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## OPERATIONAL ALERTING CONCEPT FOR COMMERCIAL SINGLE PILOT OPERATIONS SYSTEMS

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Reducing high workload levels are a major challenge to enable single pilot operations. Where the pilot is currently supported with many automated systems, the role of mission planner is relatively unsupported, i.e., the flight crew is required to integrate and combine information from various sources to extract the implications on the missions' high-level goals to determine if the mission can still be completed safely and successfully. An operational alerting display is developed to provide the pilot with a clear overview of the current and future operational flight constraints. This enables the pilot to determine if the initial plan is valid under the existing conditions. The display is not limited to system malfunctions, but combines the full spectrum of operational constraints, e.g., weather and airport operations. The display concept was tested on usability with a commercial pilot to provide a preliminary performance indication on the effectiveness of the concept.

Reduced pilot operations (RPO) for commercial flights is predicted to reduce direct operation costs, Bilimoria (2014). Other costs reductions can be found on both the operating and manufacturing side. Furthermore, RPO could reduce the issue of the projected pilot shortage. These factors make a strong business case, especially for short haul operations. It is therefore not surprising that there is much interest from industry for RPO. However, major challenges have to be resolved in order to enable such operations. One of the challenges is to handle high workload situations. It is likely that automated systems will relieve the pilot in command from many tasks, Harris (2007). Especially, the system management task will likely to be, at least partially, being taken over by automated systems. The pilot would be in command of all the automation resources, but what remains crucial is that the pilot is aware of the implications of the systems for the safe and expeditious conduct of the flight. The role of the pilot will be that of a flight planner (both on a strategic and tactical level); a communicator with ATM facilities, and a surveillance operative, Harris (2007).

Currently, obtaining information to determine if the flight plan is affected is a rather taxing and time-consuming task. Integrating information from the various sources and converting them to operational constraints is becoming more supported for certain applications. However, it is still much relying on pilots' experience and expertise, Bailey (2017). In this paper, a flight plan evaluation tool is designed with the objective to support the operator more effectively, i.e. reducing workload of determining the implications of events introduced by system and the environment. In-flight, the pilot is mainly evaluating the flight plan constraints and modifying the plan if necessary. Therefore, enabling effective evaluation is an essential step to enable effective flight planning.

The flight plan evaluation support has been developed with Applied Cognitive Work Analysis methodology introduced by Elm (2003). It is a pragmatic framework to determine in a stepwise and traceable manner information and presentation requirements. The requirements are based on an expert knowledge model, the Functional Abstraction Network (FAN). This model is built with operating manuals and interviews with subject matter experts. From the model, cognitive work requirements are derived, from which information requirements are derived. That ultimately feed into presentation requirements. This set of requirements on both information and presentation objectively guide the visual form in terms of content. The concept itself can take many visual forms, which can be adjusted to optimize usability and interaction.

## **Method**

The initial concepts are static, not interactive pictures, displaying a normal and non-normal scenario. The concept was tested on usability for two non-normal conditions, i.e. a hydraulic failure and a generator drive failure similar to recent experiments performed by Bailey (2017), with an experienced 737-800 pilot. The objective was to get initial feedback on the concept and test if the pilot could extract the implications of the failure events.

The pilot was presented with a display of the overhead panel, glare shield and pedestal, that represented the flight deck effects in a static manner. The conventional flight deck and the concept were presented on large LCD displays positioned on a desk. A paper version QRH and dispatch information was presented digitally. First, the hydraulic failure was presented on which the pilot had to act, determine the implications and decide the following actions in a conventional way. After, he was presented with the concept and asked if the consequences were as he initially had considered. This was repeated with the generation drive failure. After each scenario, features of the display were discussed.

The scenario was a flight from London Stansted to Innsbruck. The events were injected at the location of 15 minutes prior to top of descent, west of Zurich. Alternate airport was planned to be Salzburg. In scenario 1, conditions of runway 08 at LOWI had a braking action of medium forcing to divert.

