Un-alerted Smoke and Fire: Checklist Content and Intended Crew Response

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An in-flight smoke or fire event is an emergency unlike almost any other. The early cues for un-alerted conditions, such as air conditioning smoke or fire, are often ambiguous and elusive. The checklists crews use for these conditions must help them respond quickly and effectively and must guide their decisions. Ten years ago an industry committee developed a template to guide the content of Part 121 checklists for un-alerted smoke and fire events. This template is based upon a new philosophy about how crews should use the checklists and respond to the events. To determine the degree to which current un-alerted checklists of in-flight smoke or fire comply or are consistent with the guidance outlined in the template, I collected and analysed checklists from North American air carriers.

In-flight smoke, fire, and fumes (SFF) events, particularly those that are un-alerted, such as electrical smoke or fire, are among the most critical emergencies faced on-board aircraft.[1] Timely response by the flight deck and cabin crews is essential (Federal Aviation Administration [FAA], 2014). During these events, crews must divide their attention among and accomplish a wide variety of tasks. When necessary, they must protect their ability to respond and continue to fly the aircraft by donning oxygen masks and goggles and must establish and maintain good communication and must coordinate their responses. The source of the SFF must be identified and appropriate actions taken to isolate and eliminate it, if possible. At the same time, however, crews must be recognize the possible need to divert and make an emergency landing at a suitable airport, or even ditch, should it be necessary. Thus, during smoke and fire identification and elimination activities, crews must maintain the "big picture" view of their dynamic situation and be prepared, if necessary, to shift from attempting to identify and quell the source of the fire to eliminating dense smoke and fumes and preparing to land or ditch (Burian, 2005).

Approximately 10 years ago, representatives from the aviation industry constructed a template to guide the development of checklists for un-alerted SFF events (Flight Safety Foundation [FSF], 2005). The underlying philosophy for checklist content and crew response to un-alerted SFF events embodied in this template contrasted markedly with that underpinning typical checklist content and crew response expected up to that time. Previously, Quick Reference Handbooks (QRHs) contained multiple checklists for a variety of un-alerted SFF events (e.g., air conditioning smoke, electrical smoke and fire, etc.) and crews had to first determine the type of SFF before being able to access a checklist. Additionally, it was typical that reminders or directions to complete smoke removal actions, if necessary, or divert to an airport for an emergency landing appeared only at the end of these checklists, if they appeared at all, after *all* source identification and elimination actions had been accomplished. Reports of crews being unable to determine the correct type of SFF, and thus, accomplishing the wrong checklist for their situation, and SFF incidents and accidents in which a diversion was delayed (e.g., National Transportation Safety Board [NTSB], 1998; Transportation Safety Board [TSB] of Canada, 2003) spurred the industry to re-think checklist content and the underlying philosophy of how crews should respond to these events.

Four major concepts or features are represented in the checklist template that was developed (see Table 1). The first is that all actions and information necessary for response to *all* different types of un-alerted SFF events are to be integrated into a single checklist. Thus, crews will not have to first make a determination of the type of event they are dealing with before being able to identify the correct checklist to access. The second major concept is that crews should be guided to take quick action to isolate and eliminate the most likely source(s) of SFF, as determined through historical analysis of SFF on each aircraft type, *without* first being required to determine if those likely sources are indeed the source of their SFF situation; these are referred to as "Manufacturer's initial steps" and "Remaining minimal essential manufacturer's initial steps" in the template (Steps 5 and 9, respectively; see Table 1). The third major feature is that checklists constructed according to the template guidance will be appropriate for

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[1] It can be difficult to develop consistently correct and reliable alerts for some types of SFF conditions, such as the presence of toxic fumes, and electrical and air conditioning smoke and fire. As a consequence, typically no alerts for these conditions are provided through integrated aircraft crew alerting systems.

use in situations in which the source of SFF is obvious, easily accessible, and can be extinguished quickly (Steps 6-8 in Table 1) as well as for those situations in which it is not (see system specific actions, Steps 12-14 in Table 1). The final major concept incorporated in the template is that reminders or guidance to the crews regarding their overall situation management should be provided, particularly with regard to conducting a diversion (Steps 1 and 10), performing an immediate landing (the Warning after Step 10 and Step 15), and the necessity to consider accomplishing smoke/fumes removal actions (after Step 5 and Step 17). When under the stress and high workload characteristic of these critical emergencies, it can be easy to lose sight of the need to manage the overall situation; these reminders are included in the template to counteract this tendency.

