PILOT TIMELINESS OF SAFETY DECISIONS USING INFORMATION SITUATION AWARENESS

Erik Blasch, AFRL/RIEA, Rome, NY, USA
Pavel Paces, Czech Technical University in Prague, Praha, Czech Republic
Jan Leuchter, University of Defence, Brno, Czech Republic

Abstract

Information fusion includes interaction between users (e.g., pilot's) and machines (e.g., aircraft). As popularized by Boyd; the observe, orient, decide, act (OODA) paradigm captures a user's decision making ability. The OODA model has been used as a method of a pilot's situation awareness (SAW) in flying an aircraft. Improvements to the OODA model include the SAW model of perception, comprehension, and forecasting of events. SAW can include waypoint analysis, detecting emerging threats, as well as terrain navigation. In this paper, we analyze the timeliness of pilot actions to augment flight safety using the cognitive OODA (C-OODA) for engine outages. In a critical maneuver scenario, data collected and analyzed with the C-ODDA highlight pilot lead, immediate, delay, and no action responses which could shed light on cockpit control warnings.

Keywords: Pilot Awareness, Safety, C-OODA

Introduction

Aerospace technologies include understanding safe flight operations [1]. For example, airworthiness authorities seek to lower accident rates and increase flight safety for aviation transport. Evaluating human machine interaction [2, 3] is important for the aviation industry safety. The methods assuring safety of aircrafts, their parts and appliances [4], infrastructure [5], crew and personnel certification [6] requires pilots to skillfully assess the situation. Aircraft simulators (see Figure 1) conducting different flight situations, such as instrument and equipment failures, aid pilots in situation response.

Past incident reports detail key failures by machines and/or humans. The accidents are annually summarized by organizations monitoring activities in the specific area/category of airplanes. Examples include the EASA in Europe [7], or Aircraft Owners and Pilots Association (AOPA) in US [8]. Airplane accident categories include mechanical/electrical, fuel, weather, take-off, maneuvering, approach, landing, and other. Mechanical/electrical failures [9-10] are key failures a pilot must react to during flight.

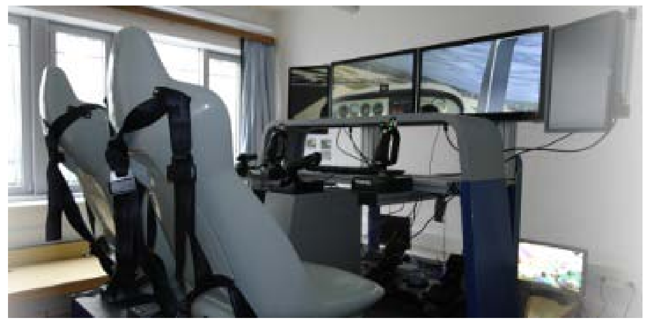

Figure 1. CTU Pilot Testing Interface

Based on an analysis of accidents, there is need for a method of pilot evaluations to recognize and cope with emergency situations [11]. Charles Technical University (CTU) has developed methods to assess pilot reactions to potentially dangerous situations as well as measure their responses. Additionally, error assessment and the related materials (e.g., an accident database [12]) serve to further understand human cognition in aircraft piloting.

To resolve emergency situation decision making, it is important to determine a time series of events. An evaluation shows trends on whether the pilot understands the situation, utilizes the cockpit instrument display, and takes corrective action. Using the evaluation method and data collected at CTU [13], we seek to analysis the timing results for better display design, feedback through indications and warnings, and/or understand human decision making.

Aviation trends show that accidents happen during landing and sometimes connected with engine failure. Some accidents happen after a chain of bad decisions related to the information presentation. We seek to model the timing of decision making as related to engine failure responses during flight.

978-1-4799-5001-0/14/$31.00 ©2014 IEEE

The decision-making evaluation is performed based on the data recorded during a simulated flight. The recorded data includes the flight envelope of the airplane, the terrain and surrounding traffic, and the available equipment monitoring. The airplane status includes e.g. taxiing, take off, climb, cruise, etc. With pilot subjects, they are tested with different scenarios and need to take corrective action. Using the timing data, we seek a model to predict normal safe flight pilot operations.

The rest of the paper is as follows. Sect. 2 discussions the OODA loop for decision making in the context of information fusion and situation awareness. Sect. 3 describes the testing method. Sect. 4 is the C-OODA analysis and Sect. 5 applies the modeling to the collected data. Sect. 6 ends with conclusions.