## **Result**

The FAN captures the high-level goals of commercial flight operation. In order to successfully and sustainably create value as a company with flight operation, the company needs to guarantee safety, compliance, expected comfort levels and operate according to flight schedule within the estimated budgeted costs. These five factors are the high-level goals that need to be satisfied to make the operation to a success. The operation itself can be classified into three types of movement, namely the movement of the vehicle in air, the movement of the vehicle on the ground and the movement of the passengers/payload. All these types of movement introduce specific functions, e.g. braking with landing gear is only applicable on the ground. This first concept, for the moment, includes only flight and ground operations of the vehicle.

Two types of abstract functional blocks, namely path and space, were found that can be used to determine if a flight plan is still satisfying the higher-level goals, i.e. safety, compliance,

schedule, cost and comfort. One can define paths and spaces for each of these high-level goals, for example compliance space (defined by intentional constraints) is generally more restricted than the safe space (defined by causal constraints).

The functions introduced by the system and environment can restrict the path horizontally, vertically, in velocity or in time. The path needs to be within the operating space in order to be unrestricted. The restrictions of the path and space are the result of lower level functions for example, the maneuvering capability, resources, navigation, surveillance, communication, ability to protect the payload and planes health and so on. These lower level functions are enabled by the power generation functions, i.e. electrical, mechanical, hydraulic, pneumatic. If these systems don't function properly, the complete system is not able to perform certain paths any longer. Multiple flight plans can be analyzed by applying the path and space principle and from interviews pilots it was found that pilots are actually assessing multiple flight plans mentally, i.e. the normal flight plan to the planned destination but also the contingency plans, e.g. to an alternate airport and/or nearest airport in case of diversion.

The basic principles of path and space are applied to the safety and compliant goals, for simplification purposes at the moment. The initial concept is presented in Figure 1, shows how the space is restricted horizontal and vertically, how the path is restricted horizontally (top view display in the center), vertically, in time and velocity (with time/distance display) related to safety and compliance. Furthermore, it shows which systems (bottom right) and environmental effects (bottom center) imply these restrictions.

