Federal Aviation
Administration

International Journal of Applied Aviation Studies

A Publication of the FAA Academy Oklahoma City, Oklahoma

Volume 9, Number 1, 2009

2009 International Journal of Applied Aviation Studies Volume 9, Number 1 A publication of the FAA Academy

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International Journal of Applied Aviation Studies
Kay Chisholm
AMA-800
PO Box 25082
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International Journal of Applied Aviation Studies
Volume 9, Number 1
ISSN Number: 1546-3214
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1st Printing July, 2009

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PHILOSOPHY STATEMENT

Cornelius Lanczos, a mathematician working in the field of applied analysis, expressed the history of mathematics in three phases:

1) A given physical situation is translated into the realm of numbers,
2) By purely formal operations with these numbers certain mathematical results are obtained, [and]
3) These results are translated back into the world of physical reality (1988, p. 1). [1]

Formal papers, in subjects related to aviation, roughly follow the same course. However, there appears to be a weakness in aviation research, that being the omission of the third phase.

It is not good enough that conclusions are drawn, if those conclusions fail to improve the system observed. Clearly, the observed have a say in implementing the conclusions of research, but their failure to implement the conclusions drawn by the researcher may be more indicative of a lack of understanding than a lack of desire. Researchers tend to peer into complex systems as through a soda straw, forming formal opinions on the finite without understanding the complete system. Industry, ever mindful of the complete system, may find research irrelevant, because it makes much to do about nothing.

The editorial staff, to include those listed as consulting editors, is committed to the improvement of all individuals within the aviation community. We seek to enhance existing systems bearing in mind that small improvements must not upset the delicate balance between too little and too much help. We also seek to promote safety, not by lip service, but by demonstration in how we execute our studies and how we report our findings.

We feel that the best way to translate results back to the physical world is to incorporate the viewpoints of people around the globe. Without the influence of a worldwide community, we deny the significance of diversity, and ignore the perspectives of gifted scientists from different countries. It is our hope that each reader will feel the same.

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[1] Lanczos, C. (1988). Applied Analysis. Mineola, NY: Dover Publications, Inc.

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EDITOR'S NOTES

Papers

Twenty years ago, we expected James Bond to have a cell phone -- not our 12 year old. Our lead article, *Flying Glass: a Qualitative Analysis of Pilot Perceptions of Automated Flight-Decks after 20 Years* by Jim Mitchell, Leopold P Vermeulen, and Prevendren Naidoo, investigates the evolution of pilot attitudes and perceptions regarding automated flight decks. Their study focuses on several themes: situational awareness, automation and technology, skills, stress, workload, and computer literacy. As we appreciate the added convenience of new technology, pilots overall have positive perceptions of the *glass cockpit.* However, pilots still have concerns about the potential over-reliance and the pervasiveness of computerized technology on the flight deck.

Rapid recognition of conflicts and a better overview of the respective flight levels are some of the positive benefits experienced by Air Traffic Contollers in Simone Sporer-Fellner, Holger Flühr, Martin Haider, Peter Kappertz, and Horst Hering's *Evaluation of a Mobile Horizontal Radar Display Filter for Air Traffic Controllers.* The mobile horizontal radar display filter allows controllers to quickly select and change the requested flight level by scrolling an Operational Display System (ODS) mouse wheel. Using a multi-method approach, the authors conducted an experimental simulation study of human factors to investigate the mobile horizontal radar display filter called *WHEELIE.*

Jeffrey A. Boyd, Ellen J. Bass, James C. McDaniel, *and* Roland Bowles present their work on the implementation of *A Framework for Analyzing Simulated Aircraft Wake Vortex Encounters.* This software runs on a standard workstation. Two analyses are conducted as a proof-of-concept using a Boeing 757-200 follower aircraft. This work demonstrates the flexibility of the framework's software implementation as its ultimate purpose is to aid researchers studying wake vortex encounters.

Where are the ethical aviators? In *Moral Development in Pilot Populations,* Erica Diels, Gary Northam, and Brian Peacock examined three groups of pilots to determine moral development levels. Aviation faculty pilots demonstrated a higher degree of moral development. Instructor and student pilots scored lower than expected. The authors suggest a need for ethics training in aviation curricula.

Dennis R. Hannon's paper on the *Integration of a Fiber Optics Mini-Course into an Existing Aviation Electronics Technology Curriculum* examines the process of integrating fiber optics training into the avionics curriculum of the Southern Illinois University avionics program and comments on its methods and results.

Book Reviews

The Multitasking Myth: Handling Complexity in Real-World Operations by Loukia Loukopoulos, Key Dismukes, and Immanuel Barshi**,** caught the attention of two of our editors, Barbara K. Burian and John C. Di Renzo Jr. Enjoy Barbara and John's different perspectives on this recommended book.

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International Journal of Applied Aviation Studies, Volume 9, Number 1
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Flying Glass: A Qualitative Analysis of Pilot Perceptions of Automated Flight-Decks After 20 Years

Jim Mitchell

School of Management
University of Western Sydney
Sydney, Australia
j.mitchell@uws.edu.au

Leopold P Vermeulen,
and
Prevendren Naidoo

Dept of Human Resource Management
University of Pretoria
South Africa

Abstract

In 1991, 2001, and 2008 surveys were conducted to determine pilot perceptions of automated flight decks or "glass cockpits." Results from these similar surveys indicated that a number of factors identified remained the same. However, over time, some changes in perceptions were noted. The 2008 survey provided airline pilots the opportunity to write comments and express their ideas and concerns about aspects of the glass cockpit. This paper provides a qualitative analysis of their comments identified as a number of themes. Their perceptions of themes such as situational awareness, automation and technology, skills, stress, workload, and computer literacy are examined. Overall, the perceptions of the glass cockpit are positive. However, there remains an underlying caution concerning several aspects of piloting including perceived loss of manual flying skills, stress, and extreme workload resulting from the potential over-reliance and pervasiveness of computerized technology on the flight deck.

