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Integrated Checklists for Un-alerted Smoke, Fire, and Fumes: Adherence to Guidance from the Industry

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April 2016

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Acronyms

ASAP .....as soon as possible
ATC .....Air Traffic Control
CL .....checklist
ECAM .....Electronic Centrlized Aircraft Monitoring
EICAS .....Engine Indication and Crew Alerting System
ETOPS .....extended range operations
FAA .....Federal Aviation Administration
FSF.....Flight Safety Foundation
InFO .....Information for Operators (published by FAA)
NASA .....National Aeronautics and Space Administration
QRH .....Quick Reference Handbook
SFF.....smoke, fire, and fumes

Integrated Checklists for Un-Alerted Smoke, Fire, and Fumes: Adherence to Guidance from the Industry

Barbara K. Burian[1]

1. Introduction

On the 2nd of September 1998, Swissair 111 experienced an in-flight fire and crashed into the Atlantic Ocean off the coast of Peggy's Cove, Nova Scotia (Transportation Safety Board of Canada, 2003). That accident, almost more than any previous one, was responsible for the industry coming together to re-think the type of guidance given to flight crews when responding to in-flight, un-alerted smoke, fire, and fumes (SFF) events, such as air conditioning smoke or electrical fires. This thinking was ultimately codified in the development of a template to guide the structure and content of checklists for these conditions (Flight Safety Foundation [FSF], 2005). As can be seen in Table 1, the template differs from what had been the traditional approach for the design of these checklists in five very important ways.

First, instead of separate checklists for each type of un-alerted smoke or fire, the template suggests development of a single, integrated checklist containing items for all types of un-alerted SFF. Thus, crews will not have to first determine what type of SFF they are dealing with before being able to identify the correct checklist to access.

Second, the first item on a checklist developed as per the template is a reminder to the pilots that a diversion may be necessary. Furthermore, the template suggests directing a diversion if the source is not immediately obvious, easily accessible, and can be confirmed to be extinguished. This appears relatively early in the checklist—quite a departure from older checklists in which diversion or landing as soon as possible was included as the very last item, if it appeared on the checklist at all (Burian, 2005).

Third, after the reminder that a diversion might be required (first item) and the accomplishment of crew protection and communication items (i.e., donning oxygen masks; establishing communication), the template suggests the inclusion of items called "manufacturer's initial steps." These are items that direct the de-powering or isolation of equipment determined, through historical records, to be the most likely causes of SFF on that aircraft type. Therefore, without any type of analysis or troubleshooting, pilots will quickly address the most likely cause(s) of their SFF event.

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Fourth, checklists developed according to template guidance will address both situations in which the source of the SFF is immediately obvious and accessible (e.g., burning food in a galley oven) as well as those conditions that are not (e.g., hidden fire in aircraft attic area). Much like older SFF checklists, conditions for which the source is not obvious are addressed in template-guided checklists through accomplishment of a series of "system specific" actions that have not already been performed earlier as part of the "manufacturer's initial steps."

Finally, template-inspired checklists include items to help crews mentally "step back" and maintain a big-picture perspective on their situation. For example, crews are reminded that any time smoke becomes the greatest threat they should leave the SFF checklist and complete the checklist for smoke removal instead. Under high stress and workload typical of these events, it can be easy to lose track of managing the overall situation. Similarly, checklist items associated with diversion and descent, mentioned earlier, also contribute to assisting pilots in managing their overall situations.

It has now been more than 10 years since the template and the rationale behind its steps were developed and published in the Flight Safety Foundation's Flight Safety Digest (June 2005). To determine the degree to which the content, structure, and underlying philosophy of un-alerted SFF checklists in current use are consistent with the template guidance, I recently completed analysis of these checklists in 11 Quick Reference Handbooks (QRHs) used by seven North American air carriers. These paper checklists (no electronic versions were evaluated) were for use on five different aircraft types: A320 (3 QRHs), B737NG (2), B777 (2), CRJ700 (2), EMB190 (2)[2]. In addition to compliance with template guidance, I also evaluated a number of other characteristics of these checklists that could likely affect their use during response to one of these events, such the inclusion of memory items, font size used, and checklist lengths.

[2] All QRHs and checklists were in current use at the time they were provided by the air carriers though it is possible that revisions have been made to one or more since then.