OODA Loop

Models (e.g. control models) can represent a system to determine what is happening, the parameters of interest, and methods for prediction [14]. System design analysis is important for information fusion applications of situation awareness [15] and integrated sensory perception for aircraft piloting. Information fusion reduces the enormous amount of data into actionable intelligence for user's to make decisions and act upon [16].

One premier model of user decision-making is the extended Observe-Orient-Decide-Act (OODA) model (or Boyd's control loop), as shown in Figure 2.

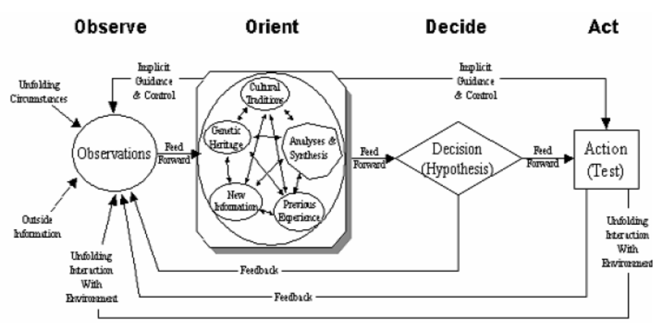

Figure 2. The Extended OODA Loop [19]

The OODA loop model has been widely used to represent decision-making in military aviation environments. The OODA applications for user modeling include military systems [17], target recognition [18], cultural modeling [19], semi-automated decision making [20], and cognitive aviation assistants [21, 22].

The OODA phases are:

- *Observe*: A user/organization interacts with the environment, typically by controlling sensors, querying information needs, and assimilating observations from a display.
- *Orient*: A user/organization distills information from data to determine situational understanding through assessment of the environment to determine a coherent state of affairs.
- *Decide*: User engages situational knowledge derived from orientation to prioritize and select plans/results.
- *Act*: The user/organization engages in a process plan that satisfies current needs.

Key to the OODA methods is situation awareness [23, 24] from which a trained user (e.g., pilot, air traffic controller) is primed for recognized situations [25]. Using the OODA paradigm, the Data Information Fusion Group (DFIG) model [26] looks at human interactions with machines with information management [27] for situation assessment. An example is the Cognitive-OODA (C-OODA) [28] models how a user responds to a situation. For example, a user must assess the resource information over the situation/impact (Level 2/3 fusion [29]) from sensors tracking impacts (Level 1/4 fusion [30, 31]) to make decisions and take action (Level 5/6) fusion. Table 1 provides the common terminology in comparing the models.

Table 1. Comparisons of Decision Making Models

Activity	DFIG	OODA	C-OODA
Command Execution	Level 6	Act	Action Implementation
Decision Making	Level 5	Decide	Recall Evaluate
Sensor Management	Level 4		
Impact Assessment	Level 3	Orient	Projection
Situation Assessment	Level 2		Comprehension
Object Assessment	Level 1		Feature Matching
Signal/Info Processing	Level 0	Observe	Perception
Data Registration			Data Gathering

Current trends in information fusion include situation awareness/assessment evaluation [32], effectiveness measures [33], and uncertainty evaluation [34]. In this paper, we explore timeliness as an effectiveness measure for safe flight operations. The aim of the modeling is to determine whether the pilot is able to identify a situation potentially leading to an accident by processing the visual information in the shortest time and identify consequences of his maneuvers. Multiple scenarios are conducted over different tests.

Testing Method

The CTU flight testing method described in [13] provides a description how to evaluate pilots in predefined scenarios with help of specially designed tools that allow for scenario generation and then recording the pilot reactions. The scenarios reflect standard flight procedures as well as situations designed based on analysis of past accidents. The accidents were simulated based on the collected data contributing to the accident. The CTU Accident Handbook [15] includes many scenarios that can be repeatedly generated for pilot testing. Accidents which were preceded by a series of decisions leading to an accident were selected to understand when and how a pilot makes decisions and/or errors.

The recoded numerical information related to the specific flight log reflects the success (or failure) rate of the pilot's ability to determine potentially dangerous maneuvers in the specific situations. An example test is as follows: the pilot will be asked to try multiple situations and mark by a time-stamp the time where they think the situation is beyond safety limits. Based on the test results, the problem solving ability for corrective action is determined. The series of tests help to understand how pilots react, leading to understanding accidents and preventing the occurrence of a series of poor decision making in emergency situation.