Requests for reprints should be sent to Kay Chisholm, FAA Academy, AMA-800, P.O. Box 25082, Oklahoma City, OK 73125. E-mail to kay.chisholm@faa.gov.

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Flying Glass: A Qualitative Analysis of Pilot Perceptions of Automated Flight-decks after 20 years

During the 1970s and 1980s there was a rapid development of automated apparatus, which were being incorporated in large aircraft. Significant developments included inertial navigation systems (INS), flight guidance systems, auto-throttle systems, ground proximity warning systems (GPWS) and various crew alerting systems (Wiener, 1989). In general terms, the new technology manifested itself as "the glass cockpit (displays driven by computer graphic systems)" (Wiener, 1988, p. 435). Wiener (1989) also indicated that as the level of automation increased there was "a growing discomfort that the cockpit may be becoming too automated" (p.1). Issues such as an over-dependence on automation, deteriorating flying skills, and diminished situational awareness began to be considered. Since the late 1980s considerable research has been given to the impact of new technology and pilots' attitudes towards automation on flight decks. Particular research focus was on training, that is, the conversion of pilots from the use of gauges to operating automated systems, safety, design aspects, situational awareness, the role and responsibilities of pilots, workload, levels of skill, and operational aspects (James, McClumpha, Green, Wilson & Belyavin, 1991).

Over a period of seventeen years (1991, 2001, and 2008) three similar surveys have been conducted in order to assess pilot attitudes or perceptions on issues of flight deck automation. The results of the first two surveys have been published as journal articles and the third formed the basis of a Master's thesis. This article provides a brief comparison of the quantitative results and then focuses on an analysis of the qualitative data from the 2008 survey.

The James et al. (1991) survey of active United Kingdom commercial pilots (n=1372), using principle components analysis of the five point Likert scale, identified four main factors. These were Understanding/Mastery, Workload, Design, and Skills and accounted for 31.48% of the total variance (James et al., 1991). Understanding/Mastery consisted of "comprehension, expertise, knowledge, and use of the system." Workload entailed "workload, demand, stress, and task efficiency." Design referred to "ergonomic efficiency, design and displays," and skills encompassed "handling skills, crew interaction, and self-confidence" (p.3.5). Among other things, the authors found pilots' perception of their own understanding and mastery was higher the more experience the pilots had on type and that younger (under 40 years of age) pilots felt they had a relatively better understanding of the glass cockpit systems. Attitudes towards the impact of computerization on workload tended to be favorable and more so among the older cohort. In respect to design, increased hours on type revealed a less favorable attitude due to the discovery of design shortcomings revealed in day-to-day operations. Older pilots were less concerned that there may be a degradation of skills due to automation. Because their skills were more ingrained, older pilots indicated that their situational awareness was better than the younger or less experienced pilots. Concerns that automation degraded flying skills were more strongly held among younger pilots.

Using an adapted version of the James et al. (1991) questionnaire, Singh, Deaton and Parasuraman (2001) surveyed 163 pilots at Embry-Riddle Aeronautical University. Retaining the five point Likert scale and principle components analysis, the researchers identified six factors: workload, design, skill, feedback, reliability, and self-confidence. Although there was "an overall inclination toward advanced automation," a majority of pilots indicated "there was too much automation in the advanced automated aircraft" (Singh et al., 2001, p. 210). The researchers also identified attitudinal differences between British and American pilots. "For example: British pilots prefer to fly advanced automated aircraft on which they rely too much, whereas Americans don't like automated aircraft and they least rely on them" (Singh et al., 2001, p. 210). Although conducted ten years apart there are similarities and differences in the results of the two surveys. Sample size and cultural differences, although not examined extensively, may account for attitudinal differences and perceptions of automation in the cockpit. A later survey is compared.

In 2008, a survey was conducted with South African airline pilots. Again, the questionnaire was adapted from the James et al. (1991) survey and took into account the ten critical issues (cf. http://www.flightdeckautomation.com) in relation to flight deck automation and operations (Naidoo, 2008). The researcher opted for a seven point Likert scale and an exploratory factor analysis was used. Shepherd (1998) contends that a seven or even a nine-point scale tend to give the items more granularity. This is supported by Gravetter and Wallnau (2002) who argue that using a larger number of intervals (seven in this case), allows the researcher to conduct a more accurate calculable investigation. The factors were identified as Comprehension, Training, Trust, Workload, and Design. Comprehension refers to the understanding of the flight management system and grasp of consequences relating to their actions and inputs. Training highlighted the need for a level of training for a pilot to acquire an adequate standard to operate automated flight deck systems. Trust indicates the confidence the pilot has in the automated systems. Workload refers to the ability of the pilot to program the various functions of the flight management systems. Design refers to the presentation of automated systems and includes ergonomic design, color, and ease of use.

Comparison of the factors identified by the three surveys indicates a strong commonality in the results. Workload, skills, and design are common labels with understanding/mastery, self-confidence, and comprehension sharing similar components. Feedback, reliability, and trust also appear to share common items. Overall, the results indicate that common threads permeate pilot perceptions of automated flight decks. These are consistent over time even allowing for differences in national cultures. Table 1 compares the factors identified by the three surveys.