Table 1. Template for Un-alerted Smoke, Fire, and Fumes Template[1] (FSF, 2005)

Initial Actions: Crew Protection and Communication	
1	Diversion may be required
2	Oxygen Masks (if required) ..... ON, 100%
3	Smoke Goggles (if required) ..... ON
4	Crew and Cabin Communications ..... Establish
Initial Source Elimination Steps	
5	Manufacturer's initial steps ..... Accomplish
Smoke Removal Reminder	At any time smoke or fumes becomes the greatest threat accomplish SMOKE OR RUMES REMOVAL checklist Page x.x.
6	Source is immediately obvious and can be quickly extinguished. 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 visually confirmed to be extinguished: If Yes, consider reversing initial manufacturer steps Go to Step **17** If No, Go to Step **9**
9	Remaining minimal essential manufacturer action steps (do not meet initial step criteria but are probably ignition sources based on historical fleet data or analysis)
Other Items of Operational Significance	
10	Initiate a diversion to the nearest suitable airport while continuing the checklist
Warning	If the SFF situation becomes unmanageable consider an immediate landing
11	Landing is imminent: If Yes, go to Step **16** If No, go to Step **12**
Additional Source Identification/Elimination Steps	
12	XX system actions[2] ..... Accomplish [Further actions to control/extinguish source] If dissipating ..... Go to Step **16**
13	YY system actions[2] ..... Accomplish [Further actions to control/extinguish source] If dissipating ..... Go to Step **16**
14	ZZ system actions[2] ..... 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**
Follow-up Actions	
16	Review Operational Considerations
17	Accomplish Smoke Removal Checklist, if required, page x.x
18	End of Checklist

1. 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.
2. XX, YY, and ZZ are placeholders for the names of sources of SFF (e.g., air conditioning, electrical, galley, etc.).

2. Compliance with Template Guidance

2.1 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 several 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 found 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 all of 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.

The Upshot: 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, at least in North America and across the four major Part 25 manufacturers. 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 (see footnote 2), 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.

It is possible that the failure to include actions for these other 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 (e.g., EFB Computer Overheat/Fire) and warranted a different approach to isolation and extinguishing than that put forth by the template. It is also possible the developers of new checklists, particularly at air carriers, are unaware of the template and the rationale for integrating items for un-alerted SFF into one checklist. On May 27, 2008, the Federal Aviation Administration (FAA) published a single-paged Information for Operators (InFO 08034) entitled "Design and Content of Checklists for In-Flight Smoke, Fire and Fumes (SFF)," which brought attention to the template and its rationale and provided a link to the FSF Flight Safety Digest in which it appeared. However, almost eight years have passed since the publication of that InFO and no reference to it or the template has been made in other relevant documents, such as Advisory Circular 120-80A "In-Flight Fires" (FAA, 2014).

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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.

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.

2.2 Reminders and Directions to Divert/Descend

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 indicates 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 cannot be visually confirmed to have been extinguished. Thus, the diversion is directed after some steps have been taken quickly—but have proved unsuccessful—and prior to the pilots accomplishing more "analytical" actions in the system specific sections.

In my analysis of the checklists I distinguished between items worded as reminders or suggestions (e.g., "Consider a diversion")—relatively consistent with the intent of template Step 1—and items that actually 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 directed the initiation of a diversion (or stated "Land Immediately/ASAP") at or near the beginning of the checklist and the other seven directed 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.

Just prior to the system specific items (steps 12–14) six of the checklists instructed the pilots to divert/ descend while completing the remaining items and five explicitly stated that the diversion/landing should not be delayed to complete remaining checklist items—excellent guidance though neither item is included in the template. After addressing a source that was obvious and easily accessible, five of the integrated checklists also stated that the flight could be continued if the source could be visually confirmed to be extinguished and the smoke was decreasing—also guidance not included in the template.

The Upshot: 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. Thus, their 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, it appears that gone is the day when checklists guide numerous actions to identify, isolate, and eliminate the source of smoke or fire before recommending that pilots conduct an immediate diversion or landing.

2.3 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" (number of such items ranged from 1-10; mean = 5.6 items per checklist). 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 (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 (n = 11 items in both B737 checklists, and n = 4 items in both B777 checklists).

Action reversal. All four of the Boeing checklists and one EMB190 checklist 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 instructed 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. Neither of the CRJ700 checklists analyzed addressed reversing actions taken previously to extinguish SFF.

The Upshot: In the integrated SFF checklists analyzed there was complete 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. However, 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 did not meet the criteria spelled out for "initial manufacturer's steps" (FSF, 2005). There was not general consensus across the four manufacturers with regard to whether or not actions taken to eliminate SFF should or could be reversed; the Boeing checklists supported such reversals at the captain's discretion (as did one EMB190 checklist) but three others (two Airbus and one EMB190) only gave this option or direction in order to reinstate equipment that might be needed for landing.