The CTU Aircraft Simulation Environment (CASE) method [15] solves pilot training especially in accident categories with the highest accident rate, such as: engine failures, electrical problems, navigation problems, low altitude flights, maneuvering problems resulting in loss of control, approach and landing, etc.. Accidents happen in conjunction with other phenomena that precludes the pilot from recognizing the salient cause, risk, and emerging situation. To better understand the impacts, object evaluations have been designed.

3.2 Objective Evaluation

An objective evaluation includes different scenario testing of a pilot's ability to fly, solve, and react to potentially dangerous situations. Repeatable testing of the pilot's skills includes determining the moment where the pilot detects the start of a dangerous situation. Using the CTU simulator (Figure 1), different scenarios were developed that mimic those of serious accidents. As compared to simulators available on the market with different degree of immersion (e.g., full motion simulators [35] with built in Motion Cueing [36]) the CTU simulator includes displays tailored to pilot reaction studies. The CTU simulator also supports platform movement that increases the realism of the situation.

The accidents summarized in [14] determined that electrical/mechanical failures are difficult to diagnose. The database provides a rich set of tests for understanding pilot reactions [15]. As reported in [15], the dangerous situation tests are performed repeatedly based on increasing the severity of the situation to challenge the success rate of the pilot to respond to the emergency. The CASE methods support self-studying flying development and can be used by pilot instructors in evaluated their students. Instructor designed scenarios are randomly selected from which the simulator will start and collect the pilot results. However, to evaluate ability of the pilot to identify potentially dangerous situations resulting in an accident requires test definitions.

3.2 Test Definition

There are two types of tests included in the CASE method described in [15]. The test type evaluates pilot's ability to determine potentially dangerous situations, e.g. it tests his reactions during the simulated flight. The two tests are observation and reaction tests.

3.2.1 Observation Test

In the observation test, a visualization of the flight is projected to the pilot who is just a viewer of the presented scenario. The task of the tested pilot subject, after he studied the database of past accidents [37], is to mark moment where in the presented scenario, a flight error potentially resulting in an accident would happen. The test evaluates the pilot's ability to perform common maneuvers, e.g. start, cruise, approach and landing where the precision of the pilot skills is determined together with limit violations.

The aim of the test is to improve pilot's situation awareness and perception of possible results if the different maneuvers on the flight safety. The method of evaluation is specially designed for pilot testing using a full-flight simulator were measured results were presented in [15]. An algorithm, such as information fusion control [38], can be used with the collected from any recording device [39] to assess cognitive aids. The other test is the reaction test.

3.2.2 "Reaction" Test

The "Reaction" test is composed from a set of scenarios randomly selected from the preprocessed accident database [39] compiled from accidents reports between 2008 to 2012. The pilot is confronted with a selected situation, which resulted in a past accident and assesses the pilot's ability to determine a potentially dangerous situation, e.g.:

- Maneuvering in low altitude
- Turning just after take-off and engine malfunction
- Lift loss – flaps engage during flight
- Too steep climbing
- Excessive roll after engine loss
- Stall during flight

The test proceeds as follows. The test subject in the simulator is confronted with a series of six flights divided into two sections (the introductory training flight does not count). The pilot does not control the plane while the scenario is being played. They view the situation presented on the cockpit screen showing the necessary instruments. In the moment, i = time, where they become suspicious about safety of the maneuver that can possibly led to an accident or the safe flight rules are violated, they press a button which initiates the generation of a time-stamp TR_i in the flight recording, as shown Figure 3.

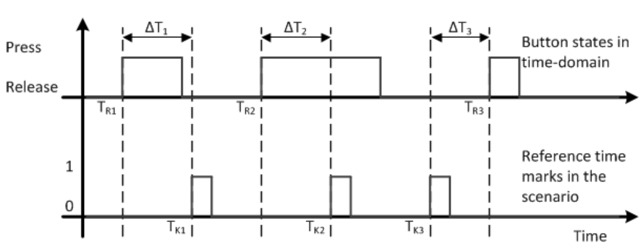

Figure 3. Principle of the Test Evaluation

Every flight scenario is pre-designed to simulate an accident situation or other related aircraft failures that caused unsafe flight. These flights scenarios are saved as binary files which contain recorded values used to replay the flight and also include a special, referential time-stamp TK_i marking the expected moment where the pilot should recognize the safety violation, e.g. moment from which the accident starts its development.

Figure 3 shows the method used to mark the moment of violation of the safe flight and where the meaning of TR_i and TK_i is highlighted in various combinations [15]. The pilot presses the button when they consider the developing scenario dangerous. The time difference ΔT_i between the button press and the reference time-stamp is recorded. Based on the time difference, the pilot's ability to determine potentially dangerous situation is evaluated. The smaller the time difference the better the pilot's performance is.

