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## OPERATIONAL ALERTING ON MODERN COMMERCIAL FLIGHT DECKS

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The glass cockpit and EFB enable new ways of information presentation and interaction on the flight deck of modern commercial jets. This information supports crews in flight plan management, which essentially entails evaluating the plan against (ever-changing) flight constraints and, if necessary, modifying it. Flight constraints emerge from the interaction between the system and its operational environment. Understanding the constraints, and checking the flight plan against these constraints, requires selection and combination of information from many sources. Operational alerting can support this process, by prioritizing and formatting information to match the operational context. A number of modern flight deck systems are evaluated on how they support alerting in an operational ready format. From the comparison we can conclude, that there is a trend towards operational alerting, especially on a tactical level.

The glass cockpit has been around for a while now, and with the introduction of the Electronic Flight Bag (EFB) the paperless cockpit became reality. Flight crews have faster access to more information than ever before. But the question that remains is how does all this information support the flight crew in performing their task? The main responsibility of the flight crew is the success of the operation and the well-being for the passengers and plane. To ensure this, a well-considered flight plan is crucial to achieve a successful operation. Flight planning starts before the flight, McGuire et. al., (1991) and includes determining the flight constraints, i.e. departure and arrival times, reviewing weather, aircraft range, reviewing terminal constraints, optimizing the horizontal profile and vertical path, planning for contingencies. The result is a flight plan that is tailored to achieve the operational goals with most up-to-date information. If the plane and its systems are found to be fit, the flight plan can be executed. While executing the plan, the flight crew is constantly monitoring the world and aircraft systems to see if any of the original flight constraints are changed and/or broken, a likely event in real world scenarios. If they detect any deviation, they are required to act, either by continuing with the initial plan or modifying the plan, by re-routing, reconfiguring or communicating. This whole process is flight plan management.

Flight plan management is therefore an information problem in which the flight crew has to combine information, from various sources, about the operating environment and the airplane systems. Sequentially, they have to transform this information to determine how the previously assumed constraints are affected and what the consequences are for their operation. The interaction between the plane and environment is crucial since the threats to safe operations are not only system malfunctions, but the majority of the threats are caused by effects from the world, like weather, traffic, terrain, ATC and airport conditions (Thomas, 2003). These sources are highly dynamic, due to the chaotic nature of the world and are difficult to accurately predict in advance. Continuously updated information is needed to determine the implications on the flight plan.

Evaluating the flight constraints and implications on the flight plan is essential, (Harris 2007), but can be a taxing task especially under highly dynamic circumstances. During recent experiments, Bailey et. al., (2017) found that pilots under severe workload are unable to fully comprehend the limitations after certain failures. Further, understanding the limitations of the plane heavily relies on the pilot's expertise and experience (Mumaw, 2017). This leaves us with the question, is the flight crew with all its resources on the modern flight deck sufficiently supported for the flight plan management task? In particular, how are the modern flight decks presenting information to the flight crew to evaluate what can and cannot be done operationally?

## Method

Five modern flight decks families are evaluated on how they represent information of the operating environment and system status with respect to the intended plan. First, information available on the flight deck from the operating environment is reviewed. This is done separately since various airplane types have similar means to obtain this kind of information. Second, information about the system status is reviewed for various flight decks, including the Boeing 737 NG, Boeing 717/MD11, Airbus A320/A330/A340, Boeing 777/787 and Airbus A380/A350. A hydraulic reservoir failure on a single system will be used as a case study to show the differences in presenting system implications. Obviously, the impact of the failure on the airplane status will be different on the various airplanes, but our interest is how and if operational implications are presented.

## Results

**Terminal / Route Information** - Information about the airport facilities, standard procedures and routes, are published in the Aeronautical Information Publication (AIP) or airport facility directory (AFD). Besides these publications, the crew has also an Operations Manual provided by the operator in which operational information can be found that the operator may deem necessary for the proper conduct of flight operations. This include for example, preferred routes, SOPs, operating minima, escape routes, and minimum flight altitudes. Day-to-day information about the current conditions are communicated by Notice to Airmen (NOTAM), while short notice information is provided by ATC or the operator. Despite the recent change to electronic format of these manuals and NOTAMs, the content of information is similar to the paper version.

One step towards integrating and transforming the content to a more operational format is done on Boeing's Airport Moving Map (AMM) and Airbus's On-Board Airport Navigation System (OANS) and shows the location of runways, taxiways, and other airport features in relation to the airplane position. Additionally, the status of the runways and taxiways is shown, e.g. closed taxiways and active runways. The crew can now clearly see if the flight plan is crossing any constraints on the ground.