2.4 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); these actions appear after the completion of the manufacturer's initial steps (Step 5). 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 focus on diversion and landing activities and were not to complete any system specific actions at all. In contrast, in the template and the nine other integrated checklists, if the source was obvious and quickly extinguishable, crews were directed to extinguish it but were not provided with specific actions to

accomplish in doing so other than being told to "remove power from affected equipment by switch or circuit breaker on the flight deck or in the cabin" if possible (FSF, 2005).

In the template, pilots are only directed to complete system specific actions (Steps 12–14, Table 1) if the SFF 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 were not successful in isolating and extinguishing the SFF. Hence, pilots start with actions for the first system (typically the one historically 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 until final items on the checklist have 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 not been successful in terminating the SFF.

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 EMB190 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.

The Upshot: All of the integrated SFF checklists included system specific items for the step-by-step identification and isolation of the source. However, the checklists for the CRJ700 differed from the others in that pilots were to make their best assessment as to which system was involved and complete the source identification/elimination actions associated with only that system, even if it turned out to not be the SFF source—just as pilots had to do before integrated SFF checklists were developed.

2.5 Support for Overall Situation Management

2.5.1 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 other task(s); 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 ensure that pilot attention is not fixated on the checklist but rather is focused on the most essential tasks relative to aircraft condition and phase of flight.

Despite the importance of such an item to help crews to keep track of landing preparation duties, 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. Also, as mentioned earlier, five checklists 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.

The Upshot: In seven of the 10 integrated checklists analyzed, 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 an EMB190) was close to matching the guidance as stated in the template.

During checklist design it is difficult to determine where to put an item that relates to an external event (e.g., imminent landing) which might occur at any time during situation response and checklist accomplishment. The five checklists that instructed the pilots to continue to complete checklist items but to not delay the descent and landing allowed greater flexibility for when to opt out of the checklist than the guidance in the template (step 11). However, this flexibility 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 suspension incorporated in the template.

Of greater concern, however, was the direction in one of the CRJ700 checklists that as many items as possible on the SFF checklist should be accomplished 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.

2.5.2 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. With regard to the first (the situation has become unmanageable), seven of the checklists included such an 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.

With regard to step 15 in the template, 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.

The Upshot: All 10 of the integrated checklists either directed crews to land as soon as possible at/near the beginning of the checklist or to consider an immediate landing if the situation became unmanageable prior to the completion of system specific items. Interestingly, two of the checklists (one for a B777 and one for an A320) said nothing about considering an immediate landing if the SFF still continued after having accomplished all SFF elimination items on the checklist.

2.5.3 Smoke/Fumes Removal and Smoke/Fumes Removal Checklists

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 the 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: three near the beginning of the SFF checklist, six in the middle before the completion of system specific actions (similar to its first location in the template), and eight at the end of the checklist (similar to its second location in the template).

With regard to the actual Smoke/Fumes Removal checklists themselves, the four for the Boeing aircraft explicitly stated that they should only be accomplished when sent there from the main integrated SFF checklist. The wording of items in two other Smoke/Fumes Removal checklists (one A320 and one EMB190) also made it clear that pilots would have accomplished at least some items on the main integrated SFF checklist prior to accessing it. The three remaining Smoke/Fumes Removal checklists (two A320, one CRJ700) were designed to be accomplished alone or before/during/after accomplishing the other SFF checklist(s) and included crew protection items (i.e., don oxygen masks) that were only found on the main integrated SFF checklists in the other QRHs. Nine of the Smoke/Fumes removal checklists included items reminding pilots to return to/accomplish the main integrated SFF checklist, if necessary.

The Upshot: All of the integrated SFF checklists analyzed addressed the issue of smoke or toxic fumes removal, almost always by reminding crews to complete the Smoke/Fumes Removal checklist whenever necessary. The degree to which the location of this reminder matched the location of the reminders in the template varied, though. Most of the Smoke/Fumes Removal checklists required or assumed that the main integrated SFF checklists would be accessed for accomplishment first.