Table 1.
Smoke/Fire/Fumes Checklist Template[1,2]

Steps	Action
1	Diversion may be required.
2-4	Crew protection (don masks and goggles) and establish crew communication
5	Manufacturers initial steps
Accomplish Smoke/Fumes Removal Checklist any time they become the greater threat	
6-8	Extinguish source if it is immediately obvious and can be extinguished quickly
9	Remaining minimal essential manufacturer's initial steps
10	Initiate a diversion to the nearest suitable airport while continuing the checklist
Warning: If the SFF situations becomes unmanageable, consider an immediate landing	
11	If landing is imminent, go to Step 16. If not, go to Step 12.
12-14	System specific actions (e.g., air conditioning smoke, electrical smoke and fire, etc.)
15	If SFF continues after all system specific actions are accomplished, consider landing immediately.
16	Review Operational Considerations (e.g., overweight landing, etc.)
17	Accomplish Smoke/Fumes Removal Checklist, if required.

[1] Steps in the template have been condensed and wording has been minimally altered to save space. Refer to FSF (2005) for the complete wording and expanded view of all checklist steps.

[2] More than one step or action in the actual SFF checklists that are developed may be included as part of a single step on the template.

It has now been a decade since the template was developed. This study was undertaken to identify the degree to which a sample set of airline checklists currently in use for in-flight, un-alerted SFF conform to the guidance and underlying philosophy of the industry's SFF checklist template (FSF, 2005).

Method

Participants and Materials

Seven North American air carriers (including international, major, and regional carriers) provided 11 QRHs containing the checklists analyzed in this study. The QRHs[2] were used on five aircraft types: Airbus A320 (n=3); Boeing B737NG (n=2); Boeing B777 (n=2); Bombardier Canadair Regional Jet-700 (CRJ700, n=2); and Embraer E190 (n=2). Un-alerted checklists for in-flight SFF events as well as checklists to be used for the removal of smoke and toxic fumes were analyzed. Additional checklists pertaining to passenger evacuation, ditching, and emergency landing/descent were also reviewed. All QRHs and checklists were current and in use by the participant air carriers at the time they were provided to the researcher.

Procedure

These checklists were analyzed for the degree to which their structure, content, and implicit philosophy of

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[2] One carrier which flies the Boeing B777 does not use a printed QRH on-board the aircraft; only the B777 Electronic Checklist (ECL) is used for response to non-normal events, such as in-flight smoke, fire, and fumes. Electronic copies of the checklists contained in this air carrier's electronic Operations Manual were analyzed for this study. For ease of wording, the electronic Operations Manual will be referred to as a QRH.

crew response to un-alerted, in-flight SFF were consistent with or deviated from guidance in the industry SFF checklist template (FSF, 2005). Particular attention was paid to the four major concepts or features of the template described earlier. Font sizes, inclusion of memory items, checklist length and numbers of items for diverse SFF scenarios, and reference to items pertaining to other checklists that might be needed in these events (e.g., evacuation, ditching, etc.), were also analyzed but are not reported here due to space limitations.

Results

Template Concept 1: A Single Integrated Checklist

At the time the template was developed the concept of a single, integrated checklist to be used for response to all types of un-alerted SFF events was relatively novel. It was not uncommon to see separate checklists for un-alerted SFF events occurring in specific locations or involving different aircraft systems: air conditioning, electrical, cabin, galley, lavatory, avionics, engine tailpipe, cargo, and unknown source or hidden. On the aircraft types included in this study, SFF involving avionics, cargo, or occurring in lavatories are now most often alerted through flight deck caution and warning systems (i.e., Engine Indication and Crew Alerting System [EICAS], or Electronic Centralized Aircraft Monitoring [ECAM]). With the exception of engine tailpipe fire[3], of the 11 QRHs analyzed in this study, the integration of actions for response to the SFF types that remain un-alerted was seen in 10; one of the three A320 QRHs analyzed did not have a main integrated SFF checklists and included separate checklists for a) cabin smoke and fire and b) air conditioning smoke or fire. The other two A320 QRHs, as well as the QRHs for the other four aircraft types, integrated response to these un-alerted conditions along with others, such as electrical smoke or fire, into a single checklist. Furthermore, the other two A320 un-alerted SFF checklists included items for *alerted* avionics SFF. Similarly, both EMB190 un-alerted SFF checklists included items for *alerted* cargo compartment fires. Thus, based upon this small sample of QRHs and checklists currently in use, it appears that the concept of providing a single, integrated checklist for many types of un-alerted SFFs, and on occasion some types of alerted SFF, has gained some acceptance within the industry.