The pilot is evaluated according to the time difference ΔT_i, (1) which is the difference between the truth reference mark and the button press moment.

$$\Delta T_i = T_{Ki} - T_{Ri} \quad (1)$$

There can be more than one event in the scenario and so the total evaluation if single moments i is summed over all occurrences.

When the test subject marks the dangerous moment too early it is evaluated as test failure. In case he presses the button repeatedly with a time difference between presses shorter then 500ms, it is evaluated as a single continuous press. The continuous press requires a subjective assessment (e.g., interview after the test) to ask the pilot for the purpose of their behavior. It may indicate the pilot wants to mark more than one event, or there are multiple events appearing concurrently. Generally both premature and delayed detection of the required moment means failure, but in case of certain interval (<500ms), a premature identification is considered as better then late marking. Using the time differences, we can use the C-ODDA control model to assess performance.

C-OODA Analysis

We model a user decision-making process as a series of linear time invariant (LTI) control operations with feedback, represented in state space as:

$$\dot{\mathbf{x}}(t) = A\,\mathbf{x}(t) + B\,\mathrm{K}\,\mathbf{u}(t) \qquad (2)$$
$$\mathbf{y}(t) = C\,\mathbf{x}(t) + D\,\mathrm{K}\,\mathbf{u}(t)$$

where A is the state matrix, B is the input matrix, C is the output matrix, D is the feedforward matrix, and K is a constant as shown in Figure 4.

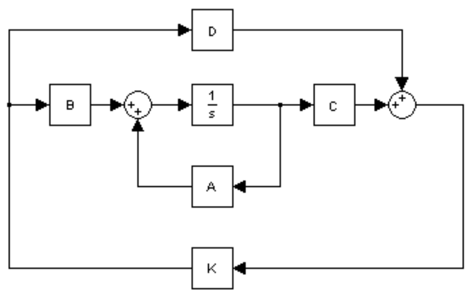

Figure 4. State Space C-OODA Control Module

To model the pilot reaction, we utilize a first order system with an exponential response as presented in Figure 5.

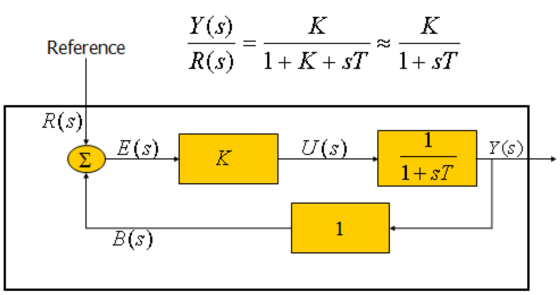

Figure 5. First Order Control Model with Time Delay

Using the Laplace notation, s, the transfer function has a typical exponential time response:

$$h(s) = \frac{e^{-TDi\,s}}{s+1} \qquad (3)$$

We simulate the deadtime for an *input time delay* (TD_i) for a decision i, as related to the user achieving a control decision. Likewise, in the action selection requires time as modeled as an output time delay (TO_i). The updated state-space representation is:

$$\dot{\mathbf{x}}(t) = -A\,\mathbf{x}(t) + B\,\mathbf{u}(t - TD_i) \qquad (4)$$
$$\mathbf{y}(t) = C\,\mathbf{x}(t - TO_i) + D\,\mathbf{u}(t)$$

To determine the estimation parameters of A and B, as well as the output analysis of C and D, we model the importance of the information processing as related to the functions in the C-OODA. We note that the transfer function response delays can vary over users and domains which might be difficult to get exact numbers, however, as per human-factor studies; we could get notional times to determine the bottlenecks.

For example, Level 1 fusion, *Orient*, or Comprehension/Projecting requires the most time in analysis (input delay), has the largest impact (amplitude) in the decision making and demarcates the first button press. The orient phase takes the most time to provide a set of prioritized actions (output delay). The final step of action selection requires the least amount of delay and amplitude as most other options have been removed to produce a single parameter control loop.

MATLAB Functions:

```
sys1 = ss (A, B, C, D, 'InputDelay', TDi)
sys2 = ss (A, B, C, D, 'InputDelay', TDo)
```

To detail C-OODA modeling, we describe the system time response over the interval that a decision could be made (similar to a probability distribution model for the timeliness of action as represented by the exponential decay). We utilize the testing input and output (I/O) time delays for the button presses for each OODA component separately, to model the contributions to the overall time response. Figure 6 is a *notional* result of the OODA timing responses. Figure 6 shows a time response function including the I/O delays used to reach a decision and the ability to evaluate and execute the decision at each C-OODA stage.

