

Modeling Increased Complexity and the Reliance on Automation: FLightdeck Automation Problems (FLAP) Model

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Abstract

This paper highlights the development of a model that is focused on the safety issue of increasing complexity and reliance on automation systems in transport category aircraft. Recent statistics show an increase in mishaps related to manual handling and automation errors due to pilot complacency and over-reliance on automation, loss of situational awareness, automation system failures and/or pilot deficiencies. Consequently, the aircraft can enter a state outside the flight envelope and/or air traffic safety margins which potentially can lead to loss-of-control (LOC), controlled-flight-into-terrain (CFIT), or runway excursion/confusion accidents, etc. The goal of this modeling effort is to provide NASA's Aviation Safety Program (AvSP) with a platform capable of assessing the impacts of AvSP technologies and products towards reducing the relative risk of automation related accidents and incidents. In order to do so, a generic framework, capable of mapping both latent and active causal factors leading to automation errors, is developed. Next, the framework is converted into a Bayesian Belief Network model and populated with data gathered from Subject Matter Experts (SMEs). With the insertion of technologies and products, the model provides individual and collective risk reduction acquired by technologies and methodologies developed within AvSP.

Introduction

Usage of automatic systems in airliners has increased fuel efficiency, added extra capabilities, enhanced safety and reliability, as well as providing improved passenger comfort since its introduction in the late 80's. However, original automation benefits, including reduced flightcrew workload, human errors or training requirements, were not achieved as originally expected. Instead, automation introduced new failure modes, redistributed, and sometimes increased workload, brought in new cognitive and attentional demands, and increased training requirements (refs. 1, 2). Modern airliners have numerous flight modes, providing more flexibility (and inherently more complexity) to the flightcrew. However, the price to pay for the increased flexibility is the need for increased mode awareness, as well as the need to supervise, understand, and predict automated system behavior (ref. 3). Also, over-reliance on automation is linked to manual flight skill degradation and complacency on commercial pilots. As a result, recent accidents involving human errors are often caused by the interactions between humans and the automated systems (e.g. the breakdown in man-machine coordination), deteriorated manual flying skills, and/or loss of situational awareness due to heavy dependence on automated systems (refs. 4, 5).

This paper describes the development of the increased complexity and reliance on automation baseline model, named FLAP for FLightdeck Automation Problems. The FLAP model is part of a series of models that serve the NASA Aviation Safety Program's (AvSP) portfolio assessment by providing simulation capability for complex aviation accidents at the system-level. These models¹ provide quantitative analysis capability, enabling the AvSP to assess the portfolio impact on the reduction of aviation system risk in the current day operations² (ref. 7). The focus of the FLAP model is on the effects of increased complexity and reliance on automation systems in transport category aircraft accidents and incidents. Consequently, the model aims to simulate contributors associated with man-machine interface breakdown, flightcrew manual flight skill degradation, automation interface, overconfidence/complacency and simulator training as well as automated aircraft systems failure and design.

Data and Literature Review

In accidents involving late model airliners, the essence of pilot error accidents is no longer related to "stick and rudder" or manual flying skills, rather, it is the efficiency of (system) monitoring of highly automated aircraft (refs. 2, 3, 8). Consequently, pilot error usually results in misalignment of automation system/modes, pilots' perceptions

¹ The first model consists of aviation accidents caused by in-flight loss of control, captured in a model named LOCAF (ref. 6).

² Future versions of these models will provide operations in NextGen environment.

and actions, and aircraft state. Currently, common taxonomies and definitions for accident and incident³ reporting systems such as the CAST/ICAO Common Taxonomy Team's (CICTT) Aviation Occurrence Categories or the accident types in National Transportation Safety Board (NTSB) categories don't have a dedicated group concerned with autonomy/automation related issues⁴. Lack of a dedicated category prevents a comprehensive search of the dataset of such accidents, which, in turn, prohibits a statistical analysis capability on automation related accidents with respect to all accidents within a certain database/timeframe. Due to these shortcomings, accident and incident data found in literature are solely used to identify key issues and provide information during framework development, and served as guidelines/examples in SME meetings.

A literature review on issues associated with increased automation and its effects on flightcrew was conducted. The available literature mostly consisted of anecdotal work; describing main problem areas associated with increased automation usage. One of the most cited works; the Federal Aviation Administration (FAA) Human Factors Team Report (ref. 10) addresses flightcrew/flight deck automation interfaces in commercial aircraft, and provides comprehensive information on the issues and recommendations⁵. Studies conducted by Billings (ref. 2), Sarter et al. (ref. 3), and Orlady et al. (ref. 11) also shed light on earlier issues encountered in automated systems as well evolution of aircraft automation, which assisted in identifying primary issues simulated in this model. Also, studies investigating incidents (refs. 4, 10, 12) pilot surveys that collect information on pilots' attitudes about flight deck automation (refs. 13, 14) were used to construct the framework structure.

Modeling Steps Overview

Employing the literature and accident/incident data review, a comprehensive list of causal factors contributing to automation problems was acquired and categorized based on responsible parties (e.g., flightcrew, regulatory body, etc.). These causal factor categories were then organized within a hierarchical manner; similar to Reason's Swiss cheese model (ref. 15) used in the Human Factors Analysis and Classification System (HFACS) (ref. 16) and the previous modeling effort, LOCAF (ref. 6). The causal factors (or nodes) and the connecting links within the framework are supported and documented by both past studies and accidents/incidents alike. The resultant framework is a generalized representation of automation related accidents/incidents, capable of showing multi-dependencies among various automation stakeholders. The next step involved the conversion of the framework into a quantitative model using a Bayesian approach via Hugin Software v.7.8⁶. The draft model was reviewed by Subject Matter Experts (SMEs) in order to obtain feedback, validation, and probabilistic data. Following subsequent calibration, the resultant model, called "baseline model", is capable of providing preliminary causal factors and their probability values leading to an automation accident and/or incident. Finally, the model will be reviewed by internal and external panels before the AvSP products are inserted for portfolio assessment purposes. The model will then provide the effect of portfolio elements (also called products) in reducing automation related events in today's aircraft operations.

