Do You Smell Smoke? Issues in the Design and Content of Checklists for Smoke, Fire, and Fumes

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Abstract

An in-flight smoke or fire event is an emergency unlike almost any other. The early cues for nonalerted conditions, such as air conditioning smoke or an electrical fire, are often ambiguous and elusive. Crews may have very little time to determine if there really is smoke, fire, or fumes, and if so, to locate the source and extinguish it. The checklists crews use for these conditions must help them respond quickly and effectively and must guide their decisions. This paper discusses three sets of issues in the design and content of checklists for in-flight smoke, fire, and fumes events.

Introduction

When a smoke, fire, or fumes (SFF) event occurs in-flight, time is the most precious resource crews have. Yet, at least some of this resource must be invested to determine if suspicious cues do in fact indicate smoke or fire, as cues are often ambiguous, especially for air conditioning, electrical and other nonalerted sources (i.e., SFF for which there are no aircraft detection systems). Also, false alarms occur frequently enough (e.g., Blake, 2000) to make crews want to have a definitive picture of their situation before committing to a diversion and emergency landing.

When smoke or fire does occur, a cascading loss of systems is likely if it spreads, and the crews' ability to respond effectively may become impaired (e.g., National Transportation Safety Board (NTSB), 1974; Transportation Safety Board (TSB) of Canada, 2003). Thus, rapid isolation and elimination of the ignition source are necessary to prevent the condition from escalating. However, timely decisions to divert and complete an emergency landing are also essential if the ignition source cannot be identified or if efforts to extinguish a fire are unsuccessful.

The stress and workload of responding to these events is exceptionally high and unlike many other types of emergency or abnormal situations, the flight and cabin crews absolutely must communicate and coordinate their assessment and response. However, even the most rigorous joint training cannot realistically present crews with the full extent of the demands they will face when dealing with smoke, fire, and fumes in flight.

Checklists are indispensable tools to guide crews' decision-making and response when faced with multiple tasks during these high stress events. Checklist designers must carefully consider all essential tasks crews must perform and prioritize when those tasks are to be accomplished, given the wide range of potential SFF events: those that are easily identified, isolated and

extinguished as well as those whose sources are unknown, hidden, and cannot be put out. Further, designers must determine the best way to help crews access the correct checklist quickly, especially when the crews may not be able to tell what kind of SFF they are dealing with. Designers must make sure that no bottlenecks exist within the checklists, especially given the time-criticality of many of these events, and must design the checklist to facilitate the high degree of communication and coordination that is needed between flight and cabin crews. Clearly, a wide variety of difficult issues face designers of checklists for in-flight SFF (a more thorough examination of these issues can be found in Burian, 2005).

Part of what makes responding to some of these issues so difficult is that they involve tradeoffs that require making choices that may conflict with each other. For example, toxic fumes and smoke can quickly enter a cockpit during a SFF event. Therefore, oxygen masks and goggles should be donned by a flight crew at the first sign of SFF; a delay in donning them may result in the crew realizing they are needed when it is too late and the crew's ability to function effectively has already become impaired (NTSB, 1998). On the other hand, oxygen masks can make communication difficult and goggles can restrict one's vision; should donning such protective gear be required if the SFF event is unlikely to cause the flight crew difficulty (e.g., a burnt muffin in the back galley)? How does one write a checklist so that crews will be adequately protected when they need to be but also not be unduly restrained when such equipment is unnecessary?

This paper will examine SFF checklist design and content issues related to three areas: *1) accessing the correct checklist; 2) guidance to divert, descend, and complete an emergency landing; and 3) source identification, isolation, and elimination*. The ways that these issues have been addressed in many current SFF checklists will be compared to newer approaches taken in a few air carrier checklists and in a new SFF checklist template, proposed by an aviation industry "steering committee" (Flight Safety Foundation, 2005). [1] Design trade-offs that exist between some of the issues will also be addressed. The issues will be considered only as they relate to checklists for nonalerted, rather than alerted, SFF events. As stated earlier, nonalerted SFF are those for which no sensors, detectors, or alarms exist, other than the humans onboard the aircraft. They commonly include such events as air conditioning smoke or fumes; electrical smoke, fire, or fumes; galley fires; cabin fires; fluorescent light ballast smoke or fire; and fires of "an unknown origin."