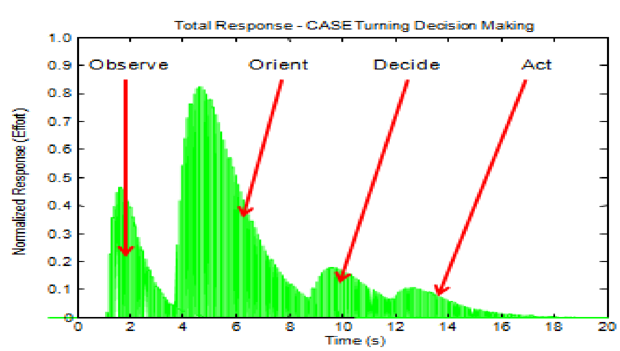

Figure 6. Delay Responses in C-OODA Decision Fusion

In our test, we are interested in the time decision points before and after the orient phase in understanding the risk with the emerging scenario.

Test Results

5.1 "Reaction" Test Results

One of the often repeated accidents is engine loss after take-off. The pilot usually taxies to the beginning of the landing strip, sets maximal revolutions-per-minute (RPM), builds speed and takes-off. In this moment, the engine works at full power and could some components to fail. The failure causes the airplane to lose engine trust, and the pilot is forced to level the flight and search for a landing strip. The recommended solution of this situation is to continue in the straight flight and land directly in the course of the start.

Two scenarios are presented with engine loss after take-off (1) turning at 137s and (2) increase of roll angle at 162 s [15]. Table 2 shows results of this scenario testing while its graphical representation is depicted in Figure 7 where the positive number means premature identification and negative number represents identification after the special time mark TK_i. For example, an unacceptable solution (FAIL) is when pilot starts a U-turn and tries to return back to the airport. It happens that during the U-turn the airplane wing loses lift, falls into tailspin and crashes to the ground.

Table 2. Reaction Delays from Subjects [39]

Subject	Event Situation 1 [s]	Event Situation 2 [s]
s001	141.34	164.49
s002	FAIL	FAIL
s003	137.00	FAIL
s004	137.97	168.60
s005	137.86	157.06
s006	FAIL	166.83
s007	135.91	156.60
s008	FAIL	158.49
s009	134.49	165.63
s010	138.49	155.97

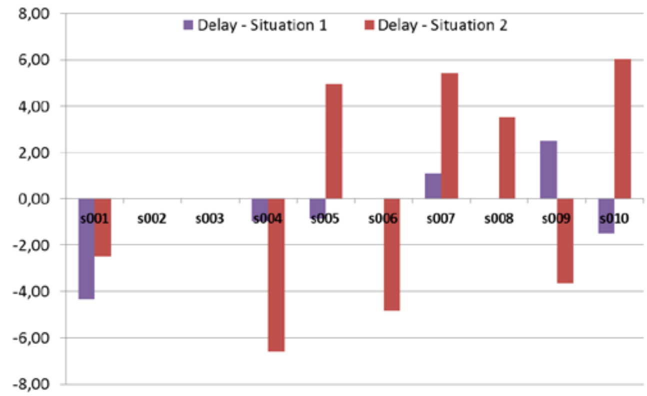

Figure 7. Reaction Delay Presentation [39]

There are two moments in this scenario in time 137 sec. and in time 162 sec. The first time represents an event where the airplane starts turning after engine failure and the second time-stamp represent event where the pilot adds significant roll angle. Figure 5 shows the tested pilot's precise times where the airplane started turning as a potentially dangerous moment. The second event, where roll angle was introduced, was determined with much higher uncertainty.

5.2 "Flight" Test

The flight tests evaluate pilot's ability to fly an airplane with regards to the physical laws of airplane characteristics. The test can be performed with different configuration files that represent different airplane characteristics. Figure 8 shows the actions performed during the testing procedure [15]. After an inbrief, the pilot is introduced to the testing scenario where he is supposed to perform a requested maneuver, e.g. proper start, navigation flight between given points, landing circle, or landing itself. The pilot's performance is assessed precision timeliness of the pilots flying abilities. The evaluation method compares the time series of events showing the pilot's decision making over time. The evaluation is performed according to flight along with the flight data:

- Flight limits (multiples of g-force)
- Aero dynamical limits (speed/altitude limits)
- Pitch and roll angles (aircraft attitude)