Table 1

Comparison of factors in three surveys

	Survey		
	James et al. (1991) (UK)	Singh et al. (2001) (USA)	Naidoo (2008) (South Africa)
Factors	Understanding/mastery Workload Design Skills	Workload Design Skills Feedback Reliability Self-confidence	Comprehension Training Trust Workload Design

Aim of the Study

The Naidoo questionnaire also allowed written comments to assess the airline pilots' perceptions of flight deck automation. Section 3 of the questionnaire consisted of two open-ended questions. Here the respondents were provided with an opportunity to list the various aircraft types they have had experience on and to provide either positive or negative comments on their experience in operating glass-cockpit aircraft. This section offers additional information for a qualitative analysis of the written statements from the participants. The analyses of these written comments from pilots operating aircraft of the highest level of automation (such as B737-800 and A320) will enhance the quantitative analysis of the three surveys and add to our insight into and deeper understanding of pilots' subjective experiences of flying glass. In the light of the above discussion, the aim with this study was to explore and describe the views of a sample of South African airline pilots regarding their subjective experiences of the advance glass-cockpit environment.

Method

Research approach

A qualitative research design was implemented to ensure that the primary aim of this study was successfully achieved. Although there is no agreement on an exact definition of qualitative research (Strauss & Corbin, 1990), this study can be considered qualitative in nature. According to Marshall and Rossman (cited in Wilson 1998, p. 2) qualitative research is divided into four taxonomies: exploration, explanation, description, and prediction. In descriptive research, the phenomenon under investigation can be described in such a way that the readers understand the experiences, perceptions, views, and feelings of participants. In this study, the descriptive approach was used to analyze, describe, and give meaning to the salient themes and patterns related to airline pilots' experiences and perceptions of flight-deck automation.

Credibility as a criterion was strongly imposed during the design, data collection, analyses, and reporting phases of the study. The term credibility replaces validity in qualitative research (Pitney, 2004). To enhance the credibility of the investigation all participants were assured of the confidentiality and anonymity of the research process, all the biographical information and comments of the participants were documented in a standardized format, and a uniform process was used to analyze the content of written comments. Furthermore, the analysis of the data and interpretation of the results was done by the expert qualitative researcher in the team, while the other researchers provided critical input during the design, execution, and reporting phases of the study.

Participants

The research group represented a purposive sample of current airline pilots at a major South African carrier operating both Airbus and Boeing type aircraft. Two hundred and forty five male pilots and 17 female pilots responded to the 2008 Naidoo survey, of which 172 provided written comments of their views and experiences in operating glass-cockpit aircraft. Table 2 outlines the biographical data of those respondents who wrote of their perceptions of the glass cockpit and other concerns.

Table 2

Respondent biographical data

Respondents		Males	Females	Total
		163	9	172
Age	– Average	45.6	31.8	45.1
	- Range	26 - 62	25 - 42	25 - 62
Years Exp.	– Average	25.4	12.0	24.9
	- Range	4 - 46	5 - 25	4 – 46
Total Hours	– Average	13147	5556	12908
	- Range	1500 - 27000	2700 - 14000	1500 - 27000
Digital Hours	– Average	4968	3278	4945
	- Range	13 - 14000	1700 - 7000	13 - 14000

As expected, male pilots outnumbered female pilots by around 14 to 1 (7.1%). Internationally, females represent about 5.2% of the airline pilot population (Kristovics, Mitchell, Vermeulen, Wilson & Martinussen, 2006). Females who responded are, on average, younger and therefore are less experienced in both flying hours in non-glass cockpit aircraft and glass cockpit (digital) aircraft.

Data collection and procedure

The data gathered was qualitative in nature and consisted of written comments that included 11,579 words. The participants' commentaries vary from a five-word statement to a 385-word essay concerning their glass cockpit experiences. All biographical data and comments were recorded, initially in an Excel spreadsheet, and then the comments were transferred to a Word document and uploaded into a computer-aided data analysis program. To ensure dependability (reliability) of the findings, crosschecks were done by the researchers during the capturing and transfer of the original data. In qualitative research, the term dependability is more appropriate than reliability because the aim is not to ensure the replication of the study, but whether the findings are reasonably based on the original data (Pitney, 2004).

Data analyses

Various qualitative analysis procedures and interpretive techniques are available. In order to bring structure and meaning to the large volume of collected data in this study, it was decided to employ computer-aided qualitative data analysis software (CAQDAS). CAQDAS is typically used in projects that have non-numerical, unstructured data, such as data in the form of text, e.g. transcripts from interviews, essays, written comments, graphics, and other multimedia formats. The researchers decided on using the NVivo 8® software package to analyze the data. NVivo 8® is software program for qualitative text analysis and is designed to assist researchers organize, manage, code, and analyze qualitative and mixed-methods research data. This program was used to facilitate the uncovering of the multifaceted themes hidden in the data. Initially, the factors identified in the three surveys were anticipated as themes that would occur in the comments. The document was then scanned for key words. Other themes were identified using key words and phrases that arose out of the comments. Comments were then coded against each theme and then analyzed. All comments from the survey quoted below are cited verbatim.

Results

The analysis of these comments revealed similar thoughts and concerns to those found throughout a number of writings such as in Hutchins, Holder & Hayward (1999); Funk, et al. (1999); and Knight (2007). While over a period of almost twenty years, it appears that there have been some significant changes in perceptions some concerns remain the same for “glass cockpit” pilots. The qualitative analysis resulted in the identification of 17 major themes within the document. Table 3 identifies the themes and the breakdown between male and female pilots in the number of references within each theme.

Table 3

Breakdown of major themes between male and female airline pilots

	Males	Females	Total
Glass cockpit	93	3	96
Use of Acronyms	73		73
Situational awareness	60	7	67
Aircraft type	66		66
Skills	52	3	55
Automation	44	3	47
Safety	34		34
Training	29		29
Operations	23	1	24

Stress	20	1	21
Technology	17		17
Workload	13	4	17
Failure	11	1	12
Experience	10	1	11
Manufacturers' Philosophy	9		9
Errors	6		6
Control	5		5

Table 4 details the breakdown of the comments by age for the six most mentioned themes. References to automation and technology have been combined, as have stress and workload. Combining stress and workload is consistent with the elements of the factors identified in the quantitative analyses of the 1991 and 2001 surveys. Comments from female pilots have been included in each total as there were only six females in the less than 35 and 3 in the 35-44 age groups.