However, some separate un-alerted SFF checklists were identified in a few of the 10 QRHs that also contained a main integrated checklist for un-alerted SFF (e.g., Aft Avionics Rack Smoke, n=1; EFB Computer Overheat/Fire, n=2; and Tailpipe Fire, n = 5). With the exception of Tailpipe Fire (discussed below), it is not known why the air carriers or manufacturers who developed these checklists chose to keep them separate and not incorporate them into the main integrated checklist for un-alerted SFF.

Template Concept 2: Eliminate the Most Likely Sources of SFF without Analysis

One of the most novel concepts in the template suggests flight crews should isolate and eliminate the most likely sources of un-alerted SFF *without* first determining if they are in fact the cause. All 10 QRHs that included a single integrated checklist for most types of un-alerted SFF included these types of steps—referred to in the template as initial manufacturers steps (range: 1-10 items, mean = 5.6 items). According to the supplementary information provided with the template (FSF, 2005), these initial steps or actions 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" (pg. 32). Additional manufacturer's steps which do not require crew analysis but may not meet the other criteria for the "initial steps" just outlined (see Step 9, Table 1) and which are distinctly separate from system specific actions (see Steps 12-14, Table 1) were found only in the four checklists for Boeing aircraft (B737: n= 11 items in each checklist, and B777: n=4 items in each checklist) . Thus, in the checklists analyzed there is high consensus on directing crews to extinguish likely sources of SFF without going through a lengthy process to confirm which source might actually be causing the event. Of the four manufacturers, only Boeing chose to provide additional actions, separate from system specific items, that might not be reversible, might inhibit further assessment of the situation, or in some other way do not meet the criteria spelled out for "initial manufacturer's steps" (FSF, 2005).

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[3] Due to the unique nature of tailpipe fires and the inability of flight and cabin crews to directly fight and/or confirm that tailpipe fires have been extinguished, actions for addressing these fires are not integrated into checklists for dealing with other types of un-alerted SFF. Five of the 11 QRHs analyzed included separate checklists for dealing with tailpipe fires.

Action reversal. All four of the Boeing checklists and one of the EMB190 checklists included an item stating that at the captain's discretion, actions just performed (i.e., manufacturer's initial steps or elimination of an obvious and quickly extinguishable source) could be reversed if the SFF could be confirmed to have been extinguished and the smoke/fumes was dissipating. One EMB190 and two A320 un-alerted SFF checklists instruct the pilots to reverse some steps to re-power some equipment needed during landing while on final approach. Additionally, two checklists (one for an A320 and one for an EMB190) also gave pilots the option or directed them to reset the Display Units to Auto if they were required for landing but did not state when this should occur.

Template Concept 3: Dealing with Sources that are Obvious and Quickly Extinguishable or are Not

Of the 10 integrated SFF checklists analyzed, nine contained actions to accomplish associated with sources that were obvious and accessible and could be extinguished quickly (Steps 6-8, Table 1); these actions appear after the completion of the manufacturer's initial steps (Step 5, Table 1). The QRH that did not (for a CRJ700) took a different approach than that suggested by the template. In this checklist, after completing the manufacturer's initial steps, if the source was known (e.g., electrical smoke or fire) crews were directed to complete that (system specific) section of the checklist. If the source was not known upon completion of the manufacturer's initial steps, pilots were directed to attend to diversion and landing activities and were not to complete any system specific actions at all. In the template, and the nine integrated checklists that adopted the template's approach, if the source is obvious and quickly extinguishable, crews are directed to do so but are not provided with specific actions to accomplish. They are only directed to complete system specific actions (Steps 12-14, Table 1) if the source is not immediately obvious or if attempts to extinguish it have been unsuccessful.