FLAP Framework

The FLAP framework is structured to contain both latent and active factors. Active failure levels are the 'pointy/sharp end' of the spear where the event takes place on the front line operator level, and are often directly linked to the accident or incident. Deficiencies or failures on each level are viewed as 'holes'. Undesirable events are caused by overlapping of these failures/breakdowns (holes) at latent and active layers (ref. 16). The FLAP framework containing three latent and two active levels and their interactions are given in Figure 1.

³ NTSB defines accident an occurrence associated with the operation of an aircraft, which takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage and, and an incident is an occurrence other than accident, associated with the operation of an aircraft, which affects or could affect the safety of operations (ref. 9).

⁴ ASRS incident database includes "human-machine interface" under human factors tab as a direct automation related factor since June 2009.

⁵ The Flightdeck Automation Working Group (FDAWG) (ref. 4) recently released an updated version of the 1996 report and findings which were compared against the FLAP model.

⁶ <http://www.hugin.com/productservices/products/commercial/explorer>

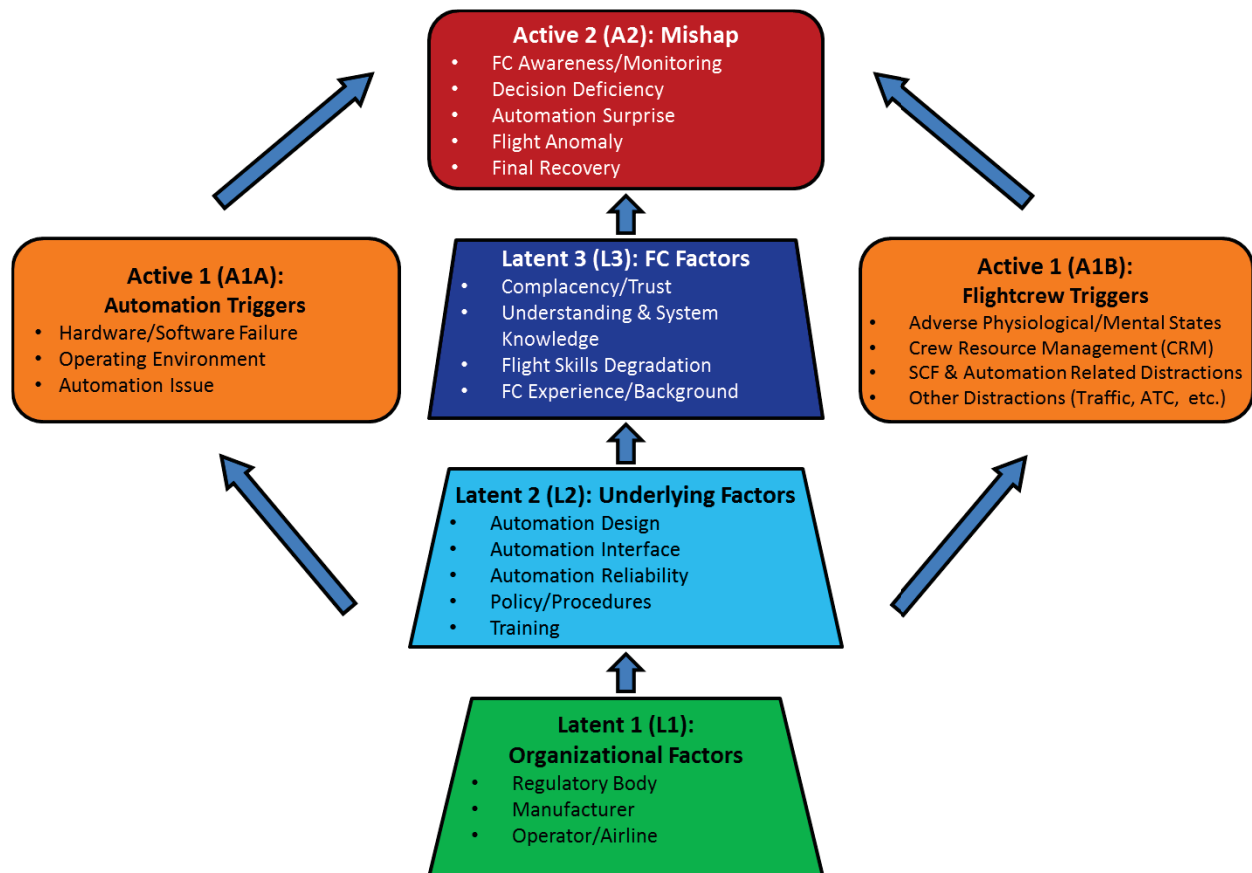


Figure 1 – FLAP Framework Overview

The first latent level (L1) includes the major stakeholders within commercial airline operations, i.e. regulatory body (FAA, Directorate General for Civil Aviation, etc.), aircraft manufacturers, and operators. Second level latent (L2) factors include issues related to high-level underlying factors including automation characteristics such as design, interface, and reliability, as well as airline policy/procedures and training practices. The third level consists of latent flightcrew (FC) related factors such as complacency/trust, understanding & system knowledge, flight skills degradation, and experience/background. There are two active causal factor levels in the framework. The first level active causal factors, (also considered as ‘triggers’ or precursors), are divided into two sub-sections, Active A1A and Active A1B. These active failures take place during flight and stem from either automation system anomalies (A1A) or the underperforming flightcrew (A1B) due to several reasons. The second active level (A2) represents automation mishap including flightcrew errors (FC awareness/monitoring, decision deficiency, and automation surprise) along with flight anomaly and recovery. The contents of the active as well as latent levels are provided within the node descriptions in the next section.

FLAP Model Overview and Node Descriptions

The framework presented in the section above was converted into a Bayesian Belief model using Hugin Software. In order to facilitate its representation and discussion, the model was divided into three sections using Hugin’s object-oriented feature⁷ which allows encapsulation of certain parts of the model. The FLAP model consists of the top-level in Figure 2 and encapsulated Automation and Flightcrew Conditions sections (called subnets) given in Figure 3 and Figure 4, respectively.