### Normal condition

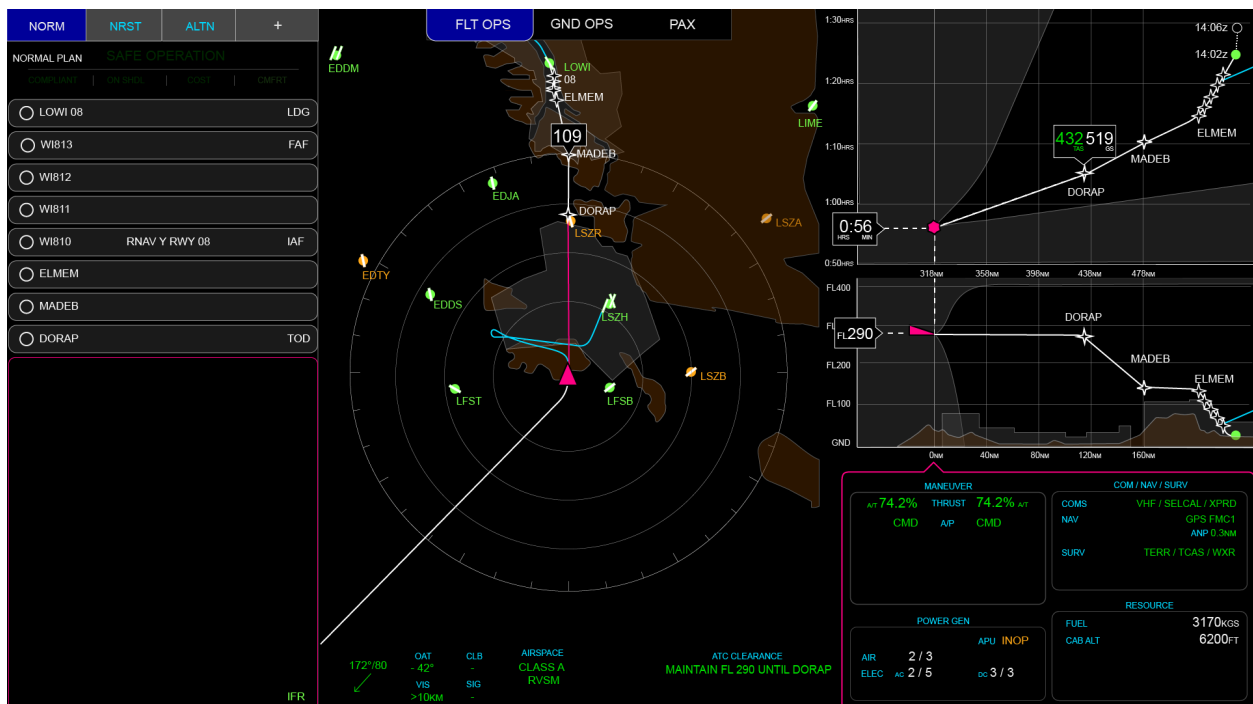


Figure 1. Flight plan evaluation concept in the normal condition.

The flight plans under current evaluation are presented in on the left-hand side in Figure 1, the landing phase is shown at the top and the current leg or ‘now’ effects are presented on the bottom. It shows all the waypoints. The cause of the restrictions is presented in the list at the leg where it will be affected.

The airports in the center display are color-coded based on the conditions and ability to land safely and within the standard operating procedures. Further, the contingency plans are displayed in cyan. Restricted space is presented as grey, where black is unrestricted space. The paths are color-coded with amber or red in case any restrictions are broken. The cause of the restriction can be obtained from the list.

### Non-Normal condition

In figure 2, the effects on the path and space are shown for a hydraulic system A failure. The landing distance is increased and the alternate plan (LOWI, go/around, divert to alternate), is not safe any longer due to increased fuel consumption due to the inability to retract the gear once lowered, which reduced the final reserve fuel under 30 minutes at LOWS. On the button right, the hydraulic power generation sources are reduced to one out of two and the hydraulic fluid is low. Furthermore, Autopilot A is not available any longer, which has the result that the minimum usable height is increased to 158 ft, which has the consequence that CAT II ILS at LOWS RWY 15 is not authorized.