2.5.4 Operational Considerations

One of the last steps on the template pertains to addressing a variety of operational considerations such as conducting an overweight landing, a tailwind landing, a ditching, a forced off-airport landing or similar concerns (FSF, 2005). Only the two CRJ700 integrated checklists included such information but it was located at the beginning of the checklist on one and in the middle of the checklist (before the system specific items) on the other. One EMB190 integrated SFF checklist included flap and landing data and the other EMB190 checklist included a list of inoperative equipment. Similarly, the A320 SFF checklists indicated flight law status (i.e., degraded to Alternate Law) and system operational status. None of the four Boeing SFF checklists analyzed included any items or information with regard to the status of systems or, as the template suggests, other operational considerations.

The Upshot: Only the two CRJ700 integrated SFF checklists included any information associated with the template's "operational considerations." All the others, with the exception of the four Boeing checklists, did not address such operational considerations but did include some information relative to system status and/or flap settings and landing data—checklists for the Boeing aircraft included neither.

2.6 Deviations from Template Guidance

There were numerous deviations from the Template Guidance observed in addition to those already mentioned. In many cases they were relatively minor wording differences or differences associated with aircraft-specific requirements (e.g., initiating a descent early on so that potential smoke/fumes removal, requiring a depressurized aircraft, could be accomplished). Some other deviations from the template guidance were more significant. In some instances this involved the inclusion of items or information that could be quite helpful to crews, such as: (1) the inclusion of Caution Statements in an A320 checklist reminding crews not to shut down air conditioning packs or reduce ventilation in an attempt to smother the fire; and (2) not to deploy the passenger oxygen masks if fire is suspected in the cabin (though this second Caution Statement does not appear in the Cabin Fire section of the integrated checklist where it might be most useful). Similarly, one checklist for a B777 included a great deal of supplemental information pertaining to things such as standards for Cockpit to Cabin Communication, the In-Flight Entertainment System, Power Ports, equipment circuit breaker locations, and information and a graphic regarding gaining access to the electronics and equipment bay. There were also a number of deviations from the template noted that were of a concerning nature but they have already been mentioned in the sections above.

3. Other Characteristics of Un-alerted SFF Checklists Affecting Their Use

There are a variety of other issues pertaining to SFF checklist design and content not addressed by the template but which are likely to affect their use. Some of these were analyzed and are discussed here.

3.1 Memory Items

The template makes no mention of performing any of its steps from memory but does include items related to crew protection and establishing crew communication (Steps 2–4) which often were to be performed from memory when older SFF checklists were in use. All of the integrated SFF checklists analyzed in this study included these items and they were to be performed from memory on six of them. One of these six (for an A320) also had the pilots performing all of the manufacturer's initial steps (Step 5 on the template) from memory as well.

However, an issue exists pertaining to memory items involving the first step on the template: "Diversion may be required." One of the B777 SFF checklists includes this as the first step but it is not a memory item whereas the crew protection and communication items which directly follow are. In this situation, depending upon how the checklist items are displayed on the B777 electronic checklist (ECL) and how crews are trained to deal with memory items once a checklist has been accessed, it is possible that the pilots will miss the first item reminding them that a diversion may be required as they look for the first items to complete that follow the memory items just performed. A B737 SFF checklist swapped the order so the "Diversion may be required" item followed, rather than preceded, the crew protection and communication memory items. The other four checklists that included memory items did not include the "Diversion may be required" step.

3.2 Font Size

It has become somewhat common practice across the industry to print paper non-normal[4] checklists that might be used in low visibility conditions (such as smoke in the cockpit) in a larger font size than that used for the other checklists. Six of the 10 integrated SFF checklists analyzed (all for non-Boeing aircraft) were printed in a larger font size, although the size used in three of them was only slightly larger. Font size in five of the Smoke/Fumes Removal checklists (two A320, one EMB190, and one CRJ700) were also larger but were only slightly larger in two of these five. Because multiple different fonts were used across the QRHs, no attempt was made to determine exactly what sizes were used for the various checklists. The industry could benefit from a study to determine the optimal font size to use for checklists that are performed when smoke is on the flight deck.

Though not pertaining to font size, one QRH for the B737 was printed with black type on paper that is a medium shade of gray which could contribute to reading difficulties when the checklist is used in a smoky cockpit.

3.3 Communicating/Coordinating with Others

Three of the integrated SFF checklists prompted pilots to contact Air Traffic Control (ATC) to declare an emergency but, interestingly, none prompted them to make such a call associated with directions to initiate a descent. In addition to actions associated with template Step 4, "establish crew communications," five checklists included specific directions to communicate with flight attendants, particularly regarding the completion of some actions on the checklist (e.g., turn off/pull galley circuit breakers) or prepare them for upcoming events (e.g., lights in the cabin will be turned off).