**Terrain Information** - Besides the charts and procedure published in the AIP and OP, modern Flightdeck are equipped with, real-time terrain information provided by (E)GPWS. These systems present terrain and alerts if the predicted path is colliding with terrain in the near future. The terrain information is integrated on the flight deck by the Navigation Display (ND)

and / or on a Vertical Situation Display (VSD). Where, Synthetic Vision Systems (SVS) present terrain constraints integrated on the Primary Flight Display (PFD).

**Weather Information** – Weather is dynamic and can be difficult to predict accurately during the planning phase. Current weather conditions are distributed by ATIS or D-ATIS, which is just the digital version of ATIS. TAFs, SIGMETS, AIRMETS, PIREPs, forecasts, prognostic charts, wind/temp charts at different flight levels, are provided through the dispatcher and are often available in digital format. Furthermore, planes are equipped with weather radar that can detect real time precipitation and turbulence. This information is readily available and integrated on the ND. Weather radar furthermore alerts for wind shears on the PFD and presents its location on the ND. Whereas the forecast needs to be requested and then processed mentally.

**Traffic Information** – Traffic is highly dynamic and to avoid collisions the Traffic Collision Avoidance System was developed. Predicted collisions are alerted on the PFD and ND. TCAS also provides a solution to avoid traffic. However, only planes equipped with a transponder can be detected and avoided. With the introduction of ADS-B traffic positions are made available and allow for airborne and ground traffic situation awareness, either displayed on the ND or EFB.

**ATC Clearances / Requests** – Obtaining information once airborne is only possible due to communications. Communication is mostly done by voice (either through VHF, HF, or satellite), however with the introduction of datalink it became possible to send and receive information in an electronic format. Clearances and requests can be sent digitally with controller pilot data link communication (CPDLC). Which allows even to upload clearances to the FMC and therefore integrate it into the flight plan. Information can either be provided by ATC, e.g. for clearances, or by the Company, e.g. gate information. Clearances are integrated by OANS on the Airbus A350, by color coding a cleared and requested path, showing intentional constraints.

**System Implications: Boeing 737 NG** - The Boeing 737 continuously evolved since it was introduced back in 1967. However, information presentation regarding the status of the engines and systems on the Boeing 737NG is however very similar to the classic 737. Dials are replicated in an electronic format, together with alerting block lights. The main alerting method relies on annunciator lights in front of the pilot together with corresponding lights on the overhead / pedestal panel. The crew has to scan the flight deck to determine what systems are causing the malfunction. Once the lights are identified, the crew will consult the QRH, either a paper or digital version, and look-up the corresponding alerting light. This will guide him/her through a non-normal checklist, which assists in reconfiguring the system to prevent and minimizing further deterioration of the plane systems. Once the failure is stabilized, the QRH provides the implications for the remainder of the flight. For the hydraulic system failure, various alert light across the flight deck will illuminate. After the reconfiguration of the systems, the crew is left with instructions and notes that are useful for the remainder of the flight, see Figure 1 for an example of this.

3. Check the Non-Normal Configuration Landing Distance table in the Advisory Information section of the Performance Inflight chapter.

...  
5. Plan for manual gear extension.

**Note:** When the gear has been lowered manually, it cannot be retracted. The drag penalty with gear extended may make it impossible to reach an alternate field.

**Note inoperative Items:**

**Autopilot A inop**

Autopilot B is available.

....

Figure 1. Example of checklist items that have implications on a flight plan.

This is not only a lot of information to interpret, but it is also not straightforward to determine what the exact effect is. The first step for the crew is to determine when an affected system will be used. Next, one has to determine if and how it impacts the intended operation. The landing distance for example needs to be checked with tables, which require additional information about the weather and runway conditions. As an example, take the note about the manual extension, shown above. It requires considerable effort to figure out if a go-around and reaching the alternate field after lowering the gear is still possible. This is already a challenging task on the ground, needless to say that this is a difficult task once airborne.

**System Implications: Boeing 717 / MD 11** - The Boeing 717 and MD11 share a similar flight deck, termed *the advanced flight deck*. The main system display is the Engine Alerting Display (EAD) this shows the engine status with an overview of all systems alerts. The B717 has also synoptic displays, which show the status of a particular system with alert related to the applicable system. Even though alert messages are presented in a centralized alphanumerical manner, flight crews are still depended on the assistance of the QRH, which is similar to the B737. An addition to the B737 is that the B717/MD11 also include a consequence page in which the alerts and consequence are summarized, Morgan (1992). In the case of the hydraulic failure, the consequence page would include: “SPOILER INBD FAIL | REDUCED ROLL RATE AVIALABLE”. This is very similar to the notes from the QRH, only now in an electronic format.