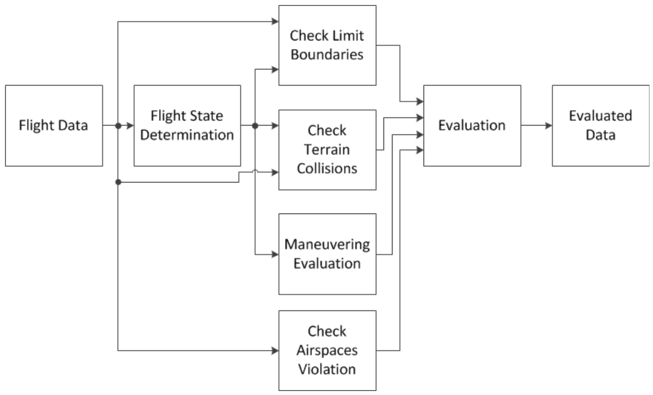

Figure 8. Interconnection of the Computing Modules Collaborating on the Evaluation

These parameters (limits) change according to the actual stage of the flight, e.g. taxiing, take-off, approach, landing, taxiing, etc. The automatic flight evaluation is performed by CASE computing modules which are designated to different aspects of the flight.

The evaluation of the test data is shown with the C-OODA modeling in Figure 9. For the subjects modeled, the interesting cases are S007 in which the subject assesses the situation and leads in taking corrective action. Subject S003 takes immediate action while S001 has a slight delay. S002 takes no action which could be from determining no action is needed or is unsure which results in an unsafe outcome. The key to the analysis is that the timeliness in the C-OODA orientation phase determines the resulting actions as shown by the blue line in Figure 9.

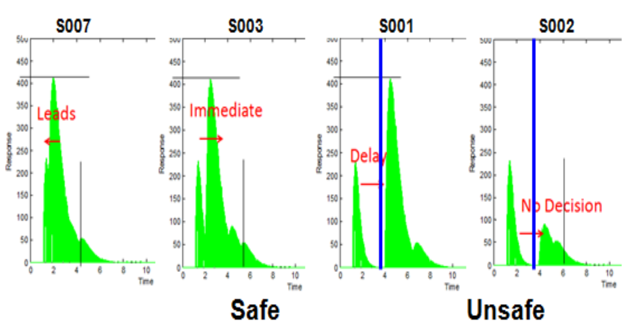

Figure 9. C-ODDA Modeling for Timeliness of Decision Making with Attributes of Orientation

Further analysis is needed beyond just timeliness of actions. For example, test subject S002 did not mark any of the events as potentially dangerous because, based on his knowledge he came to decision the maneuver being performed is possible to safely finish. It is worth to note this pilot was the most experienced pilot from the group. Using the modeling, along with the CASE simulator can lead to more exhaustive studies available in the Accident Handbook.

Future uses of the methods could look at exploring the pilot interface and designing warning systems if the pilot has a delayed reaction or takes too long for a given circumstance. Testing display indications over different types of failures would lead to different forms of corrective actions.

Conclusion

The paper describes a system for a complex evaluation of pilot's performance during flying an airplane using the CTU simulator. The CASE evaluation in [15] was extended with modeling human decision making with the C-OODA model.

Past accidents described in airworthiness bulletins were used to design different scenarios to understand how a pilot to learns to recognize potentially dangerous situations. Providing the pilot with an accident handbook before the flight test affords cognitive preparation for situation awareness and recognition primed decision making in the C-OODA modeling.

The CASE system evaluates how precise the pilot is with identification of the situation and timeliness analysis was evaluated by the decision making time stamps. The test includes the pilots' abilities to recognize potentially dangerous situations and is evaluated based on the time difference between the time-stamp generated by the pilot and the referential time-stamp in the scenario dataset. Four phenomena were modeled with leading, immediate, delay, and no action results over inexperienced and experienced test subjects.

Future tests will look at different accident cases over various failures evident in the aviation industry. The tests, included with display warnings, could better understand pilot decision making and ways to enhance cockpit designs and methods of support such as visualization from air traffic controllers [40].

References

[1] R. Oliva, E. Blasch, R. Ogan, "Applying Aerospace Technologies to Current Issues Using Systems Engineering, 3rd AESS Chapter Summit,"

IEEE Aerospace and Electronic Systems Magazine, Vol. 28, No. 2, Feb. 2013.