Table 4

Comments by age for the six most mentioned themes

	Age Group				
Main Themes	Less than 35 (n=27)	35-44 (n=57)	45-54 (n=51)	55-65 (n=37)	Total
Glass cockpit	10	37	29	20	96
Situational awareness	12	22	20	13	67
Automation/ Technology Technology	9	19	24	12	64
Skill	4	21	19	11	55
Stress/ Workload	3	8	22	5	38
Safety	1	13	14	6	34
Total	39 (11.0%)	120 (33.9%)	128 (36.2%)	67 (18.9%)	354 (100.0%)

Acronyms and Aircraft

Aircraft make and type identified the manufacturer's aircraft and type the pilots had or were flying. Some comments reflected pilots' preference in terms of the aircraft they flew, that is, Boeing or Airbus. Similarly, while the use of acronyms was high, these mainly described, in "pilot speak," various technological aspects of the aircraft. Further, all occupations develop a discourse that is specific to the needs of the industry, the organization, and the occupation. Aviation pilots use a large number of acronyms as a shorthand method to identify various aspects of their work. Examples from the comments include OPS (operations), MCDU (multi-purpose control display unit), FMC (flight management computer), EFIS (electronic flight instruments system), PFD (primary flight display), EGPWS (enhanced ground proximity warning system), SOP (standard operating procedures), HUDS (heads up displays), FBW (fly by wire), and many others. In addition to the practical aspects of using the acronyms, it also provides the pilots with a discourse that readily identifies them as belonging to a professional body or "in-group" and excludes those who do not speak their language. To speak and understand the language provides individuals a level of legitimacy within that occupation or cohort.

Glass cockpit

Glass cockpit is defined as "an aircraft cockpit that has a number of multicolored displays instead of conventional instruments" (Kumar, DeRemer, & Marshall, 2005, p. 311). While references to the glass cockpit were the most common, they were often used to describe its role in relation to other themes. However, there were a number of instances where comments focused solely on the glass cockpit. "Glass cockpits are much more user friendly," "Glass cockpits provide a huge improvement," "Glass Cockpit is great," and "I love flying glass" are representative of the positive comments made about glass cockpits. There were no comments that could be construed as a negative in the pilots' view of the glass cockpit. It was seen as "the way forward" and that "Glass is the only way to go."

Situational Awareness

Clearly, references to the glass cockpit and situational awareness dominated the responses. The definition of situational awareness used in analyzing the comments is drawn from Endsley (1988) (cited in Garland, Wise, and Hopkin, 1999). "Situational awareness – the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" (p. 258). Not only were they the dominant themes, there is a strong association between them. Of the 96 references to the glass cockpit, 43 also referred to effective and increased situational awareness. Comments included "Glass cockpits provide a huge improvement in situational awareness when compared to older generation cockpits." "Situational Awareness is greater in the glass cockpit." "Far better situational awareness." "Glass-cockpit is excellent for situational awareness." The overall responses were strongly positive in the pilots' appreciation of the benefits of the glass cockpit in its enhancement of situational awareness. On the other hand, and in reference to younger, less skilled pilots, "Automation can mask a lack of situational awareness (also in younger pilots who lack skills)." Overall, their comments help to alleviate concerns expressed by Wiener (1989), Federal Aviation Administration (1996), and Ishibashi (1999) that diminished situational awareness could result from the introduction of glass cockpit technology. The loss of situational awareness remains a possibility regardless of pilot attention as happened in the recent Turkish Airline crash (The Boeing Company, 2009). Female pilots' comments were favorable to an increase in situational awareness when flying glass cockpit aircraft. Comments generally were evenly distributed over the various age groups. Younger pilots tended to have fewer comments in these areas.

Automation and Technology

While initially identified as separate themes, references to automation and technology revealed a use of the terms interchangeably. Wiener (1988, p. 436) indicates, “By cockpit automation we generally mean that some task or portions of tasks performed by the human crew can be assigned, by choice of the crew, to machinery.” This included the use of computer technology. He also indicated the eight reasons for flight–deck automation:

1) Availability of technology
2) Safety
3) Economy, reliability, and maintenance
4) Workload reduction and certification of two-pilot transport aircraft
5) More precise flight maneuvers and navigation
6) Display flexibility
7) Economy of cockpit space
8) Special requirements of military missions (p. 444).

Continuing rapid development of high technology has provided a greater level of technological sophistication in today’s aircraft.

Comments on current automation and technology indicate a favorable opinion. These include “Never have too much automation.” “Thumbs up to Glass cockpit and automation.” “Best thing since sliced bread.” “Automation is vital for future air transportation.” “It is inevitable that aircraft become more automated to allow the pilot to manage better.”

There was also a strong undercurrent of caution in the application and use of automation and technology. “Automation on the other hand, can be taken too far.” “Technology is there to assist – not fly the aircraft. The technology is only as good as the information programmed into it.” “We however don’t need to [be] slaves of the automation.” “However crew need to guard against complacency and too much reliance on automation.”

Overall, comments about automation and technology were positive but had a cautionary undertone. This is a consistent theme over the 20 or so years since the introduction of the glass cockpit. These comments reflect concerns from Wiener (1988, 1989), James et al. (1991), Kabbani (1995), Endsley and Strauch (1997), Billings (1997), and Funk and Lyall (1999). It remains an issue today and probability will remain an issue as people from all occupations are confronted with the introduction of new technology and automation of mechanisms and procedures.