**System Implications: Airbus A320 / A330 / A340** - Airbus provide system alerting through the electronic centralized aircraft monitor (ECAM) system. The status of the plane is automatically sensed and the appropriate actions to reconfigure the systems to prevent any further damage are shown. These actions are sensed and marked green when the system is in the correct state. After all actions are performed, a page appears with the limitations and inoperative systems, see Figure 2. This can be compared with deferred items, notes, inoperative systems and consequence page. The A320/A330/A340 are also equipped with synoptic displays.

STATUS	<u>INOP SYS</u>
- L/G.....GRVTY EXTN	GREEN HYD
LDG DIST PROC.....APPLY	SPLR 1+5 CAT 3
SLATS/FLAPS SLOW	NW STEER
CAT 2 ONLY	AUTO BRK

Figure 2. Example ECAM items that have implications on a flight plan.

These indications tell the crew to check the landing distance and that they can do a CAT II approach with Autoland. It's still up to the pilot to look up the landing distance in the tables and determine if an Autoland with Cat II will be sufficient for their operation. Although this overview is quite clear, some items, e.g. the capability to retract the gear once lowered, is not provided and has to come from pilot's experience and system knowledge. If this implication is not considered by the flight crew, the consequences can have a major impact on the flight plan.

**System Implications: Boeing 777/787** - EICAS, which was first introduced on the Boeing 757, is Boeing's main system status and alerting display. It shows alert messages in a centralized alphanumerical manner with an indication if a dedicated checklist exists. This checklist will appear in the electronic checklist (ECL), which is similar to the QRH but has the functionality to sense if systems are in the correct position, like the ECAM system. The notes will be stored on a dedicated page. So, finding the checklists and storing the notes are easier with ECL. However, integration with the flight plan needs to be done by the flight crew.

**System Implications: Airbus A380 / A350** - On the A350 and A380, the ECAM system is provided with more real estate due to the larger displays. The inoperative systems are split-up into two categories, namely 'All phases' and 'Approach & Landing'. This makes it easier for the flight crew to determine in what flight phase the effects will limit the operation. However, much of the actual impact needs to come from the crew themselves.

**System and environment: ROPS & RAAS** - The Airbus' Runway Overrun Prevention System (ROPS), (Airbus, 2011) and the Honeywell Runway Awareness and Advisory System (RAAS) (Clark, 2011) are systems that integrate the airplane configuration and status with the operational environment, e.g. runway conditions, weather. They calculate the stopping distance required on a specific runway under various conditions. This is done in real time and considers changing conditions like wind. It will alert if the runway is too short. This system off-loads the crew from making the calculation of the landing distance for the current configuration. The system makes the calculation eight times per second, faster than the crew can ever do. The system is providing the crew with essential information if a landing is possible yes or no. The brake-to-vacate function is another operational focused function, which can determine how to apply and configure the brakes to vacate the runway at an optimal taxiway.

## Discussion

From this case study, it can be observed that the accessibility of the information is largely improved by the introduction of electronic presentation. ECAM and ECL made it easier to obtain the required checklist. However, much of the content is similar to the paper version and the crew still has to combine all the limitations to determine when and what the effects are on the flight plan. This requires time, effort and continuous attention, which are scarce in flight and during non-normal events. Secondly, there is a trend in integrating information and provide operational alerting, e.g. TCAS, EPGWS, weather radar, airport map and ROPS/RAAS. These systems provide alerts in case collisions, or overruns are predicted. Alerts like, RUNWAY TOO SHORT, or NO TAKE OFF are clear in terms what operation cannot be performed. However, the support from these alerts and systems are limited to the tactical level, a cause of this limitation is due to

restrictions in the available data, e.g. traffic can only accurately be observed in a short time span. Finally, checklists provide guidance after a malfunction with notes, limitations and deferred items, but considerable effort need to be spent by the crew to determine how events affects the operation. Therefore, system-wise the crew is relatively unsupported to fully comprehend and predict the repercussions of a change in system status.

## Conclusion

Comparing the various flight decks, we identified that more recently introduced flight decks and systems are integrating and transforming information in a more operational format. However, currently operational alerting is limited to support on a tactical level, but this could be expanded to combine more information for the entire flight plan, supporting the flight crew also on a strategical level. This will make it easier for pilots to obtain an overview what operations can and can't be done, which is beneficial during high-workload, complex and time-critical events. Systems that can assess the intended plan(s) based on up-to-date information have the potential to off-load the pilot, improve the quality of the assessment, reducing unconsidered effects and reducing the dependency on pilot's experience and expertise, which is favorable with reduced flight crew experience with non-normal events.

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