[2] E. Blasch "Assembling a distributed fused Information-based Human-Computer Cognitive Decision Making Tool," IEEE Aerospace and Electronic Systems Magazine, Vol. 15, No. 5, pp. 11-17, May 2000.

[3] E. Blasch "User refinement in Information Fusion", Chapter 19 in Handbook of Multisensor Data Fusion 2nd Ed, Eds. M. E. Liggins, D. Hall, and J. Llinas, CRC Press, 2008.

[4] P. Pačes, L. Jelínek, R. Jaroš, R, "LUN 1794 Converter - Special Functions," in Proceedings of International Scientific Conference Measurement, Diagnostics and Reliability of Avionics Systems, p. 55-66, 2008-0.

[5] P. Pačes, K. Draxler, "Airborne Electronic Equipment and Software Certification in the Czech Republic," In Nové Trendy Rozvoja Letectva - Zborník 7. Medzinárodnej Vedeckej Konferencie. Košice: Slovenský Letecký Inštitút a. s., 2006.

[6] Joint Aviation Authorities, Flight Crew Licensing, 2006, [Online] . Available at: http://lis.rlp.cz/predpisy/predpisy/dokumenty/Jar/JAR-FCL_1/index.htm. [Cited: 10. 5. 2013] .

[7] European Aviation Safety Agency, Annual Safety Review 2011. [Cited: 8 Oct. 2014] . Available at: http://easa.europa.eu/communications/docs/annual-safety-review/2011/EASA-Annual-Safety-Review-2011.pdf.

[8] D. J. Kenny, "National Report -2010 Accident Trends and Factors for 2009,“ AOPA Air Safety Foundation, 2010.

[9] D. Galler, G. Slenski, "Causes of aircraft Electrical Failures," IEEE National Aerospace and Electronics (NAECON), 1991.

[10] P. Bojda, M. Dub, "Concept of a complex navigation signal generator," IEEE/AIAA Digital Avionics Systems Conference (DASC), 2012.

[11] P. Bojda, "The GNSS Signal Phase Measurement to Determine the Trajectory Disturbances for a Small Air Vehicle," IEEE/ION Position Location & Nav. Symp., 2012.

[12] J. Leuchter, "Investigation EMC Compliance with Aircraft Communication System and Switch-Mode Power Supplies," IEEE/AIAA Digital Avionics Systems Conference, 2013.

[13] P. Pačes, M. Hruška, O. Bruna, "A Methodic for Objective Evaluation of Flight Quality and Pilot's Ability to Recognize Emergency Situations. a Certified Methodic Under Certification Process," CTU in Prague, FEE, 2013.

[14] O. Bruna, P. Paces, "the Most Often Aircraft Accidents – Model Situations,“ CTU in Prague, Prague, 2012.

[15] P. Paces, M. Hruska, O. Bruna, "A Tool for Objective Evaluation of Pilot's Ability to Determine Dangerous Flight Situations," IEEE Digital Avionics Systems Conf., 2013.

[16] E. P. Blasch, D. A. Lambert, P. Valin, M. M. Kokar, et al., "High Level Information Fusion (HLIF) Survey of Models, Issues, and Grand Challenges," IEEE Aerospace and Electronic Systems Mag., Vol. 27, No. 9, Sept. 2012.

[17] E. Blasch, I. Kadar, J. Salerno, M. M. Kokar, S. Das, G. M. Powell, D. D. Corkill, et al., "Issues and Challenges in Situation Assessment (Level 2 Fusion)," J. of Advances in Information Fusion, Vol. 1, No. 2, pp. 122 - 139, Dec. 2006.

[18] E. P. Blasch, E. Bosse, and D. A. Lambert, High-Level Information Fusion Management and Systems Design, Artech House, Norwood, MA, 2012.

[19] D. S. Fadok, J. Boyd, and J. Warden Air Power's Quest for Strategic Paralysis. Maxwell Air Force Base AL: Air University Press, (AD–A291621), 1995.

[20] E. Blasch, "Situation Impact and User Refinement", Proc. SPIE 5096, April 2003.

[21] E. Blasch, "Proactive Decision Fusion for Site Security", Intl. Conf on Info. Fusion, 2005.

[22] E. Blasch, P. Valin, E. Bosse, M. Nilsson, J. Van Laere, and E. Shahbazian, "Implication of Culture: User Roles in Information Fusion for Enhanced Situational Understanding," Intl. Conf on Info. Fusion, 2009.

[23] M. Nilsson, Capturing Semi-Automated Decision Making: the Methodology of CASADEMA. Doctorial Thesis, Orebro Univ., Sweden, 2010.