⁷ Note that Hugin Software allows encapsulation only if subnets do not receive any inputs from top level nodes, a requirement of directed acyclic graph structure of Object-Oriented Bayesian Networks (OOBNs) to prevent directed cycles. In order to overcome this constraint and for the sake of discussion, the common causal factors nodes are duplicated in all three model sections/subnets. Actual model calculations are performed on a “flat” model, without subnets.

Top-level FLAP Model: The top-level model is used to integrate the subnets and convey the causal factors to the event of interest, i.e. probability of an automation related accident and incident. Similar to the structure shown in Figure 1, the top-level model, shown in Figure 2, includes several layers of latent and active factors and their interactions, described in detail in the sections below.

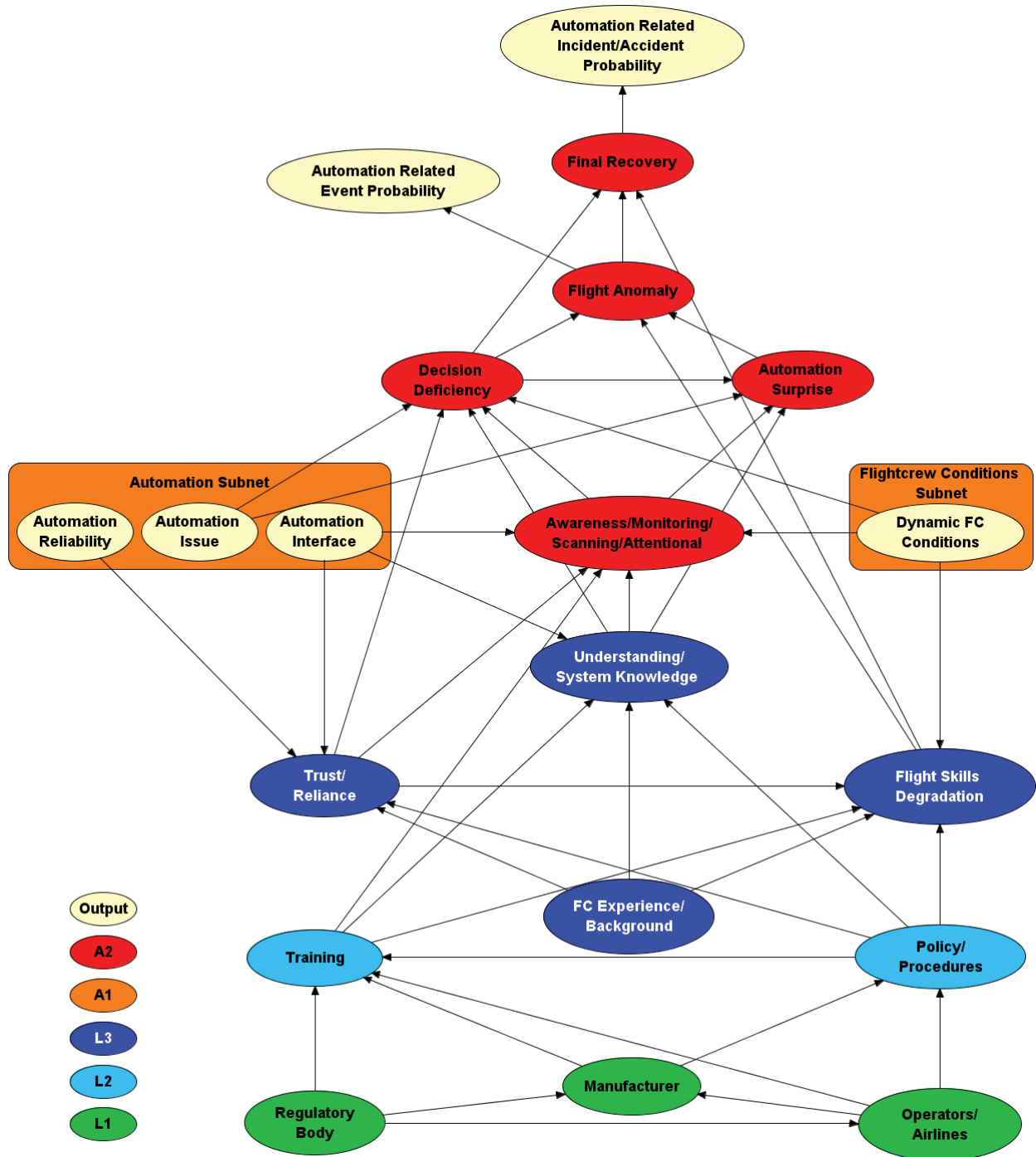


Figure 2 – Top-Level FLAP Model

The bottom three nodes include the L1 level organizational latent factors such as the *Regulatory Body*, *Manufacturer*, and *Operators/Airlines*. The L1 level nodes and their respective links are duplicated in Automation and Flightcrew Conditions subnets, but are only described in this section. The *Regulatory Body* node represents

deficiencies within the regulatory process in both aircraft certification and flight standards of commercial transport operations (ref. 4). *The Regulatory Body* node is linked to five other nodes: *Manufacturer*, *Training*, and *Operators/Airlines* (Figure 2), *Automation Design*, *Automation Interface* (links shown in Figure 3). *The Manufacturer* node represents large aircraft manufacturers as well as automation system/avionic equipment manufacturing companies. The node covers deficiencies in automation design philosophy and approach (ref. 11), level of automation including over-automation (ref. 13), economic benefit (ref. 17), and standardization and cultural diversity (refs. 10, 18) that could eventually lead to human factors issues. The *Manufacturer* node influences characteristics of *Automation Design*, *Automation Interface* (links shown in Figure 3), and also affects *Training* and *Policy/Procedures* nodes (ref. 10) (Figure 2). *The Operators/Airlines* Node delineates the organizational aspects of corporate airlines as causal or contributing factors in automation accidents/incidents. The organizational deficiencies can trickle down and materialize as *Training* (refs. 10, 14, 17) or *Policy/Procedure* (ref. 10) issues (Figure 2). Also, lack of adequate supervision and management guidance can result in *Adverse Physiological* or *Mental States* in flightcrews, links shown in Figure 4. Finally, link between the *Operator/Airlines* and *Manufacturer* nodes represent unrealistic airline expectations/requirements imposed on the manufacturers, driven by economic motivation and operational efficiency.