Furthermore, the template guides the accomplishment of actions for *additional* aircraft systems if those accomplished in the *first* system specific section are not successful in isolating and extinguishing the SFF. Hence, pilots would start with actions for the first system (typically the one identified as most often the source of SFF on that aircraft type) and continue accomplishing items through that system and subsequent system sections until the source has been eliminated or the end of the checklist has been reached. All 10 of the integrated SFF checklists analyzed contained system specific items, although in the two CRJ700 checklists, pilots were directed to accomplish *only* the items for the specific system thought to be the source of the SFF. In other words, in those checklists, pilots were not directed to accomplish items associated with any other systems, even if those accomplished associated with the suspected system had been unsuccessful in terminating the SFF. It should be noted that in six checklists, although system specific items were provided, which system they pertained to was not specified (i.e., through a header or section title) and in some checklists it appeared that all or most items for some systems (e.g., electrical smoke/fire) were included as part of the initial manufacturer's items near the beginning of the checklist. Furthermore, analysis of the checklists in one CRJ700 QRH revealed that actions for dealing with air conditioning smoke or fire were not located in the integrated SFF checklist but instead were included in the checklist for Smoke and Fumes removal.

Template Concept 4: Support for Overall Situation Management

Diversion. The template includes two items with regard to a diversion. The first is Step 1 and is intended to be a reminder to the crew or "establishes the mindset" (pg. 34) that a diversion may be necessary (FSF, 2005). The second (Step 10) actually directs that a diversion to the nearest suitable airport should be initiated while continuing with the rest of the checklist. This action is reached if the initial manufacturer's actions have proved unsuccessful and if the source is not immediately obvious or is immediately obvious but cannot be visually confirmed to have been extinguished. Thus, the diversion is directed after some steps have been taken quickly—that have proved unsuccessful—and prior to the pilots accomplishing more "analytical" actions in the system specific sections. In this study checklist analysis distinguished items worded as reminders (e.g., "Consider a diversion"), consistent with the intent of template Step 1, from items that directed that a diversion be initiated/conducted, consistent with template Step 10 (see Table 1).

The degree to which the checklists analyzed conformed with these two template steps varied greatly although all of the main un-alerted SFF checklists analyzed did address diversion, most often going beyond what is suggested by the template. Five checklists included some type of reminder that diversion may be necessary at or near the beginning of the checklist and six checklists made such reminders (three of them for the second time) in the middle of the checklist. Three checklists actually direct the initiation of a diversion (or stated "Land Immediately/

ASAP") at or near the beginning of the checklist and the other seven direct the initiation of a diversion in the middle of the checklist, similar to placement of this direction in the template (Step 10). One CRJ700 checklist actually contained nine separate places where a diversion was directed, many of these occurring at the end of sets of items to be completed in the system specific sections. Thus, with regard to the intent of the template relative to reminding or directing a diversion, the checklists analyzed in this study conformed and even went beyond by often directing a diversion much earlier during situation response than suggested by the template.

Landing is Imminent. Step 11 in the template is what is known as an "opt out gate" (Burian, 2014). An opt out gate is a Conditional/Decision Item that, if true, directs the user to abandon checklist accomplishment and to shift attention to some tasks other than accomplishment of the checklist; in this case, the user jumps to the final items on the checklist in preparation for an impending landing. Such items can be critical in helping to assure that pilot attention is not fixated on checklist accomplishment but rather is focused on the most essential tasks relative to aircraft condition and phase of flight.

Despite the importance of such an item, none of the checklists analyzed in this study incorporated this item as stated in the template. However, approximately half way through a 4½ page checklist for use in an EMB190, there were directions about what actions to take if an airport was nearby. Additionally, four checklists (all for Boeing aircraft) stated that diversion/landing should not be delayed in an attempt to complete the following (system specific) items. In contrast, the checklist for a CRJ700 instructed pilots to complete as many items as possible before completing the Descent and Before Landing checklists. In each of these six checklists, the manufacturers or air carriers attempted to address the distribution of attention given to fighting the fire relative to diversion/landing. However, this was accomplished in three different ways, only one of which (for the EMB190) was closest to matching the guidance as stated in the template. This is explored in the Discussion section below.

