. The outcome of this assessment is an immediate landing or landing at a suitable airport if additional steps identified the source.

- **Rationale:** Operational considerations provide information to support real-world decision making. The crew may need to be reminded to review conditions that may affect continued flight operations and decisions. Operational considerations vary by aircraft model and may be lengthy so should be provided outside of the checklist.
PHILOSOPHY AND DEFINITIONS
Industry Checklist Template for Smoke/Fire/Fumes

This philosophy was derived by a collaborative group of Industry specialists representing aircraft manufacturers, airlines/operators and professional pilot associations. The philosophy was used to construct the Smoke/Fire/Fumes Checklist Template.

General
- The entire crew must be part of the solution.
- For any smoke event, time is critical.
- The Smoke/Fire/Fumes Checklist Template:
  - Addresses smoke/fire/fumes events (smoke/fire/fumes event not annunciated to the flight crew by aircraft detection systems);
  - Does not replace alerted checklists (e.g., cargo smoke) or address multiple events;
  - Includes considerations to support decisions for immediate landing (an overweight landing, a tailwind landing, a ditching, a forced off-airport landing, etc.);
  - Systematically identifies and eliminates an unknown smoke/fire/fumes source.
- Checklist authors should consider a large font for legibility of checklist text in smoke conditions and when goggles are worn.
- At the beginning of a smoke/fire/fumes event, the crew should consider all of the following:
  - Protecting themselves (e.g., oxygen masks, smoke goggles);
  - Communication (crew, air traffic control);
  - Diversion; and,
  - Assessing the smoke/fire/fumes situation and available resources.

Initial Steps for Source Elimination
- Assume pilots may not always be able to accurately identify the smoke source due to ambiguous cues, etc.
- Assume alerted-smoke-event checklists have been accomplished but the smoke's source may not have been eliminated.
- Rapid extinguishing/elimination of the source is the key to prevent escalation of the event.
- Manufacturer's initial steps that remove the most probable smoke/fumes sources and reduce risk must be immediately available to the crew.
  - These steps should be determined by model-specific historical data or analysis.
- Initial steps:
  - Should be quick, simple and reversible;
  - Will not make the situation worse or inhibit further assessment of the situation; and,
  - Do not require analysis by crew.

Timing for Diversion/Landing
- Checklist authors should not design procedures that delay diversion.
- Crews should anticipate diversion as soon as a smoke/fire/fumes event occurs and should be reminded in the checklist to consider a diversion.
- After the initial steps, the checklist should direct diversion unless the smoke/fire/fumes source is positively identified, confirmed to be extinguished and smoke/fumes are dissipating.
- The crew should consider an immediate landing anytime the situation cannot be controlled.

Smoke or Fumes Removal
- This decision must be made based upon the threat being presented to the passengers or crew.
- Accomplish Smoke or Fumes Removal Checklist procedures only after the fire is extinguished or if the smoke/fumes present the greatest threat.
- Smoke/fumes removal steps should be identified clearly as 'removal steps' and the checklist should be easily accessible (e.g., modular, shaded, separate, stand-alone, etc.).
- The crew may need to be reminded to remove smoke/fumes.
- The crew should be directed to return to the Smoke/Fire/Fumes Checklist after smoke/fumes removal if the Smoke/Fire/Fumes Checklist was not completed.
# New Format Checklist

**SMOKE, CABIN/COCKPIT**

<table>
<thead>
<tr>
<th>Item</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen mask and regulator</td>
<td>On, 100%</td>
</tr>
<tr>
<td>Crew and flight attendant communications</td>
<td>Establish</td>
</tr>
<tr>
<td>Cabin fans switch</td>
<td>Off</td>
</tr>
<tr>
<td>Blower switch</td>
<td>Override</td>
</tr>
<tr>
<td>Extract switch</td>
<td>Override</td>
</tr>
<tr>
<td>Galley/galley and cabin switch</td>
<td>Off</td>
</tr>
<tr>
<td>Cabin signs</td>
<td>On</td>
</tr>
<tr>
<td>Descent</td>
<td>Initiate</td>
</tr>
</tbody>
</table>

**WARNING:** Do not delay descent or diversion to find the smoke source.

If dense smoke at any time, accomplish reverse side.

**REFERENCE ACTION:**

- If cabin or galley equipment smoke/fire is suspected:
  - Emergency exit light switch:
    - On
  - If commercial switch installed:
    - Commercial switch: On
  - If commercial switch is not installed:
    - Bus tie switch: Off
    - Generator 2 switch: Off
    - Just before landing gear extension:
      - Generator 2 switch: On
      - Bus tie switch: Auto
  - END OF CABIN OR GALLEY EQUIPMENT SMOKE

- If air-conditioning smoke is suspected:
  - APU bleed switch: Off
  - Blower switch: Auto
  - Extract switch: Auto
  - Pack 1 switch: Off
  - If smoke does not decrease:
    - Pack 1 switch: On
    - Pack 2 switch: Off
    - Cargo heat air isolation valve switch: Off
  - If smoke persists:
    - Pack 2 switch: On
    - Blower switch: Override
    - Extract switch: Override
  - END OF AIR CONDITIONING SMOKE

- If electrical or avionics smoke is suspected:
  - END OF ELECTRICAL OR AVIONICS SMOKE
Open Window

- 70 Seconds from Runway
- Open Window did NOT Provide Sufficient Visibility
- High Noise
- Reverse Air Flow
  - Cabin Air into Flight Deck
- Visibility is Proportional to Increase Flow Rate
  - Double the rate double the visibility
Conclusions

- There are going to be in-flight fires
- Multiple layers of mitigation are necessary

Implementation
- FAA NPRMs
  - Wiring & Fuel Tank
Conclusions

- Fire is an unexpected event
- Fire is a very high stress event
- Fire may be from an unexpected source
Most Recent Examples
Reports indicate electrical fire on board
In-flight breakup
No survivors

RAF Nimrod
September 2006
Afghanistan
February 27, 2007
United 955
February 27, 2007
United 955
What are we going to do about it?
Implementation

- Operators
  - FSF checklist template
    - Eliminate open window
  - Retrofit arc fault circuit breakers
  - Improved wiring maintenance
  - Improved thermal acoustic blanket maintenance
  - Vision assurance
  - Improved flight crew training
  - Mark location of minimum damage for crash ax
Implementation

Manufacturers

- Adopt FSF checklist template
  - Eliminate open window
- Install arc fault circuit breakers
- Improve wiring maintenance
- Improve acoustic blanket maintenance
- Install vision assurance technology
- Improve flight crew training
Implementation

Regulators

- Require arc fault circuit breakers
- Improved wiring maintenance
- Improved thermal acoustic blanket maintenance
- Require continuous flight deck smoke testing
It is up to us