Accessing the Correct Checklist

Currently, when crews wish to complete a checklist for a nonalerted SFF situation, they typically access a checklist that has been developed for a specific type of smoke, fire, or fumes, (e.g., Air Conditioning Smoke, Electrical Smoke, Fire, or Fumes, etc.). Thus, crews are presented with a list of several different SFF checklists and they must first determine what type of SFF they have in order to select the proper checklist from the list. However, some cues for nonalerted events are often quite ambiguous and making a distinction between air conditioning, electrical, materials, florescent light ballast, dangerous goods (i.e., hazardous materials), or some other type of SFF can be quite difficult. Precious time is wasted if a crew completes a checklist for the wrong type of SFF.

In response to these issues, several air carriers (e.g., Delta, United) have independently developed a single integrated checklist to be used for multiple types of nonalerted SFF events. With such an integrated checklist, the time crews would initially spend trying to figure out which checklist to complete is actually spent by completing actions that have applicability for all types of nonalerted events. Similarly, the template developed by the steering committee, and proposed for industry-wide use, is for an integrated nonalerted SFF checklist. As can be seen in Appendix A, the first 11 steps/sections are to be accomplished irrespective of the specific type of SFF faced. Actions that are pertinent to specific types of SFF are to be grouped according to SFF type and appear in sections 12, 13, and 14 of the template.

Even though the template guides development of a single checklist to be used for multiple types of SFF events, crews may still be required to access more than one checklist during their response to such events. For example, the template calls for crews to refer to a separate Smoke Removal Checklist when necessary. (A template for the separate smoke removal checklist was not developed by the steering committee; manufacturers and/or air carriers are expected to provide them.). Similarly, the integrated checklists developed by individual air carriers also do not generally include all items that might be required to respond to all SFF events. For example, the integrated checklist developed by one air carrier requires that crews refer to the second page for smoke removal actions and to a separate checklist if they have avionics smoke.

Design Tradeoffs: Integrated vs. Separate Checklists. The decision to not include all SFF-related items into a single integrated checklist represents an approach to one of the many checklist design tradeoffs that exists. Integrating all types of nonalerted SFF checklists into one can result in a very lengthy checklist. The longer the checklist, the more time it takes crews to complete it. Additionally, such a comprehensive integrated checklist might require crews to complete a number of jumps within the checklist, to get to those items that are applicable for their specific situation, thus increasing the likelihood of checklist navigation errors. Nonetheless, with an integrated checklist crews always know the correct checklist to access and crews are not required to make difficult (or impossible) distinctions between different types of SFF before beginning their response to such a time-critical event.

Diversion and Landing Guidance

Some of the most hotly debated issues in the design of nonalerted SFF checklists concern whether or not crews should be given guidance to divert and, if so, where in the checklist this guidance should appear (i.e., at the beginning, at the end, etc.). In many current nonalerted SFF checklists, guidance to complete a diversion and/or emergency landing is given as one of the last steps, if it is given at all, and the guidance to complete such a diversion is only pertinent if efforts to extinguish the SFF were unsuccessful (e.g., TSB of Canada, 2003, NTSB, 1998). The philosophy implicit in this design is that continued flight to a planned destination is acceptable if in-flight smoke or fire is extinguished. If crews follow these types of checklists exactly as written, a diversion is initiated only after the completion of steps related to other actions, such as crew protection (i.e., donning of oxygen masks and goggles), establishing communication, source identification and troubleshooting, source isolation and fire fighting, and smoke removal, and then only if the SFF is continuing.

In a study of 15 in-flight fires that occurred between January 1967 and September 1998, the TSB of Canada determined that the amount of time between the detection of an on-board fire and when the aircraft ditched, conducted a forced landing, or crashed ranged between 5 and 35 minutes (TSB of Canada, 2003). These findings indicate that crews may have precious little time to complete various checklist actions before an emergency landing needs to be completed and, hence, the checklist guidance to initiate such a diversion should be provided and should appear early in a checklist.