The overall distribution would suggest that pilots, regardless of age, tended to have similar perceptions and concerns as to the impact of the glass cockpit and its technology and automation. The continued development of technology and its applications in the design and manufacturer of aircraft would appear to draw continued concerns as new types of automation are built into aircraft. Future developments of unmanned aerial vehicles (UAV) in non-military environments may have broader concerns for the piloting profession (Baker, 2009).

Skill

Another theme discerned from comments was that of Skill. This theme was identified in 55 comments. The potential loss of flying skills due to the introduction of automation has attracted the attention many writers including Wiener (1989), James et al. (1991), Rudisill (1995), and Roessingh et al. (1999). A general concern was the loss of flying skills as automation took over many of the functions that previously determined the acquisition and level of piloting skills. As James et al. (1991) pointed out, automation reduced pilot involvement and potentially changed the nature of pilot involvement. Comments from the current survey confirm that there is still concern for the loss of skills. “Pilots can loose the basic flying skills required due to lack of ‘hands on’ actual flying.” “One loses [sic] flying skills.” “I miss the flying!! But realize this is the way to go.” “But manual flying skills deteriorate over time.” “Over automated which is, and will continue to degrade the pilots handling skill over time!” “Automation does degrade flying skills to a level lower than most professional pilots would like their own level to be.”

While in favor of the application of technology and automation as reflected in the generic glass cockpit there remains a concern for the loss of manual flying skills. Some suggested that they be allowed to “turn off” the automatics and fly the aircraft manually to retain these skills. As one suggested “to preserve basic flying skills, more encouragement should be extended to manually flown visual approaches at airfield with which the crew are well acquainted and when there is not increased pressure from other traffic.”

Stress and Workload

The level of workload has been identified as an important determinant of human error (Kantowitz & Casper, 1988). Human factors research found that people are most reliable under moderate levels of workload whereas extreme or sudden increases in workload increase the incidence of errors occurring. There was general agreement that the introduction of the glass cockpit and its associated technology and automation has reduced the levels of workload experienced by pilots. “Reduced workload.” “Reduces in-flight workload dramatically.” “It relieves you of some work load.” “Reduced the workload in the dynamic environment that has become more complex.” “Generally all the toys make life easier.”

A number of comments also linked the reduction in workload with a diminution in levels of stress and fatigue. “Modern automation greatly increases situational awareness at the same time reduces stress and fatigue.” “Overall workload during the flight is a lot less and less stressful.” “Automation allows for less stress in cockpit.” “Overall workload during the flight is a lot less and less stressful.” “Glass-cockpit aircraft definitely aid in ease of workload which helps reduce fatigue.” “Fatigue on long-haul flying is definitely reduced.” However, there was this comment. “You are more likely to become fatigued on the flight deck during long range cruise when there is virtually nothing to do compared to a less automated cockpit where there is more work for the flight deck crew to do.”

While there are periods of reduced workload, a concern for errors and failure of the automatics was expressed as being stressful. “High work load and stressful situations allow possible error factors to creep in.” “Biggest negative: the more sophisticated the system, the more stressful it is when it fails!” “A shortcoming of present automation systems (autopilots in case) is that they are not yet ‘intelligent’ enough to cope with extra-ordinary situations. These situations are still left to the skills of experienced or talented pilots."

An additional concern was that junior or relatively inexperienced pilots had difficulties in coping when the automatics fail and there is a corresponding increase in workload. "Junior pilots are not as experienced. That is why they cock it up in a glass cockpit when they remove the automation. It is pilot problem, not a place problem." "It is often noticeable with younger pilots rapidly gaining R/H seat status in large jets being less proficient than read [sic] with basic flying." "Younger pilots are far more comfortable with automation." "Automation can tend to lead to complacency especially in younger pilots with less hands-on experience." "Piloting skills are a function of AB initio training quality and experience levels, not exposure to 'glass'." It may be the case of a generational issue in that more experienced pilots see those with less experience as possibly contributing to errors and being unable to cope when the automatics fail.

Safety

Safety is always a concern in aviation. The survey conducted in 1991 by James et al. revealed a concern for flight safety from the introduction of automated systems. Issues such as the possibility of faulty data, difficulties in detecting malfunctions, unquestioning belief in the information presented, and complacency were identified. By 1995, research indicated that there was a general consensus that automation had increased the level of flight safety (Rudisill, 1995). Results from the current research indicate that glass cockpit aircraft were much safer to fly than non-glass cockpit aircraft. Comments include "Generally glass-cockpit aircraft have made airline flying a lot safer." "Probably the most important advancement the industry has made in the last ten years – the sky is a lot safer." "Automation increases safety to a large extent." "In general glass cockpits have made aircraft much safer and more reliable." "It is really helpful at the usual dangerous airfields in Africa."

While there is a general recognition of the benefits of automation to increase safety there was also an underlying concern. Complacency and over-reliance on the technology continues to be a worry for pilots. "In my opinion complacency is a threat and we need good self discipline in order to remain vigilant." "I believe that automation can easily lead to complacency. The pilot must exercise self-discipline in order not to be complacent and to stay ahead of the aircraft." "However, I strongly believe that complacency can creep in (and almost always does) where technology is relied upon too much. Young pilots are particularly susceptible to this in my view."

Training

Wiener (1989), and the two surveys by James et al. (1991) and Naidoo (2008), identified that the introduction of automation as having an impact on both the transitioning from automated to less automated aircraft and back and pilots training. Roessingh et al. (1999) raised issues concerning the identification of skills critical to the operation of glass cockpits. These included knowledge of automation/decision making, crew resource management, manual flying/determination of appropriate SOPs/knowledge of SOPs, and standard cockpit handling. Current pilot perceptions continue to identify training and transitioning as an ongoing problem for them. Many of the 29 comments were strongly worded. "The conversion from 'Traditional' to 'Glass' was grossly inadequate, rushed, insufficient technical cover-age, and very poorly managed." "The amount of information provided during training on technical aspects of the aircraft is insufficient." "Modern conversions are extremely frustrating and time consuming. Trying to understand some of the detailed and intricate systems is like trying to teach yourself calculus or trigonometry – it is possible but far from efficient or ideal."