The second latent layer includes underlying factors affecting both automation systems and airline operations. These factors are *Policy/Procedures* and *Training* in the Top-Level Flap model in Figure 2, and *Automation Design*, *Automation Interface*, and *Automation Reliability* (given in the automation subnet, Figure 3). The *Training* node includes deficiencies associated with inadequate training, generally associated with limited resources and the common practice of “on-the-job” training of the remainder automation functions that were left out during initial training (refs. 3, 10, 11). This node is connected to several causal factors in the model. Different components of training are represented via the node it is linked to, for instance *Training to Flight Skills Degradation* designates the basic flight (stick & rudder) component of training. Similarly, *Training* is connected to *Awareness/Monitoring/Scanning/Attentional* (*Awareness/Monitoring* for short) and *Understanding/ System Knowledge* nodes as shown in Figure 2 and Crew Resource Management (*CRM*) node in Figure 4, representing respective training constituents. The *Policy/Procedures* node covers deficiencies associated with inappropriate flightcrew guidance caused by issues stemming from *Manufacturer* and *Operators/Airlines*. For instance, some examples of inadequately determined procedures are: operator procedures inconsistent with manufacturer recommendations and design philosophy, incorrect modification of procedures for economic or fuel saving reasons, or inappropriate level of proceduralization (refs. 4, 10). The *Policy/Procedures* node is connected to the *Flight Skills Degradation* and *Trust/Reliance* nodes to represent cases where operator guidance on automation usage level solely promotes automatic flight aircraft handling. Similarly, inappropriate guidance on aircraft control could interfere with pilot understanding and system knowledge and affect training procedures.

The third level of latent causal factors consists of *Flightcrew Experience/Background*, *Trust/Reliance*, *Flight Skill Degradation*, *Understanding/ System Knowledge* nodes. The *FC Experience/Background* node distinguishes the varying flightcrew personal factors including experience level (seasoned vs. young pilots), training background (military vs. civil aviation), and operational environment. The *Flightcrew Experience/Background* node is linked to *Flight Skills Degradation*, *Understanding/ System Knowledge*, and flightcrew *Trust/Reliance* nodes (refs. 3, 17). The *Trust/Reliance* node includes flightcrew complacency and inappropriate confidence level assigned to autoflight systems. The *Trust/Reliance* node is a parent causal node for three nodes, namely, *Awareness/Monitoring* (ref. 3), *Flight Skills Degradation* (ref. 19), and *Decision Deficiency* (ref. 17). The *Flight Skills Degradation* node contains erosion of manual flight skills (e.g. basic stick-and-rudder capabilities, flight control errors, instrument scan, etc.) due to continuous operation of autoflight systems and lack of practice (refs. 5, 11). The *Flight Skills Degradation* node is connected to both the *Flight Anomaly* and *Final Recovery* nodes to represent the cases where degraded skills can cause flight anomalies or unsuccessful flight recovery. An additional link from *Dynamic FC Conditions* subnet was added to provide crew’s current status including physiological, mental factors and distractions. The *Understanding/System Knowledge* node refers to issues related to flightcrew knowledge of aircraft systems or presence of gaps and misconceptions in their mental model of the system (e.g. autoflight modes, flight management computer, system couplings). This node is connected to the *Decision Deficiency* node since issues with pilot *Understanding/System Knowledge* is one of the primary sources of errors captured in the *Decision Deficiency* node. Pilot understanding is also linked to *Automation Surprise* and flightcrew *System Awareness/Monitoring* nodes. (ref. 10).

The A2 active failure level includes nodes associated with flightcrew *System Awareness/Monitoring*, *Decision Deficiency*, *Automation surprise* which lead to *Flight Anomaly*, and *Final Recovery*. The *Awareness/Monitoring* node includes insufficient system awareness, defined as the inability of a supervisor to track and anticipate the behavior of a) the automation system variables and controls, b) aircraft state and flight parameters (position, speed, flight path, energy state), and c) operating environment (terrain, air traffic clearances, and traffic) (refs. 1, 3, 10). This node is linked to two nodes; *Decision Deficiency* (refs. 10, 17) and *Automation Surprises* (ref. 3). The *Decision Deficiency* node includes all cognitive errors made by the flightcrew such as mode selection/confusion error, flight management system (FMS) programming, checklist use/procedures errors, misdiagnosis of faults, etc. The *Decision Deficiency* node influences three nodes; *Automation Surprise* (due to improper programming or mode errors), *Flight Anomaly*, and *Final Recovery* (representing deficiencies in recognizing the anomaly and selecting proper mitigation strategy). The *Automation Surprise* node defines cases where the operator is surprised by the automation systems, unable to comprehend its current behavior or estimate future occurrences (ref. 1). The presence of automation surprises is one of the prominent causal factors for the *Flight Anomaly* node where the flightcrew recognizes that the aircraft is outside its flight envelope or restrictions via cues from aircraft systems or air traffic control (ATC) interventions. The *Flight Anomaly* node designates any departure from the intended flight plan or safe flight envelope that qualifies as an incident. These anomalies include aerospace deviation in altitude, speed, position, aircraft performance parameters and energy management deficiency as well as aircraft entering a flight state without being properly configured. Depending on the anomaly, the aircraft could potentially experience stall, loss-of-control, over-speed, loss of separation (and consequent near mid-air collision, mid-air collision), controlled flight into terrain, or other accidents/incidents. The *Final Recovery* node refers to the ability of the flightcrew to recover from an abnormal flight condition defined in the *Flight Anomaly* node. Given that the model simulates an accident/incident environment, the *Final Recovery* node plays a decisive role on whether the incident turns into an accident.

Automation Subnet: As previously discussed, issues stemmed from automation systems are compiled under the Automation Subnet given in Figure 3. Similar to the top-level model, the automation subnet also follows the active/latent causation structure, leading to active errors/issues. L1 level latent organizational factors including *Regulatory Body*, *Manufacturers*, and *Operator/Airlines* node descriptions are given above. The L2 level latent underlying factors include the *Automation Design*, *Automation Reliability* and *Automation Interface* nodes. The *Automation Design* node encompasses issues within the automation system design process including system, hardware, and software designs from preliminary phase to flight hardware including assumptions, requirements, testing/debugging, implementation, verification and validation, quality assurance, etc. (ref. 20). The *Automation Design* node is connected to all the downstream nodes in the automation subnet since improper planning and execution of automation requirements can result in failures and unexpected behavior throughout the system.