However, some types of fire or smoke may be relatively simple to identify and extinguish, such as a burned muffin in a galley oven. Few people would argue that an emergency landing is required in such a situation and it is undesirable to complete an unscheduled landing unnecessarily because of the many safety and operational concerns involved (e.g., tires bursting and possible emergency evacuation after an overweight landing). Thus, developers struggle with the priority to place on guidance to complete a diversion in nonalerted SFF checklists.

In the newly developed template, the very first item states "Diversion may be required." The intent of this item, and the reason it appears first in the checklist, is to "establish the mindset that a diversion may be required" (see the philosophy developed by the Steering Committee to accompany the template in Appendix B). The placement of this item as the very first in a SFF checklist represents a significant change from the current philosophy about how crews are to respond to SFF events described above. It is not intended that crews read this item as direction to immediately initiate a diversion or even begin planning a diversion however, just that they should keep in mind that a diversion may be necessary.

Step 10 is the first place in the template where crews are specifically directed to "Initiate a diversion to the nearest suitable airport" and they are to do this "while continuing the checklist" (See Appendix A). This step follows five steps (5, 6, 7, 8, 9) pertaining to source identification and/or source isolation/elimination. The steering committee believe that crews will be able to complete all of the actions in these five steps fairly quickly – the philosophy even states "Checklist authors should not design procedures that delay diversion" (see Appendix B). Thus, using a checklist developed according to the template, crews will complete self-protection and establishing communication items (steps 2, 3, and 4), five sections of "quick" actions to eliminate probable sources of SFF and then initiate a diversion in Step 10 if the earlier actions to eliminate the SFF source were unsuccessful.

Current checklists developed by some air carriers and manufacturers reflect a different approach as directions to divert, initiate a descent, or "land ASAP" are given earlier and do not follow actions to extinguish an easily identifiable and accessible source of SFF. For example, one air carrier's integrated SFF checklist directs crews to initiate a descent after completing six steps: donning smoke masks and goggles, establishing communication with flight attendants, and turning off or overriding four different switches. Further, this air carrier checklist warns crews "Do not delay descent or diversion to find the smoke source."

Design Tradeoffs: Divert vs. Descend. It is important to note that guidance to divert is not the same as guidance to descend. Some in the industry believe that at the first sign of SFF, crews should initiate a descent to the minimum enroute altitude or get fairly close to the water if flying

over the ocean. This would allow a crew to complete the descent and landing/ditching quickly in the event that a situation becomes uncontrollable. Others in the industry point out that such a descent may commit a crew to completing an unscheduled landing as they may no longer have enough fuel to reach their planned destination (due to the higher rate of fuel consumption at lower altitudes). The template is constructed so that crews will always have the option to continue to their planned destination if the source of SFF "is confirmed to be extinguished and the smoke/fumes are dissipating" (see Appendix B). Checklists developed by some carriers and manufacturers are more compulsory in their directions for crews to descend and land – all SFF events, even those that have been extinguished, will result in a descent and diversion if the destination airport is not already close at hand.

Source Identification / Isolation / Elimination

In many current nonalerted SFF checklists, a number of items are devoted to identifying the specific source of SFF and concurrently isolating and eliminating it. Thus, in a checklist for Air Conditioning Smoke, crews are often told to, in a stepwise fashion, turn off various pack switches, bleed air switches, and other air conditioning system components and after each configuration change, make a determination about whether the smoke is continuing or decreasing. If it is continuing, crews are commonly instructed to reverse the action(s) just taken (i.e., turn the switch(es) back on) and proceed with making the next configuration change. One drawback to this approach is that it can be quite time consuming to complete these steps particularly because it can take several minutes for crews to be able to tell if the configuration change they just completed has had the desired effect or not. Nonetheless, given the state of current technology and aircraft design, completing such stepwise actions is typically the only way that crews can identify and isolate a hidden source of SFF.