Consider an Immediate Landing. There are two steps in the template in which the pilots are told to consider an immediate landing: if the SFF situation has become unmanageable and if all the appropriate actions to isolate and eliminate the SFF have been accomplished but were unsuccessful. Seven of the checklists include the first item although none of them worded it as a Warning Statement as it appears in the template. The three other un-alerted SFF checklists directed the pilots to accomplish a diversion or land ASAP/immediately early in the checklist, obviating the need to suggest later in the checklist that an immediate landing be considered. Only five of the integrated checklists include the suggestion to consider an immediate landing if all SFF elimination actions have failed. However, three of the other five integrated checklists instructed their pilots to land as soon as possible at or near the beginning of those checklists; hence, a later suggestion to consider an immediate landing was unnecessary.

Smoke/Fumes Removal. Only one of the ten integrated SFF checklists failed to include some reference to the completion of the Smoke/Fumes Removal Checklist, if necessary, and that checklist (for a CRJ700) appeared to include actions for smoke removal in the main integrated SFF checklist. Where reference to the possible need to complete the Smoke/Fumes Removal Checklist appeared in the main SFF checklist varied, with some checklists containing more than one reminder: 3 near the beginning of the SFF checklist, 6 in the middle before the completion of system specific actions (similar to its first location in the template), and 8 at the end of the checklist (similar to its second location in the template).

Discussion

This study reveals general compliance with the main guidance put forth in the industry-developed template for un-alerted SFF, although this was by no means a perfect match. As it is just that—guidance—some deviations are to be expected. Thus, the underlying philosophy with regard to checklist content and crew response to these events was adopted in the checklists examined with just a few notable exceptions. Ten of the 11 QRHs analyzed provided an integrated checklist to be used for a variety of types of un-alerted SFF situations. However, some un-alerted checklists that appeared on their face to be appropriate for integration (e.g., EFB Overheat) were not integrated. It is possible that the failure to include actions for these un-alerted SFF events into the main integrated checklist was an oversight. However, it may also have been intentional, thinking that the sources for these events were easily identifiable and warranted a different approach to isolation and extinguishing than that put forth by the template. Checklist developers will need to carefully weigh the pros and cons when deciding that new un-alerted SFF checklists should remain separate (and not be integrated) lest as some point in the future, pilots again find

themselves with a long list of un-alerted SFF checklists that must be searched through when looking for the correct one.

Another area where some deviation from the template was observed pertained to diversion and landing guidance. Rather than just a reminder that such a diversion might be necessary at the beginning of the checklist, as suggested by the template, three of the checklists analyzed directed that a diversion or landing be initiated right away. In all of the checklists analyzed developers appear to have embraced the idea of suggesting or even directing a diversion, early on during event response, or at least before extensive source identification actions are undertaken. Extrapolating from the small sample of checklists analyzed in this study, it appears that gone is the day when checklists guide numerous actions to identify, isolate, and eliminate the source of fire before recommending that pilots conduct an immediate diversion or landing.

Related to this, but more concerning, however, is that, at best, only one of the checklists analyzed fully adopted the template's suggested approach for dealing with an imminent landing. During checklist design it is difficult to determine where to put an item that relates to an external event (imminent landing) which might occur at any time during system response and checklist accomplishment. Rather than, at a specific point in the checklist, calling for an assessment of phase of flight and directing which items to bypass if landing is imminent, as per the template guidance, the four Boeing checklists instructed the pilots to continue to complete checklist items but to not delay the descent and landing. While allowing for greater checklist flexibility for use in a wide range of situations occurring at a variety of phases of flight, it places the onus on the pilots for keeping the big picture in mind while also focusing narrowly on checklist accomplishment and deciding where in the procedures to break off relative to landing—two demands on pilot situation awareness and cognition meant to be alleviated through the directed evaluation and checklist accomplishment suspension incorporated in the template. Of far greater concern was the direction in one of the CRJ700 checklists that as many items on the SFF checklist should be accomplished as possible before turning attention to the completion of Descent and Before Landing checklists. Such guidance could actually have the effect of delaying the descent and landing in an effort to complete the SFF checklist; something that is completely opposite from that intended by the template guidance.

Acknowledgments

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