The active layer within the automation subnet includes *Operating Environment*, *Hardware/Software Failure*, and five automation function nodes. *Operating Environment* node provides external causes that potentially affect the operation of hardware/software (HW/SW) either by disrupting sensor outputs (e.g. cold weather, ice, volcanic ash) or by damaging aircraft systems directly (e.g. lightning, impact damage). Similarly, the *HW/SW Failure* node includes all glitches and malfunctions of the systems that were not anticipated by the designers, including malfunctions of antennas, sensors, or other measuring equipment that provide information to the automation systems downstream nodes. The *Performance Systems* node includes issues associated with the performance function of the FMS, specifically, weight and balance, fuel weight, engine thrust limits, take off reference data, maximum/optimum altitude calculations, or carrying out the projected altitude or speed targets (ref. 21). The *Warning & Monitoring Systems* include automated warning systems such as aircraft configuration, monitoring of aircraft systems and presence of environmental threats (ref. 11). This node covers the failure of warning systems due to both faulty design and/or HW/SW failure stemming from the design and implementation of these systems. The issues related to ergonomic aspects of the warning systems (e.g. selection and characteristics of visual, auditory or tactile alerting systems) are included in the *Automation Interface* node. The *Navigation Systems* node covers the components and systems used in navigation including the global positioning system, Very High Frequency omnidirectional radio range, and other precision approach system components (ref. 21). The *Flight Control Systems* node encompasses all the systems involved in automatic flight within the FMS and implementation of inputs via flight control surfaces. The node also includes authority and autonomy related issues and assumptions such as envelope protection and stall/bank limiters (ref. 21). Finally, the *Communication Systems* node includes data link and surveillance systems. Systems like the Aircraft Communications Addressing and Reporting System, telemetry, communication radios, satellite links, telemetry, and ADS-B/C are included in this node (ref. 21).