Other comments were positive. "Pilots who have never flown 'glass' before find it extremely daunting before embarking on their conversion. However, the transition to glass could not be more simple." "Transition from conventional round-dial instruments cockpits to glass is over-rated." "Was told it is a difficult conversion and it was not!" The level of ease or difficulty involved in training and transition for the pilots may well be a function of their computer literacy and not their piloting skills. Details of the pilots' perceived level of their own computer literacy was sought through the Naidoo survey.

Computer literacy

Table 5 details the respondents' perceptions of their current computer literacy based on the ratings of excellent, above average, average, and poor. There is an assumption that the pilots are comparing themselves against the level of computer literacy of other pilots rather than that of the general population. The majority of both males (50.1%) and females (55.6%) rated their level of computer literacy as average while 7 (4.0%) males rated themselves as having poor computer literacy. Two pilots who rated themselves poor also made the following comments - "Found it a difficult transition initially, but very happy now" and "Airbus Automation slightly more sophisticated than Boeing but far more complex for pilots." "Easier for younger generation as they grew up with computers." A problem for pilots new to automation is for them to become "task-saturated," that is, focusing on programming information into the Flight Management System (FMS) and using the FMS during the flight (Meintel, 2004).

Those that rated themselves excellent, above average, or average had a range of both positive and negative comments, but there is little or no evidence that their level of computer literacy impacted their ease or difficulty during their training or transitioning to automated aircraft or back again. It would seem that pilots require specific and in-depth training in computer literacy both in the broad sense of understanding computers, and in a narrower sense of understanding the computerized technology of the aircraft. This is supported by Rigner and Dekker (2000) who identified that pilots require training of new knowledge in both technical and non-technical skills together with cross-cockpit coordination in the use of computers. Casner (2005) and Dekker and Nahlinder (2006) found that pilots who learned on small, but technically advanced aircraft, were readily able to transfer their learning and skills to large commercial jets.

Table 5

Respondents' perceptions of their current computer literacy

	Rating				
Gender/Age	Excellent	Above Average	Average	Poor	Total
Male					
<35	5	6	9	1	21
35-44	8	20	24	2	54
45-54	4	15	29	3	51
55-64	2	13	21	1	37
Total	19	54	83	7	163
Female					
<35	1	1	4		6
35-44	1	1	1		3
Total	2	2	5		9
Overall total	21 12.2%	56 32.6%	88 51.2%	7 4.0%	172 100.0%

Operations

Roessingh et al. (1999) identified Standard Operating Procedure (SOP) as an issue that needed to be addressed. They found that airlines utilize aircraft differently from how it was designed, were selective in its capabilities, and either prescribed the use of the automatics or left it to the crew's discretion. In the current survey, pilots were in favor of SOP. “SOPs are a vital part of the operation.” “Flight SOP is enhanced by well trained crew in a glass environment.” “Company SOPs have generally (in consultation with aircraft manufacturers, etc) been well thought out.” “If you don't apply the correct procedures on the flight deck then the glass cockpit and the FMS [Flight Management System] could be an accident waiting to happen.”

Others raised concerns about some aspects based on both the company and the aircraft manufacturers. “My company tends to be rather conservative & infeasible [sic] to constructive comments with regards to potential operational improvements. ‘More of an ear’ should be put towards pilots comments.” “The problem is our SOP's discourage us from hand flying and that do [sic] have a negative impact on confidence and ability to physically fly the aircraft.”

The application of SOPs also depends of the type of aircraft being flown and the manufacturer's philosophy underlying the aircraft's development and operations. Several pilots commented on these differences between Boeing and Airbus and displayed varying preferences. “Boeing mindset is better i.e. ‘when in doubt fly the A/C’ airbus's when in doubt use the automatics’ - Boeing philosophy keeps the pilot in the picture - airbus tries to remove him/her.” “1. Boeing FMS much easier to program and use than Airbus. 2. Airbus aircraft should have a single guarded switch to give a pilot full authority of flight controls if needed.” “I enjoy the Boeing philosophy because I still have the final say in the operation of the aircraft." "The Airbus operation of PF/PM [pilot flying/pilot monitoring] per sector is the way to go."

The different philosophies of the aircraft manufacturers, Boeing and Airbus, have an impact on the SOPs and the benefits and difficulties pilots experience in the daily operations. "The differences between Boeing and Airbus flight deck philosophies are mainly in the amount of control that is afforded the pilot." Pilots, in their view, need to be in control.

Overview

A quick review of the quantitative results from the three surveys indicates a high level of commonality of the factors identified. Differences in the number and labeling of factors may be the result of the modifications made to the 1991 survey that manifest themselves in the 2001 and 2008 survey results. However, the content of each factor gives the results their commonality. The qualitative analysis of the 2008 survey provides an extension and enhances the quantitative analysis of the three surveys. As indicated in the quantitative analysis, workload, skills, and design are common labels with understanding/mastery, self-confidence, and comprehension sharing similar components. Feedback, reliability, and trust also appear to share common items. The qualitative analysis addressed the major issues identified by airline pilots.

Generally, in all themes identified, pilots possessed positive perceptions of glass cockpits. While they were mainly positive, there was a concern or underlying caution about certain aspects of flying glass. They recognized that the introduction of computerised technology that manifests itself as the glass cockpit was of benefit and, overall, improved the nature of the work. The greatest benefit, as they saw it, was improved situational awareness. Many of the pilots identified this benefit but they were also well aware of the limitations and problems that could arise. These situational awareness problems such as complacency and over reliance on the technology were identified as occurring primarily with younger, less skilled pilots. However, this did not exclude the older, more experienced pilots from being immune from loss of situational awareness. Another major issue was the perceived loss of skills, particularly manual flying skills. There was a genuine concern for the diminution of skill levels among the pilots. Being able to "turn off" elements of the technology and fly manually, and being allowed to do so via the airline's SOPs, was seen as a possible solution. Another solution may involve aircraft manufacturers rethinking their philosophical approach to aircraft design.