The steering committee's checklist template and integrated air carrier SFF checklists do include sections of system-specific source identification items (in the template, these are sections 12, 13, and 14; see Appendix A). However, in both the template and air carrier integrated checklists, these system-specific steps typically follow *earlier* steps designed to isolate and eliminate a source of SFF that do *not* involve a systematic, system-specific analysis of actions. These earlier steps remove "the most likely" sources of SFF as determined by the history of the aircraft type.

For example, following the completion of crew self-protection and communication steps in the template (steps 1-4), crews would complete items related to step 5, which states "Manufacturer's initial steps…….Accomplish" (see Appendix A). In the accompanying philosophy document, "manufacturer's initial steps" are described as those "that remove the most probable smoke/fumes sources and reduce risk…These steps should be determined by model-specific historical data or analysis" (see Appendix B). Furthermore, the philosophy specifies that these 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 the crew" (see Appendix B).

Thus, when using a checklist designed according to the template, crews will eliminate the most likely sources of SFF early on during checklist completion *without* making a determination first as to whether one of these sources is in fact causing the smoke, fire, or fumes; this step involves source isolation/elimination but *not* source identification. Hence, a crew may complete the

checklist successfully (i.e., fire is extinguished, smoke is dissipating) without ever having positively identified the source of the SFF.

Design Tradeoffs: Lengthy Source Identification vs. Quick Source Elimination. The inclusion of both system-specific source identification items as well as smoke elimination items that do not require source identification in integrated SFF checklists addresses two, sometimes competing needs felt by the crews when dealing with these events. When they are needed, items that support a systematic identification of a SFF source are available. Likewise, actions that will eliminate the most likely sources of SFF are also provided allowing the possibility of quickly eliminating a source without requiring lengthy and systematic analysis.

Conclusion

The construction and design of checklists to be used for nonalerted SFF events is very challenging. The types of events for which they might be needed vary widely but, at their extreme, are highly time-critical and life threatening. Additionally, the cues available to crews may not be very helpful in determining their situation and at times may actually be misleading. The industry is moving toward the use of integrated checklists to guide crew response to nonalerted SFF events. There are a number of issues that are often beyond the scope considered in these integrated checklists however, which checklist designers will also need to consider when designing SFF checklists (Burian, 2005). Nonetheless, integrated SFF checklist designers at air carriers and the steering committee that developed the template (Flight Safety Foundation, 2005) should be commended for addressing some of the most thorny issues, balancing tradeoffs, and for helping to move the industry forward in thinking differently about response to in-flight SFF.

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Endnotes

[1] Beginning in 2004, group of approximately 10 individuals (a “steering committee”) began meeting to develop nonalerted SFF checklist content and design guidance that could be adopted across the industry. Representatives from the four major aircraft manufacturers (Airbus, Boeing, Bombardier, and Embraer), the International Federation of Air Line Pilots Associations (IFALPA), and four air carriers (Air Canada, British Airways, Delta, and United) comprised the steering committee. During the development process, one meeting was also held, which the author attended, whereby feedback was solicited from individuals representing other industry groups (e.g., FAA, NASA, NTSB, TSB of Canada, etc.).

The steering committee has recently completed two products it hopes will be adopted by the international aviation industry as the standards that will guide the design and content of nonalerted SFF checklists (Flight Safety Foundation, 2005). One product is a template to be used by designers when developing a nonalerted SFF checklist (Appendix A) and the other is a description of the philosophy upon which the template is founded, as well as a few definitions of various terms and concepts used in the template (Appendix B). It is important to note that the

template is not, in and of itself, a checklist. As its name states, it is a framework to guide checklist design and content. Some of the steps on the template are actually sections and several checklist items might be developed for a single template "step." The accompanying philosophy and concept definitions must also be consulted during checklist development so that the resulting checklist is truly in keeping with the intent of the template.