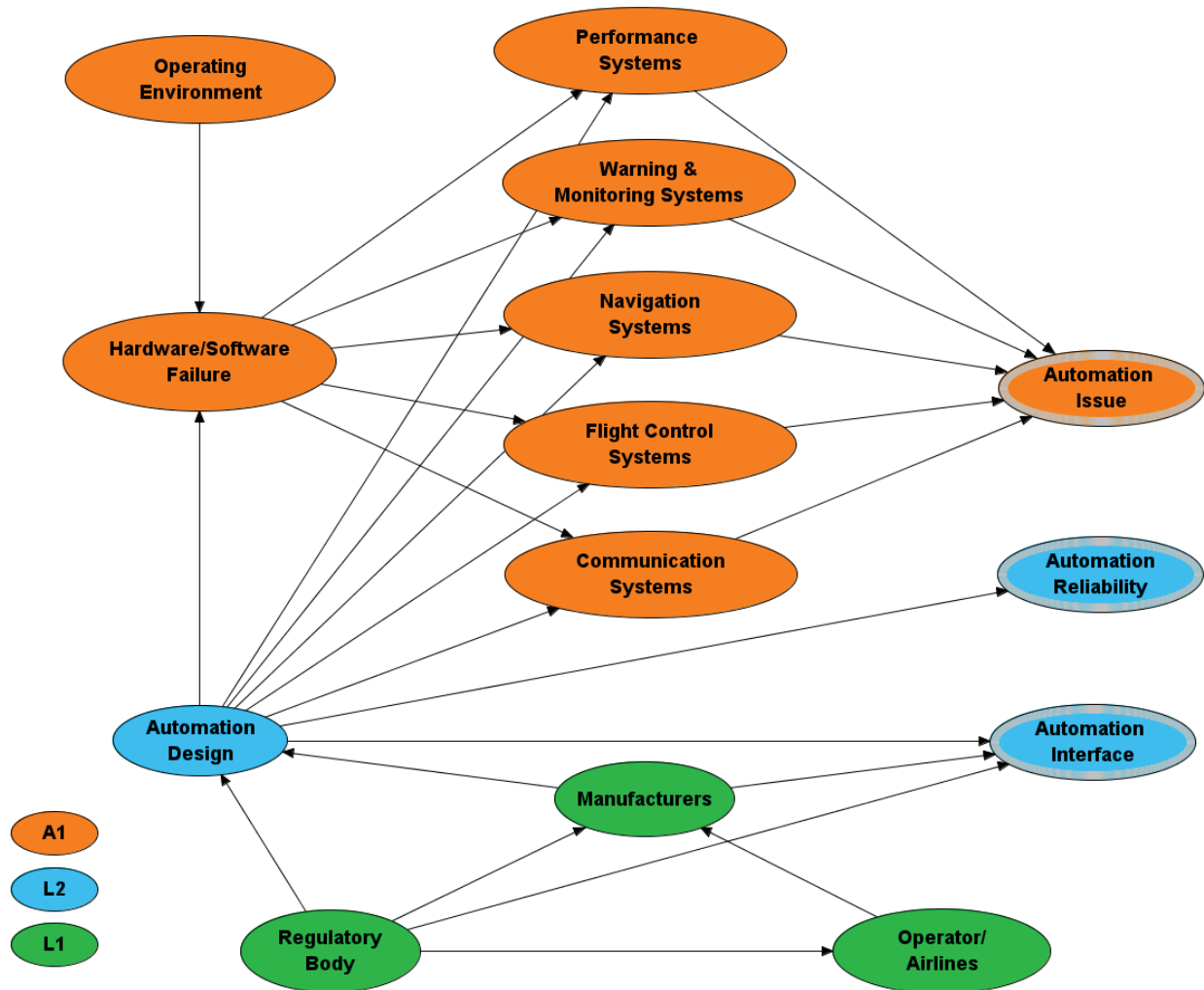


Figure 3 – Automation Subnet

The Automation Subnet provides three output nodes⁸ that are transferred to the top-level FLAP model. The first active output node, *Automation Issue*, provides the probability of an automation system exhibiting malfunction or failure, stemming from any of the five functional systems described above. *The Automation Reliability* node is L2 level output of the subnet, stemming from the *Automation Design* node. Automation reliability primarily affects the flightcrew’s perception where highly reliable automation systems inherently increase reliance on automation (connected to *Trust/Reliance* node at the top-level). The final output node of this subnet is the *Automation Interface*. The interface node is identified as one of the most prominent causes of man-machine breakdown due to its effects on flightcrew situational awareness, pilot saturation and/or confusion (refs. 2-4, 10, 22). This node contains the human-factor related aspects of the cockpit design such as inappropriate determination of the characteristics of visual, auditory, and tactile alerting systems as well as alert categorization issues (ref. 22). This node also includes the non-intuitive flightcrew interface including inadequate feedback and standardization. The *Automation Interface* node is linked to three causal factors; *Trust/Reliance*, *Awareness/Monitoring* (refs. 3, 10), and *Understanding/System Knowledge* (ref. 4) as shown in Figure 2.

Flightcrew Conditions Subnet: The flightcrew conditions subnet provides dynamic flightcrew conditions to the top-level FLAP model, in an approach similar to Reason’s model of accident causation. As in the automation subnet, the flightcrew conditions subnet includes active and latent layers, providing one output node to the top-level FLAP model.

⁸ The output nodes have gray-shaded borders, as shown in Figure 3.

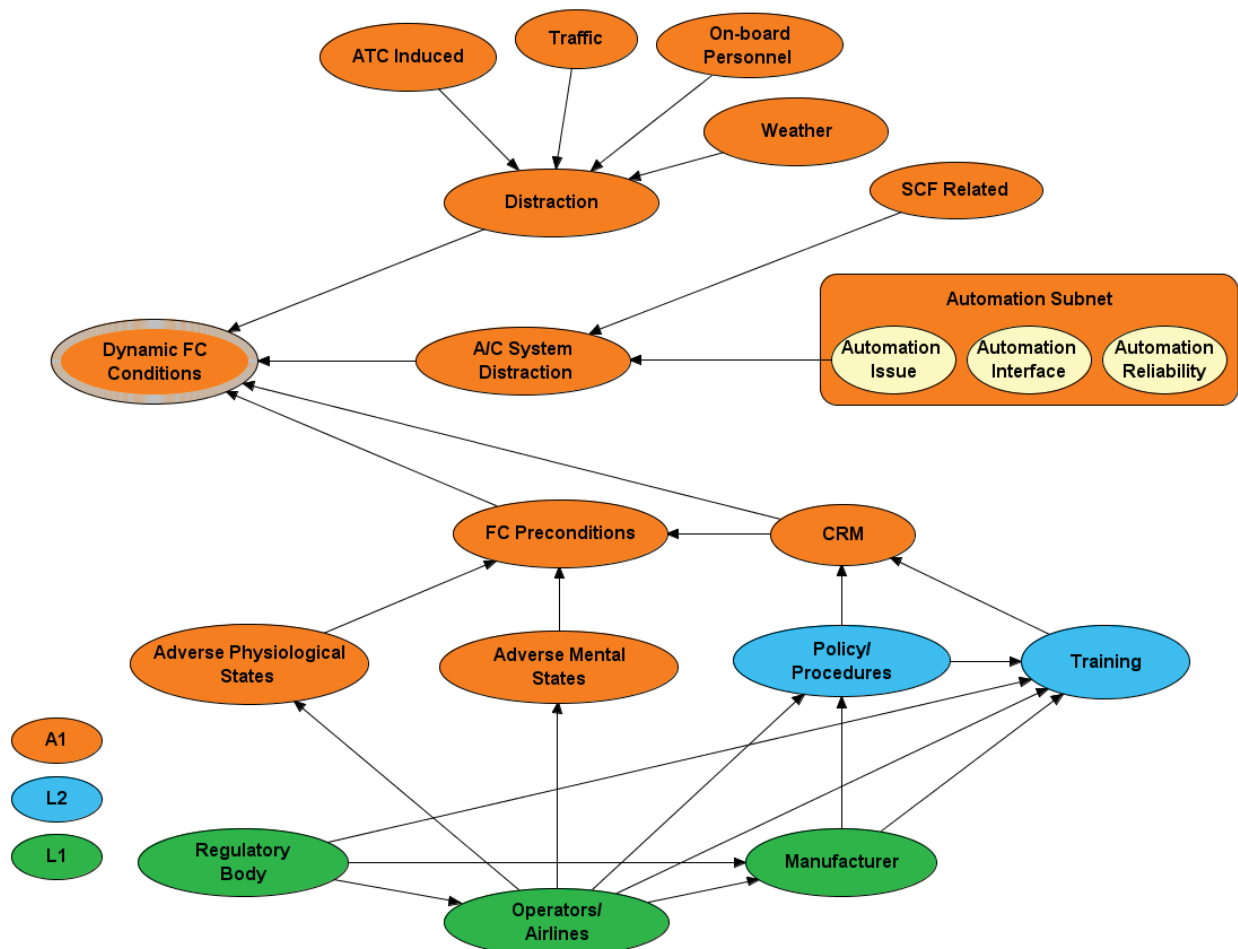


Figure 4 – Flightcrew Conditions Subnet

Similarly to the Automation Subnet, the L1 and two L2 latent layer nodes (*Regulatory Body*, *Operational/Airlines*, *Manufacturer*, *Policy/Procedures*, and *Training*) are duplicated in this subnet. *Adverse Physiological* and *Mental States* and *FC Preconditions* nodes in this subnet belong to A1 level pre-flight causal factors and help determine the probability of flightcrew readiness before the flight takes place. The *Flightcrew Preconditions* node is an aggregation node that considers flightcrew adverse physiological and mental states as well as CRM deficiencies and determines how fit the flightcrew is for the upcoming flight. This node is linked to the *Dynamic Flightcrew Conditions* node, providing a baseline which is then updated by considering the presence of distractions throughout the flight. The *Adverse Physiological States* node include physical fatigue/lack of sleep, medical illness, impaired physiological state, physiological incapacitation, self-medication, violation of crew rest requirement (ref. 6). The node is connected to the *FC Preconditions* node which then connects to *Awareness/ monitoring* node which is greatly affected by the presence of physiological issues. *Adverse Mental States* node include complacency, distraction, *get-home-itis*, misplaced motivation, mental tiredness, distraction, confusion, depression, and/or alcoholism (ref. 6). The presence of adverse mental states can be the cause of decision deficiencies (via the *Dynamic FC Conditions* node) which include omission errors. *Crew Resource Management (CRM)* node includes deficiencies like communication skills and coordination that take place among the flightcrew as well as between other entities before, during, and after the flight (ref. 6). CRM deficiencies surface as cross-verification errors and crew coordination problems including workload management. The node is linked to both *FC Preconditions* and *Dynamic FC Conditions*, indicating issues associated with the pre-flight briefing as well as in-flight communication and coordination, respectively.