3.4 Checklist Lengths for Different Types of SFF Events

The lengths of SFF checklists has been a topic of some discussion in the industry and the inclusion of opt out gates or similar items to help counteract attention tunneling can be critical in helping pilots manage their overall situations. In many SFF events, however, all of the items for the specific SFF source will be accomplished by the crews, so it is important to consider not only the physical length of the checklists (i.e., number of pages/items to accomplish) but also their "timing" length—the amount of time it takes to accomplish the items. Timing length is a particular concern regarding air conditioning smoke checklists as the crews must often wait some time (typically 2–5 minutes) to judge the effect that PACK configuration changes have had and determine if they've successfully isolated/ extinguished the source or if further configuration changes are necessary. Of course with all types of checklists, interruptions, distractions, and the need to interleave other tasks will increase amount of time it takes for their accomplishment.

In this study, only timer items, relative to the timing lengths of the checklists, could be analyzed. Seven checklists included timer items: four instructed crews to wait 2 minutes unless the smoke or fumes were increasing, one instructed crews to wait 3 minutes, and two instructed crews to wait an unspecified amount of time.

The physical lengths of the checklists were more easily evaluated. Three integrated checklists were printed on paper 8 ½ inches in height. These checklists ranged from 4 to 6 pages long (mean = 5

[4] The term "non-normal" in this document refers to conditions labeled as "emergency," "abnormal," or "non-normal" by the industry.

pages), however one of them also had 5 additional pages of supplemental information. Furthermore, two of these checklists were for the B777 aircraft and it is unknown how many ECL screens were needed to display them. The remaining seven integrated checklists were printed on paper 11 inches in height. These checklists ranged from 3 to 10 pages long (mean = 7 pages). The number of checklist pages is not the best indicator of a checklists physical length, however, because, due to the grouping or formatting of items and information, some pages may not be completely full (i.e., blank space appears at the bottom of the page even though subsequent items appear on the following page).

Therefore, in this study, the actual number of items that crews would need to read and/or accomplish for several different un-alerted SFF scenarios were also counted and are presented in Table 2. Although the overall mean and median number of items are provided, it is most informative to compare the number of items only within a specific aircraft type as aircraft design has a significant effect on the number of actions required. Additionally, equipage differences within an aircraft type might also partly explain differences in the number of checklist items to be accomplished for a specific SFF situation. Nonetheless, the differences in number of items for some SFF situations, even within an aircraft type, was sometimes astounding (see for example: A320 – Source cannot be identified, and CRJ700 – Landing is imminent).

Table 2. Number of Checklist Items to be Read/Accomplished in Different Un-Alerted SFF Situations[1,2]

Situation/Source	N of CLs[3]	A320			B737NG		B777		CRJ700		EMB190		Mean	Median
		a	b	c	a	b	a	b	a	b	a	b		
Greatest total number to accomplish[4]	10	164	-	100	59	42	61	49	91	70	108	81	83	76
Landing is imminent[5]	10	164	-	100	59	42	61	49	91	18	75	51	71	60
Source cannot be identified[6]	10	132[a]	-	60	59	42	61	49	88	18	108	81	70	61
Electrical smoke/fire	8	-	-	-	36	42	43	49	91	70	108	81	52	60
Cabin smoke/ fire	5	67[b]	24	43[c]	-	-	-	-	22	47	-	-	41	43
Avionics[7]	3	92	52	60	-	-	-	-	-	-	-	-	68	60
Galley	2	-	-	-	-	-	-	-	39	42	-	-	41	41
Air conditioning smoke/fire	10	64	20	51	59	42	61	49	58	55	69	- [d]	53	57

1. Includes all types of Action Items, Conditional/Decision Items, Notes, Cautions, Warnings, Checklist Titles, Condition Statements (if any), Objective of Checklist Items (if any), Continued on Next Page indicators (if any), and checklist flow charting symbology to facilitate checklist navigation (if any). Does not include repetition of Checklist Titles on subsequent pages or jumping to/accomplishing items on Smoke/Fumes Removal checklists.
2. Does include counts from system specific checklists in the A320 QRH that did not contain a single integrated SFF checklist.
3. The number of checklists included in analysis/the number of checklists that had specific sections to address this source.
4. The greatest number of items on the checklist the pilot would need to accomplish if the source was not obvious and all attempts/actions to identify, isolate, and extinguish the source had been unsuccessful.
5. Focuses solely on the guidance for this situation included in the checklist (if any) and assumes that at no point is the checklist abandoned by the pilots to focus on landing. In the checklists that did not address this situation, these numbers match the greatest number of items that pilots would have to accomplish (i.e., assumes source has not been identified and all actions have been unsuccessful).
6. Many checklists did not address this situation so this number matches the greatest number of items that pilots would have to accomplish.
7. Avionics smoke/fire is an alerted condition on the A320 but two of the QRHs analyzed included items to address Avionics smoke/fire in the single, integrated checklist.