[24] M. Wohler, A. Schulte, "On Board Assistant System for UAS Integration into Civil Airspace," In: AIAA Infotech@Aerospace Conference 2013.

[25] A. Rauschert, A. Schulte, "Cognitive and Cooperative Assistant System for Aerial Manned-Unmanned Teaming Missions," In: Supervisory Control of Multiple Uninhabited Systems – Meth. Enabling Human-Robot Interface Tech.. NATO RTO Task Group HFM-170 Report, 2012.

[26] M. R. Endsley, "Design and Evaluation for Situation Awareness Enhancement," Proc. of the Human Factors Soc. Ann. Mtg. 1988.

[27] M. R. Endsley, "Toward a Theory of Situation Awareness in Dynamic Systems", Human Factors J., 37(1), 32-64, March 1995.

[28] G. A. Klein, "Recognition-Primed Decisions," In W. B. Rouse (Ed.), Adv. In Man-Machine Systems Res.: Vol.5. JAI Press, 1989.

[29] E. Blasch and S. Plano, "DFIG Level 5 (User Refinement) Issues Supporting Situational Assessment Reasoning," Int. Conf. on Info Fusion, 2005.

[30] E. Blasch, "Level 5 (User Refinement) issues supporting Information Fusion Management" Int. Conf. on Info Fusion, 2006.

[31] E. Blasch, R. Breton, P. Valin, and E. Bosse, "User Information Fusion Decision Making Analysis with the C-OODA Model," Int. Conf. on Info Fusion, 2011.

[32] E. Blasch, "Sensor, User, Mission (SUM) Resource Management and Their Interaction with Level 2/3 Fusion" Int. Conf. on Info Fusion, 2006.

[33] H. Ling, L. Bai, et al., "Robust Infrared Vehicle Tracking Across Target Pose Change using L_1 Regularization," Int'l Conf. on Info Fusion, 2010.

[34] Y. Wu, et al., "Multiple Source Data Fusion via Sparse Representation for Robust Visual Tracking," Int. Conf. on Info Fusion, 2011.

[35] J. Salerno, E. Blasch, M. Hinman, and D. Boulware, "Evaluating Algorithmic Techniques in Supporting Situation Awareness," Proc. of SPIE, Vol. 5813, 2005.

[36] E. Blasch, P. Valin, et al., "Measures of Effectiveness for High-Level Fusion," Int'l Conf. on Info Fusion, 2010.

[37]P. C. G. Costa, K. B. Laskey, et al., "Towards Unbiased Evaluation of Uncertainty Reasoning: The URREF Ontology," Int. Conf. on Info Fusion, 2012.

[38]E. Thöndel, "Design and Optimal Control of a Linear Electromechanical Actuator for Motion Platforms with Six Degrees of Freedom," Intelligent Automation and Systems Engineering, Springer, 65-77, 2011,

[39] E. Thöndel, "Design and Optimisation of a Motion Cueing Algorithm for a Truck Simulator," In Proc. European Simulation and Modelling Conference, Pp. 165-170. 2012.

[40] O. Bruna, T. Levora, P. Paces, "Subjective Stress Rating in Use of EFIS Systems on Board of Ultra-Light Aircraft," Proc. of the Int'l Conf. on Mil. Technologies. p. 979-984. 2013.

[41] E. P. Blasch, "Learning Attributes For Situational Awareness in the Landing of an Autonomous Aircraft," IEEE Digital Avionics Systems Conference, 1997.

[42] P. Makula, J. Leuchter, "Investigation and Measurement Of Aircraft Communication System Immunity," AIAA/IEEE Digital Avionics Systems Conference, 2012.

[43] E. Blasch, "Enhanced Air Operations Using JView for an Air-Ground Fused Situation Awareness UDOP," AIAA/IEEE Digital Avionics Systems Conference, 2013.

Acknowledgements

This work was supported in part by AFOSR for Dynamic Data-Driven Application Systems and research program no. TA01030651 "Safety Improvement of Flight, Crew and Other Participants of Flight Transport in Normal and Emergency Situations by Assistive Technologies" of the Czech Technical University in Prague, sponsored by the Technological Agency of the Czech Republic and partially by the project no. SGS12/193/OHK3/3T/13 "Safe and Safety Elements in Aerospace and Space Technology" of the CTU in Prague, sponsored by the Ministry of Education, Youth and Sports of the Czech Republic.

33rd Digital Avionics Systems Conference

October 5-9, 2014