Excessive stress and extreme workload caused by systems failures retain a level of concern. These were countered by a majority of opinions that saw stress and workload being generally at a lower level than in conventional aircraft. Similarly, safety was recognized as being improved by the utilization of appropriate technology. Again, the concern for safety was linked to complacency, an over-reliance on the technology, and a loss of situational awareness. Linked to this was the identification of poor or inadequate level of training, particularly during the transition stage from conventional to automated flight decks of which the level of understanding of computer technology played a part.

The 2008 survey of South African airline pilots sought information on their perceived levels of computer literacy. Although only 4% indicated that their computer literacy was poor, overall comments indicated that their confidence and ability in the understanding and use of computers could have been better. This has implications for training other than flight training, and the results indicate that an in-depth level of understanding and use of broader computer technology and applications would be of benefit. This would help, for example, in understanding the different approaches to automating the flight deck adopted by both Boeing and Airbus. Pilots had their personal preferences to the type of aircraft flown and the SOPs appropriate to each aircraft but there seemed to be a general agreement that, ultimately, the pilot should have control of the aircraft and not leave it to the computer to fly the aircraft.

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International Journal of Applied Aviation Studies, Volume 9, Number 1
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Text Communications in Single-Pilot General Aviation Operations: Evaluating Pilot Errors and Response Times

Randal J. DeMik

Lewis University
Romeoville, IL

Abstract

The researcher examined how the introduction and application of text-based Controller-Pilot Data Link Communications (CPDLC) technology will affect human performance in the single-pilot general aviation work environment. Instrument-rated pilots (N = 30) were tested on both a series of CPDLC text command tasks and a series of conventional voice command tasks in a simulated flight environment. Results revealed a statistically significant decrease in both errors in pilot recall/execution and response times in moving from the conventional voice ATC commands to the CPDLC text commands. Results lend support for a text-based communications technology that extends pilot's working memory, thereby improving both accuracy and efficiency in performing flight tasks to complex commands.

Requests for reprints should be sent to Kay Chisholm, FAA Academy, AMA-800, P.O. Box 25082, Oklahoma City, OK 73125. E-mail to kay.chisholm@faa.gov.

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Text Communications in Single-Pilot General Aviation Operations Evaluating Pilot Errors and Response Times

Representatives of the aviation community are interested in implementing alternatives to the conventional voice exchanges between air traffic controllers and pilots. One of these alternatives is to implement a Controller-Pilot Data Link Communication (CPDLC) system. Unlike conventional voice-based air traffic control (ATC) communications technology, the CPDLC system allows pilots and controllers to exchange text-based messages via specifically designated data links, thereby reducing voice communication congestion (Baik & Trani, 2005). The current CPDLC technology uses a Very High Frequency (VHF) or satellite communication link to route text messages that are displayed on the Flight Management System (FMS) or Aircraft Communication Addressing and Reporting System (ACARS) screens in the cockpit (Nolan, 2004). In a study by Kerns (1991), the perceived benefits of CPDLC included an improved clarity and efficiency of communication, reduced number of misunderstood communications, expanded airspace capacity, freeing up of frequencies used in voice communications, and reduced pilot and controller workload.

In the current National Airspace System (NAS), the bulk of exchange between controllers and pilots is carried out by voice communication. Flight operations in the NAS depend on the timely and accurate exchange of information between ATC and pilots in the cockpit (McGann, Morrow, Rodvold, & Mackintosh, 1998). According to Helleberg and Wickens (2003), “data link is one of the new technologies designed to replace or alter more traditional information exchanges between the pilot and ATC” (p. 1). Wickens, Mavor, Parasuraman, and McGee (1998) reported on the challenges facing the NAS and determined the need to upgrade the system through advances in technology. The next generation air transportation system (NGATS) concepts were committed to significantly enhancing airspace capacity, primarily through the application of new information technologies, communication technologies, and navigation technologies (Borener, Carr, Ballard, & Hasan, 2006; Erzberger, and Paielli, 2002).

Several researchers addressed the problem of human error in voice-based controller-pilot radio communications technology. Morrow, Lee, and Rodvold (1993) reported the vulnerability of ATC radio communication as primarily that of errors in speech perception and human working memory. Billings and Cheaney (1981) found that eighty percent of pilot information transfer problems in the cockpit occurred over the radio voice communication issues of perception and memory. Both studies concluded that both human factors and system factors contributed to the information transfer deficiencies. The authors cited the human factors as distraction, forgetting, failure to monitor, and phraseology. The systems issues included unavailability of traffic information, ambiguous procedures, and high workload. Other studies emphasized that complex voice messages over radio frequencies overtax a pilot’s working memory (Galvin, 2002; McGann et al., 1998; Morrow et al., 1993).

According to a study by Baik and Trani (2005), CPDLC systems were expected to improve air safety and efficiency by freeing up communications bandwidth for urgent voice messages. Baik and Trani indicated that the CPDLC component of the NGATS would ease voice communication congestion, reduce flight delays in congested airspace, and decrease pilot-controller operational and communication errors. These observations were validated by a growing body of research that included laboratory experiments, simulator studies, field studies, and conceptual analyses (Helleberg, Wickens, Goh, Helleberg, Horrey, & Talleur, 2003; Lee et al., 2003; Olson, 1996; Risser, Scerbo, Baldwin, & McNamara, 2006; Wickens et al., 2003). Many of these studies, although not all, relate to a human factors approach to understanding the effect of CPDLC technologies and systems on human and systems performance.