a. N = 164 items if the user does not know that the source is unknown and accomplishes items for Air Conditioning Smoke and Cabin Electrical Smoke/Fire first.

b. if COMMERCIAL pushbutton is installed (n = 72 items if pushbutton is not installed).

c. if COMMERCIAL pushbutton is installed (n = 46 items if pushbutton is not installed).

d. Unknown, it appears that at least a few items for air conditioning SFF are included in the Smoke/Fumes Removal checklist.

3.5 Incorporation of Other Types of Items: Normal Checklists, Emergency Landing, Ditching, Evacuation

The premise of the "get-in, stay-in" philosophy of checklist design (Burian, 2014) is that all needed items from other checklists or materials (e.g., normal checklists, other non-normal checklists, performance data, etc.) are integrated into a non-normal checklist, particularly for a condition that has implications through the remainder of a flight (e.g., a hydraulics failure: approach and landing). Doing so eliminates the need to jump around among checklists or materials and thus, reduces the amount of time needed for checklist accomplishment and the likelihood of error, such as accessing the wrong material.

In this study of integrated checklists for un-alerted SFF, all normal checklists were co-located with the SFF checklist in one EMB190 QRH, and normal checklist items associated with flap setting and approach speeds were incorporated into the other EMB190 SFF checklist. No other SFF checklist or QRH incorporated or co-located items found on the air carriers' normal Approach or Landing checklists.

None of the SFF checklists incorporated, co-located, or even mentioned non-normal checklists for Emergency Landing, Ditching, or Evacuation with the exception of one CRJ700 SFF checklist that referred the user to the Evacuation checklist in the QRH if needed.

It should also be noted that neither of the B777 SFF checklists included any items or discussion of SFF issues associated with extended range operations (ETOPS) and none of the SFF checklists mentioned dealing with hazmat/dangerous goods fires in the cabin, such as lithium battery fires, although this information may be included in SFF checklists or procedures used by flight attendants.

4. Conclusion

To a large degree, the content and structure of the checklists/QRHs analyzed were consistent with the guidance proposed by the template. However, there were a few notable exceptions. One A320 QRH did not include a single, integrated checklist, and in one CRJ700 integrated checklist, if the source was unknown, crews were to focus on landing preparation and not complete any system specific or similar items. Additionally, in both of the CRJ700 integrated checklists crews were instructed to perform only the system specific actions for the one system thought to be the source, even if those actions were ultimately unsuccessful in terminating the SFF. Some QRHs also included a few separate checklists—i.e., non-integrated—for some un-alerted SFF conditions, e.g., EFB Overheat/Fire.

At best, only one EMB190 integrated checklist came close to guiding crews about what to do if landing was imminent in a way that was consistent with template guidance (Step 11). Studies of actual crew use of the checklists which do not conform with this template step could help determine if specific guidance about when to opt out of the checklist is necessary or if it is sufficient to leave it up to the crews to determine when/if to suspend checklist accomplishment to focus on landing. In any event, wording of items in these checklists should be carefully scrutinized so as not to give the impression that crews are to actually delay landing in an effort to accomplish the checklist actions.

It was surprising that so little information pertaining to various operational considerations identified in the template supporting documentation (e.g., overweight landings; FSF, 2005) were included in

the checklists. However, the advantages of the get-in, stay-in philosophy of non-normal checklist design are not well known across the industry so it was not surprising that there was almost no mention, let alone inclusion, of checklists or actions associated with situations such as ditching or evacuation. Crews may well find the inclusion of items related to these operational considerations or situations to be of great benefit, as well as from specific guidance about what to do if the source is unknown (i.e., accomplish all of the system specific items or do something else). Furthermore, the data presented in Table 2 suggest that there may be some benefit in carefully analyzing the content in these checklists to find the optimal lengths/number of items to provide the guidance and support needed without unduly adding to crew workload. The template guidance appears to have gone a long way toward addressing the many shortcomings identified in earlier approaches to un-alerted SFF checklist design and content but many opportunities exist for further refinement to provide flight crews the best support possible in these dire situations.

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