A1 level in-flight causal factors including *A/C System Distraction* and *Distraction* provide the model with the updated flightcrew conditions that are present during the flight. Along with the input from the *FC Preconditions* node and several sources of external distraction, the ability of the crew to perform flying duties is aggregated in the *Dynamic FC Conditions* node and outputted to the top-level model. Possible distractions the flightcrew may encounter during a flight are divided into two categories; general distractions and aircraft system related distractions. *The Aircraft (A/C) Systems Related Distractions* node is an aggregation node which provides the probability of flightcrew to get distracted by the presence of a) *Automation Issues*, and b) *SCF*. Distractions stemmed from troubleshooting autoflight system anomalies/behavior as well as reprogramming the FMS are captured in this node. The *SCF* related node provides all other failures within the aircraft systems that are not associated with autoflight systems. Another aggregation node, *Distractions*, takes into consideration all other major sources of mental disturbance that potentially result in fixation or absorption. The causal factors considered are fourfold; *Traffic, ATC, On-board Personnel*, and *Weather*. The presence of traffic and frequent changes in the flight trajectory were identified as sources of distraction in several incidents (ref. 1, 12). Besides ATC and traffic, numerous cases where cabin crew interference with cockpit or presence of check pilot during flight were also identified as causes for the flightcrew overlooking the autoflight systems (ref. 12). Lastly, the presence of adverse weather (icing, fog/visibility issues, thunderstorms, rain, wind, and low ceiling) causes additional mental work to the flightcrew (ref. 12). Presence of distractions inherently increases probability of flightcrew experiencing fixation or saturation since they require identification and mitigation.

As previously mentioned, the *Dynamic Flightcrew Conditions* node is the sole output of this subnet and it is linked to key causal factors including *Decision Deficiency*, *Flight Skills Degradation*, and *Awareness/ Monitoring*. This node takes into consideration the presence of distractions along with crew related issues in order to calculate the probability of a crew member suffering fixation or absorption. Fixation is described by “being locked into one task or one view of a situation even as evidence accumulates that [...] the particular view is incorrect” (ref. 10, p.59). On the other hand, absorption is a state of mind where the pilot is focused on one single task such as FMS programming or flight management computer troubleshooting while discarding others (also referred to as task shedding).

FLAP Model Output Nodes: The output values of the FLAP model (shown in Figure 2) are determined as the incident and accident probabilities associated with automation related issues. The model is designed to identify the prominence of automation related issues among all foreseeable accidents and incidents. For that reason, by definition, the *Flight Anomaly* node provides the probability of an in-flight upset resulting from the combination of the upstream automation-related nodes. The *Automation Related Event Probability* node reflects all automation related events including both incidents and accidents. This node is comprised of automation related events (A%) and non-automation related events (B%). A% and B% sum up to 100%, representing all considered accidents and incidents. Automation related *Flight Anomaly* node probability combined with that of the *Decision Deficiency* and *Flight Skills Degradation* nodes are the inputs to the *Final Recovery* node, which determines the probability of an incident evolving into an accident. The assumption is such that recovered incidents remain as incidents (e.g., correction of over-speed or stall situation) where, unsuccessful recovery efforts may result into injury to crew and passengers and/or damage to the aircraft, hence an accident. Consequently, the second output node, *Automation Related Incident/Accident Probability*, provides accident and incident probabilities (e.g., X% accidents and Y% incidents, totaling up to 100% of flight anomalies or A%). Given the risk is defined as the product of likelihood of event and its severity, the model provides risks associated with heavy automation in today’s aircraft operations. This is achieved by providing likelihood (probabilities) of such events occurring (via *Automation Related Event Probability* node) and their severity (via *Automation Related Incident/Accident Probability* node which distinguishes between accidents and incidents).

AvSP Product Insertion Process

NASA’s AvSP is responsible for developing methodologies and technologies (referred to as products) to improve air transportation safety within the NextGen environment. The AvSP is comprised of three projects, namely, Vehicle Systems Safety Technologies project, System-Wide Safety and Assurance Technologies project, and Atmospheric Environment Safety Technologies project (ref. 23). As previously discussed, the goal of the modeling effort is to gauge the impact of the products developed within these projects on current and future aviation risks. In order to do so, the products will be inserted into the model by the SMEs and then verified by involved stakeholders to ensure proper placement. The next step involves SME re-evaluation of affected nodes’ probability by considering the effect of the product. The rectangular nodes shown in Figure 5 represent notional products and the arrows designate the

affected nodes. Owing to the Bayesian Belief structure, the benefits of the products are propagated downstream from the affected node. For instance, a new technology that improves pilot situational awareness is applied at the *Awareness/Monitoring* node and can prevent a *Flight Anomaly*.