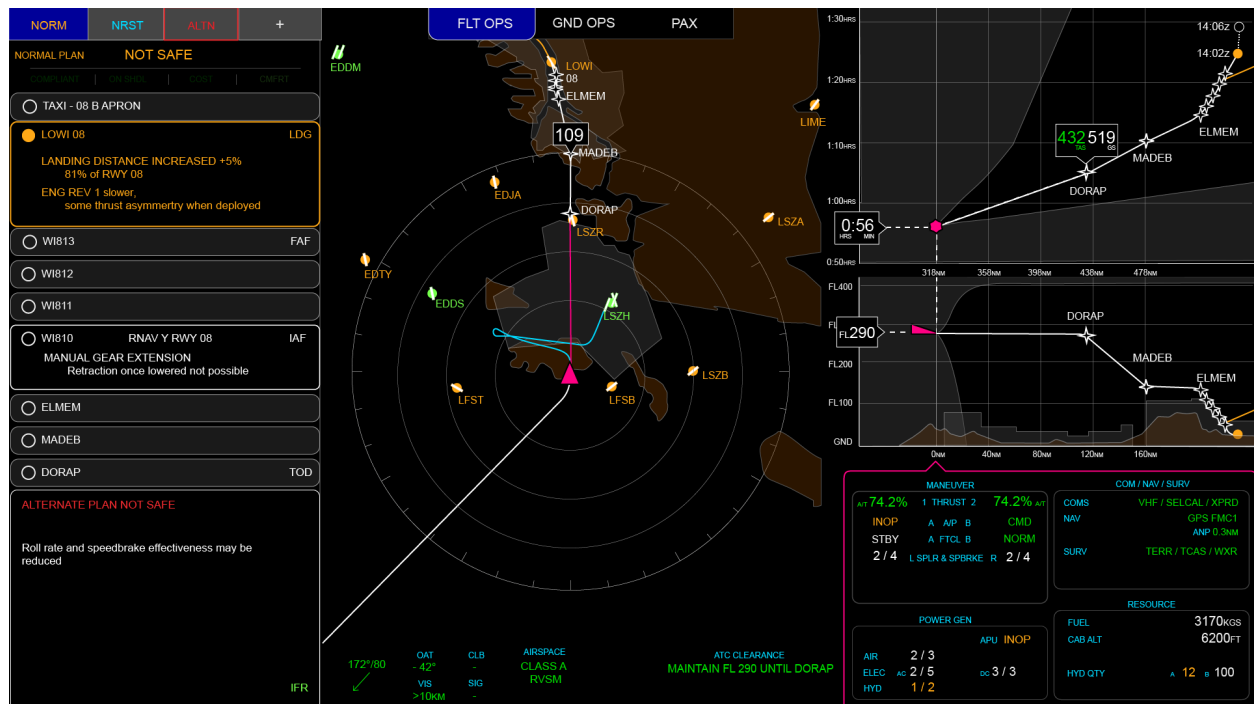


Figure 2. *Flight plan evaluation concept in the non-normal condition of a hydraulic failure.*

## **First impressions**

The first impression was that the majority of the attention was focused on the list with the operational effects. The system status and the time / distance display were not used much. The pilot had a clear picture, from the conventional method (QRH and performance tables), that LOWI with braking action less than good was not a safe option, therefore the fact that the item about landing distance increased in the list was not a surprise. However, that implied that trying an approach and lowering the gear was not considered to be realistic. This caused a mismatch with the thinking process. The question that remained was where to divert to. For that case the support is, in its current form, too leading, i.e. only a divert to Zurich is shown. Where, other fields were also a feasible option(s) worth reviewing, e.g. direct to LOWS or another closer airport. Preferred is full option space to choose the suitable diversion airport and not a single indicated path.

Besides this, the link between the system failure to the actual consequence was not always understood. Determining what operational effects were caused by what system/environment effect was not always clear. For example, separating between the effects of an inoperative autopilot and the result of the load shedding was not easy. Also, the feeling existed that some steps were skipped in restoring the systems and the consequences were shown too pessimistic. This included that the cabin altitude pressurization auto mode was inoperative in the second scenario. The feeling existed that it could have been restored by switching it to alternate mode and not fully in manual operating mode.

Furthermore, the list of legs and affected items is presented future-up and felt counterintuitive since the waypoints listed in the FMS are presented the other way around. Another comment was that the time/distance display, especially for ground operations display was not very usable, since it is very difficult to accurately predict taxi time and merely an indication would be sufficient.

## **Discussions**

These initial findings show that it is challenging to match the presented information to the operator's thinking process. If effects or plans do not completely align, a mismatch occurs and the concept becomes a burden rather than a support Westin 2015. Wording and conventions need to be taken further into consideration. The workflow of the concept should be reconsidered to further streamline the process and support the pilot step by step from event to consequence. Furthermore, the concept in its current form is found to be too leading. The pilot should be given more flexibility to evaluate nearest alternates.

The majority of the consequences were extracted in advance using the conventional manner. Some consequences were not extracted at first glance, especially which approaches are authorized, e.g. CATII and RNAV. The reason for this is could be that weather was not limiting ILS operations, and the note 'land at nearest suitable airport' was making the RNAV approach in proximity of high terrain not favorable, when compared to a closer large international airport with multiple runways and approach types.

Linking the consequences and system effects was not completely clear. This might be due to the physical distance between the system status display and the flight plan list. The time / distance display was not found to be effective yet. However, the plan that was affected by time and speed constraints was a plan that was found to be not a realistic option for the pilot. Currently, expected arrival time and fuel are presented by the FMS by two lines, which is less difficult to comprehend than the time/distance display. Scenarios in which time/speed restrictions play a crucial role should be tested to determine if the potential of this display. This initial test was performed statically and the pilot was given as much time as he required. This doesn't represent the real environment, in which interruptions occur, and time is limited. Furthermore, the display was not interactive yet.

## Conclusions

The designed concept to evaluate flight plan constraints was designed and tested on usability. This initial feedback provided great insight on how important it is to align the display to the mental workflow of the pilot. Guiding the pilot through the complete process, i.e. from event to consequence, would make it easier to understand the cause-effect relations. The principle of the path and space restrictions is still very useable, but the pilot should be given more flexibility to obtain information. Here, the concept will profit from interaction to extract relevant information in the right context. The concept will probably prove its value better, with some initial training and human-in-the-loop experiments under real, dynamic scenarios, which will be future steps.

## Acknowledgements

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