Effects of Aircraft Health on Airspace Safety

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Abstract

This manuscript investigates the effects of aircraft health on the surrounding airspace, and proposes a methodology to understand how different aircraft-level faults (system faults, communication faults, etc.) can adversely affect the safety of the airspace, and qualitatively assess the impact of such faults on airspace safety metrics (such as congestion, controller/pilot workload, etc.). The topic of systems health management deals with continuously monitoring the performance of an engineering system, identifying and detecting the presence of faults, predicting the growth/progression of faults, computing the remaining useful life, and aiding online decision-making for the robust, continued operation of such engineering systems. The topic of real-time airspace modeling and safety analysis deals with defining and computing safety metrics for airspace operations in order to support risk-informed decision-making activities for various airspace entities including pilots, air traffic controllers, airlines, etc. This report presents recent research efforts that focus on combining multiple aspects of the aforementioned topics, and investigates the impact of aircraft-level faults on the airspace safety.

Problem Definition and Scope

The presence of faults in an aircraft either due to onboard malfunctions or external entities may not only be affecting the "health" of that particular aircraft, but also, in some situations, may affect the surrounding airspace, to some extent. While some faults can be easily remedied during flight, other faults may be extremely critical and directly affect the health of the airspace considerably. For instance, if an aircraft were to lose communication abilities, then it may have to rely on visual flight rules, and this may pose an increased risk (not only to itself, but also) to the surrounding airspace.

The scope of this work is to identify key factors which cause operational malfunction in an aircraft and determine how those malfunctions affect previously specified airspace safety metric[1] and/or propose additional safety metric definitions. First, certain background and motivation is provided for this work, and then, the proposed approach is discussed.

Background and Motivation

During the past few years, a significant amount of research effort has been geared towards measuring, monitoring and improving safety of the National Airspace System (NAS). Especially pertinent to our SMARTNAS and Real-Time Safety Monitoring (RTSM) research work. The SMARTNAS research work[2] is an effort to develop an air traffic management simulation capability to explore integrating alternative concepts, technologies and architectures into the NAS. As part of the RTSM project, Roychoudhury et al.[1] presented a

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methodology and framework for computing the safety of the NAS, defined by the FAA as "Freedom from those conditions that can cause death, injury, occupational illness, or damage to or loss of equipment or property, or damage to the environment". This approach utilizes a model-based prediction framework developed by the Diagnostics and Prognostics group at NASA Ames Research Center. Applying the framework first requires offline analysis and modeling. The models are then utilized for online real-time monitoring and prediction for the airspace. In parallel, a significant amount of research has been happening in the topic of component-level and system-level prognostics and health monitoring (PHM) in the context of integrated vehicle health management (IVHM). In this area, the focus is on continuously monitoring the performance a given component/system, constantly performing diagnosis[3]to identify the presence of possible faults,[4] prognose the future degradation of the component/system, estimate the remaining useful life [8], and aid online operational decision-making[5] using optimization and fault mitigation approaches.

It is worth noting that the problem of real-time monitoring and prediction for the airspace can be viewed to contain certain elements of the health monitoring problem, because it is of interest to identify certain airspace-level hazards and predict the occurrence of such hazards, similar to the prognostics problem where it is of interest to predict component-level and system-level failures. Nevertheless, the problem of airspace monitoring/prediction treats the entire airspace as a whole system and past research efforts have not focused on identifying how aircraft-level faults will affect the "health-state" of the airspace. If there is a malfunctioning aircraft, what aspects of airspace safety (if any) will be affected? What different types of malfunctions need to be considered in such an analysis? What aspects of airspace safety need to be investigated and what safety metrics would be affected? The goal of this report is to delve into these questions and present some preliminary research results that are first steps towards answering them.

A significant amount of research effort has been spent analyzing aircraft level malfunctions and faults. The topic of airworthiness explores this topic in detail; an aircraft is airworthy "when it meets its type design and is in a condition for safe operation?. This topic of research also considers different types of faults, their causes and their effects. Some commonly considered aircraft-level defects, failures, and threats include :

1. Operation outside the certificated limits such as those laid down for flight in ice or snow conditions.
2. Component degradation due to fatigue, creep, fretting, wear or corrosion, depending on the system or component
3. Accidental Damage (AD) and Environmental Damage (ED)
4. Procedural (Design, Manufacturing, Maintenance or Supply) error and Human Factors
5. Ageing components

Approach

The approach for this analysis focuses on understanding what are the various types of aircraft-level faults/malfunctions (we discuss key types in this report) and how they impact the airspace safety and the safety metrics. This procedure can be explained in the following steps:

1. Review the Aviation Safety Reporting System (ASRS) database, NTSB and Skybrary for incident/accident references and identify aircraft-level incidents that may possibly affect the safety of the surrounding airspace.
2. Classify the incidents into four different categories: avionics-related malfunctions, airframe- and power plant-related malfunctions, human factors/errors, and external disturbances, as further explained below.
3. Investigate how the aforementioned types of malfunctions affect the overall airspace safety, and in particular, the safety metrics such as congestion, workload, etc. Explain the first two categories of malfunctions with example scenarios from database and their correlation to safety metrics.

There are several types of malfunctions that may happen at the aircraft level. For the purpose of investigation, this report classifies such malfunctions into 4 different categories. The first category focuses on avionics related malfunctions that may result in total/partial loss of communication, sensing errors that may result in the aircraft reaching undesirable altitudes, etc. The second category of airframe- and power plant-related faults and malfunctions considers faults in engines, brakes, flaps, landing gear, cabin pressurization, etc. The third category of human factors and errors considers malfunctions that have a human origin, i.e., for instance, mistakes made while executing a checklist, malfunctions due to crew fatigue, etc.. The fourth and final category of external disturbances considers externally caused malfunctions, such as debris on the runway, bird-related disturbances, etc. Another key goal of this work is to integrate airspace health predictions with earlier work on system-level prognostics. Predicting aircraft-level faults would enable a longer look-ahead on predicting airspace safety metric violations.

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