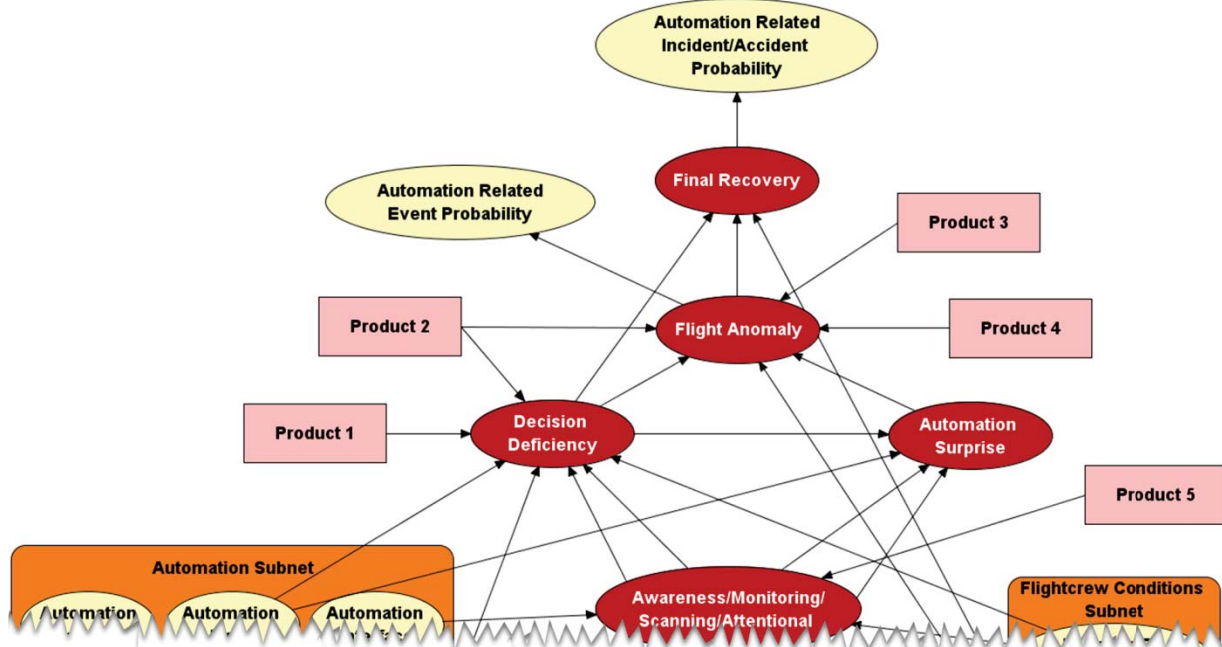


Figure 5 – Nominal Product Insertion

Data Collection

The probability data elicitation process consists of a series of SME sessions. The model structure and probability values as well as the impacts of AvSP portfolio elements are acquired from the same set of SMEs, called operational SMEs. For the FLAP model, the operational SMEs consist of two commercial pilots; experienced in Part 121 and 135 operations and airline management/training as well as one human factors expert specialized in flight deck automation. The additional SME panels held in between operational SME meetings are used to ensure the model assumptions and structure are sound for the given study purpose. A typical elicitation process for the modeling effort is highlighted in Luxhøj (ref. 24). At the time of writing, the baseline model was established following the first operational SME meeting. The goal of this four-day meeting was to review the preliminary model developed by the team, make revisions, and populate probabilities for the causal factors⁹.

Boundary Conditions: As previously stated, the model is intended to solely capture the probability of automation related flight anomalies that could result in incidents and accidents. The two top-level output nodes provide accident and incident probabilities of automation related anomalies with respect to all conceivable accidents and incidents. For that reason, the elicitation process strictly considers probabilities within the accident/incident perspective instead of all aviation operations when querying causal factor probabilities in the model. This assumption renders the probabilities more tangible; e.g. probability of situational awareness deficiency with respect to all yearly U.S.-based flights (over 8 million departures in 2013¹⁰ alone) versus all accidents and incidents within the last 10 years (over 1200 accidents¹¹ in Part 121 and 135 and 35000 incidents in ASRS database¹²). The model considers today's aircraft operating within the United States, under FAR Part 121 & FAR 135 with considerable but varying degrees of automation usage, such as Boeing 737, -47, -57, -67, -77, -87 families and Airbus 300, -10, -20, -30, -40, -50 as well as regional jets like Embraer and Bombardier CRJs. The timeframe for this study was a 10 year period including aircraft commissioned in year 2003 until 2013.

⁹ Since the model results were uncalibrated, the preliminary numerical values were not included in the context of this paper.

¹⁰ <http://www.transtats.bts.gov/>

¹¹ <http://www.nts.gov/aviationquery/>

¹² http://akama.arc.nasa.gov/ASRSDBOnline/QueryWizard_Filter.aspx

Assumptions and Limitations: There were several assumptions made throughout the modeling effort due to limited resources. As in the previous modeling effort and some other BBN approaches, the FLAP model embraces SME opinion for the sole source for data generation primarily due to lack of statistically meaningful data. Although several accidents, incidents and studies were used to develop the model structure, the required probability values in the model were acquired from the SMEs. Additionally, in order to keep the model size manageable and still achieve a generalized automation problem model, nodes like *Awareness/Monitoring* and *Decision Deficiency* contain several assumptions and error types, lowering the model resolution. However, since the model is primarily used to evaluate future NASA technologies' impact as part of a system-level comprehensive portfolio analysis study, the model resolution and fidelity satisfy the analysis purpose. Consequently, the model output is not intended to assist flightdeck design or policy decision making processes. Also, due to the variance in application within the industry, the automation system was developed based on major functions instead of actual system components.

Conclusions & Next Steps

This paper highlights the development process of a high-level automation related accident/incident model aimed to serve as a platform for AvSP portfolio assessment. In order to do so, past automation studies and accidents/incidents were reviewed and key issues were identified. Similarly to LOCAF modeling effort, these key issues are then represented in a hierarchical manner and their interdependencies were mapped within the FLAP framework. The network was then modeled using the Hugin Software. In order to populate the model, SME opinions were employed due to lack of a comprehensive historical dataset.

The next steps in the current modeling effort consist of an external review to check the baseline model soundness and validity, followed by the second operational SME session allocated for model calibration, review of concerns/comments provided by the external panel, and insertion of AvSP portfolio products into the model. Following a set of internal review meetings, the third operational SME meeting is planned to revisit the model and provide updated probabilities for inserted AvSP products and their impacts. The analysis of the data stemming from the model provides insight on a) increased automation dependence on today's aircraft and its implications, and b) impact of NASA products in mitigating such issues. Finally, the FLAP model will be integrated into the past and future modeling efforts owing to the OOBN modeling techniques and will be further used in portfolio prioritization efforts.

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