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Appendix A

Smoke/Fire/Fumes Checklist Template

1	Diversion may be required.		
2	Oxygen masks (if required)	.....	On, 100%
3	Smoke goggles (if required)	.....	On
4	Flight crew and cabin crew communication	.....	Establish
5	Manufacturer's initial steps[1]	.....	Accomplish

If smoke or fumes become the greatest threat, accomplish *Smoke or Fumes Removal Checklist,* page __.[2]

6 Source is immediately obvious and can be extinguished quickly:
If yes, go to Step 7.
If no, go to Step 9.

7 Extinguish the source.
If possible, remove power from affected equipment by switch or circuit breaker on the flight deck or in the cabin.

8 Source is confirmed visually to be extinguished:
If yes, consider reversing manufacturer's initial steps. Go to Step 17.
If no, go to Step 9.

9 Remaining minimal essential manufacturer's action steps ..... Accomplish
[These are steps that do not meet the "initial steps" criteria but are probable sources.][3]

10 Initiate a diversion to the nearest suitable airport while continuing the checklist.

Warning: If the smoke/fire/fumes situation becomes unmanageable, consider an immediate landing.

11 Landing is imminent:
If yes, go to Step 16.
If no, go to Step 12.

12 XX system actions[4] ..... Accomplish
[Further actions to control/extinguish source.]
If dissipating, go to Step 16.

13 YY system actions ..... Accomplish
[Further actions to control/extinguish source.]
If dissipating, go to Step 16.

14 ZZ system actions ..... Accomplish
[Further actions to control/extinguish source.]
If dissipating, go to Step 16.

15 Smoke/fire/fumes continue after all system-related steps are accomplished:
Consider landing immediately.
Go to Step 16.

16 Review *Operational Considerations,* page __.

17 Accomplish *Smoke or Fumes Removal Checklist,* if required, page __.

18 Checklist complete.

Operational Considerations

[These items appear after "checklist complete." This area should be used to list operational considerations, such as an overweight landing, a tailwind landing, a ditching, a forced off-airport landing, etc.]

Notes

1. These aircraft-specific steps will be developed and inserted by the aircraft manufacturer.

2. The page number for the aircraft-specific *Smoke or Fumes Removal Checklist* will be inserted in the space provided.

3. Bracketed text contains instructions/explanations for the checklist author.

4. "XX," "YY" and "ZZ" are placeholders for the environmental control system, electrical system, in-flight entertainment system and/or any other systems identified by the aircraft manufacturer.

Appendix B

Smoke/Fire/Fumes Philosophy
and Definitions

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 nonalerted 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.); and,
  - 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 has been 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, standalone, 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.

Additional Steps for Source Elimination

- Additional steps aimed at source identification and elimination:
  - Are subsequent to the manufacturer's initial steps and the diversion decision;
  - Are accomplished as time and conditions permit, and should not delay landing; and,
  - Are based on model-specific historical data or analysis.
- The crew needs checklist guidance to systematically isolate an unknown smoke/fire/fumes source.

Definitions:

Confirmed to be extinguished: The source is confirmed visually to be extinguished. (You can "put your tongue on it.")

Continued flight: Once a fire or a concentration of smoke/fumes is detected, continuing the flight to the planned destination is not recommended unless the source of the smoke/fumes/fire is confirmed to be extinguished and the smoke/fumes are dissipating.

Crew: For the purposes of this document, the term "crew" includes all cabin crewmembers and flight crewmembers.

Diversion may be required: Establishes the mindset that a diversion may be required.

Land at the nearest suitable airport: Commence diversion to the nearest suitable airport. The captain also should evaluate the risk presented by conditions that may affect safety of the passengers associated with the approach, landing and post-landing.

Landing is imminent: The airplane is close enough to landing that the remaining time must be used to prepare for approach and landing. Accomplishing further smoke/fire/fumes-identification steps would delay landing.

Land immediately: Proceed immediately to the nearest landing site. Conditions have deteriorated and any risk associated with the approach, landing or post-landing is exceeded by the risk of the on-board situation. “Immediate landing” implies immediate diversion to a landing on a runway; however, smoke/fire/fumes scenarios may be severe enough that the captain should consider an overweight landing, a tailwind landing, a ditching, a forced off-airport landing, etc.