Wickens et al. (1998) reported on the potential vulnerabilities of the CPDLC process within human factors issues, workload concerns, communication errors, and automation matters. They wrote that keyboard interactions may become cumbersome and error prone and that data link services would not permit the passage of nonlinguistic information such as the sound of urgency, competence, or confidence in a pilot's or controller's voice. Another automation issue included pilots experiencing a loss of situational awareness due to some information being discretely addressed with data link, and not having party-line information overheard, as in the traditional voice-based communication system (Midkiff & Hansman, 1993).

According to earlier research, most of the results of previous data link studies focused on airline crews and airline operations (Billings & Cheaney, 1981; Lee, 1989; McGann et al., 1998). With the advent of Very Light Jets (VLJs) and the use of multi-function displays with data link capabilities in light piston Technically Advanced Aircraft (TAA), general aviation now has the ability to use data link in their operations. Few studies have compared the two delivery methods of voice and text in the single-pilot flight deck environment for VLJ and TAA general aviation aircraft.

One study (Risser et al., 2006) employed non-pilot graduate students to manipulate a panel using a computer screen and mouse controls in response to simulated speech and text ATC commands while measuring response time and accuracy. Another study (Helleberg et al., 2003) used fifteen rated pilots in a simulator with a visual display focusing on heads-down time results while scanning for traffic using three different data link display conditions. A third study (Wickens et al., 2003) used twelve rated pilots in a flight simulator that incorporated data link and cockpit display of traffic information while primarily reporting results on visual scanning. This study focused on how CPDLC affects the human performance issues of errors in recall/execution and response time to ATC commands in a single-pilot flight deck environment. This study advances a previous pilot study (DeMik & Welsh, 2007) that primarily focused on only errors in recall and execution regarding voice and text commands.

Statement of the Problem

Safe and efficient flight operations depend on accurate and timely exchanges of information between ATC and pilots. Therefore, this study investigated the problem of how conditions of voice or text controller communications affect pilot performance in both accuracy and speed of recall/execution to ATC commands in a single-pilot flight deck environment. This human-technology interaction based research project attempted to answer the following research questions:

1. Will pilots flying in single-pilot general aviation operations have fewer pilot recall/execution errors when conducting flights using CPDLC (text) commands than when conducting flights using the conventional voice ATC commands?

2. Will pilots flying in single-pilot general aviation operations have faster response times to commands when conducting flights using CPDLC (text) commands than when conducting flights using the conventional voice ATC commands?

Methodology

Participants

Participants for this study included only Federal Aviation Administration (FAA) instrument-rated pilot volunteers who all held a current FAA medical certificate. Thirty participants from two Midwestern university flight schools took part in this study.

Measures

The Frasca 142/242 flight training devices (FTD) consisting of a primary flight instrument panel, radio control panel, and traditional aircraft controls were used to conduct the trials. An Optimus 9-inch color monitor was mounted in the FTD in the pilot's normal field of vision. An aural tone was used to alert participants of an incoming text message.

Procedures

Participants flew two cross-country flights (each approximately 15 minutes long) under instrument flight rules (IFR) in simulated instrument meteorological conditions (IMC). Each trial consisted of two flights: a flight under the ATC voice command condition, and another flight under the ATC text (CPDLC) command condition. The order of flights were alternated among participants as a counter-balancing technique.

Each flight included nine ATC command blocks. Three ATC command blocks featured a load of four parameters or more in length and were considered high workload (e.g., Frasca 142 is cleared to the STL airport except fly heading 280 to intercept the VLA 250 radial via the VLA 4 arrival, climb and maintain 5,000 ft., squawk code 2312). Another three ATC command blocks featured a load of three parameters in length and were considered moderate workload (e.g., Frasca 142 turn right heading 360 descend and maintain 4,500 ft., and maintain 110 knots.). The other three ATC command blocks featured a load of one or two parameters in length and were considered low workload (e.g., Frasca 142 contact St. Louis Approach on 126.5).

The researcher recorded errors in participant recall/execution and recorded the response time from beginning of commands to initiation of task(s). The two dependent variables were: (1) the number of errors in pilot recall/execution, and (2) the time from initial command to initiation of task(s). The three independent variables were: (1) condition of ATC command (voice or text); (2) loads in parameters of commands (high, moderate, or low); and (3) a between-subjects factor of order of trial (voice first or text first).

Data Analysis Procedures

The characteristics of this research study were consistent with a repeated measures design that includes within-subjects factors where each of the participants provided data from two trials (flights), each under a different condition (voice or text ATC commands). The order of trials was altered using a counterbalancing technique, which also provided a between-subjects factor. All data for this study was entered into SPSS version 14.0 for analysis. Each of the two dependent variables were analyzed using a *3* (levels of ATC commands) X *2* (conditions of voice or text) X 2 (order of trials) mixed model Analysis of Variance (ANOVA) to provide the initial analysis for this study. The dependent variables were the number of errors in pilot recall/execution and response times to ATC commands as recorded by the observer. The within-subjects independent variables were conditions of ATC commands (voice or text) and loads in parameters of commands (high, moderate, or low). There was also a between-subjects factor of order of trial (voice first or data link first).

The Type 1 error for this investigation was set at 0.05 ($\alpha = 0.05$). Minium, Clarke, and Coladarci (1999) noted that the Type 1 error of 0.05 is the most commonly used for this type of research. While this alpha gives a higher probability of incorrectly accepting a false alternative hypothesis (Type 1 error) than an alpha of 0.01, the results of this CPDLC study were informational only. In this case, the risk involved in a Type 1 error was small, and reducing the Type 1 error to 0.01 was not necessary.

Results

Fifteen participants were from Purdue University and another fifteen participants were from Indiana State University. Twenty-four men and six women participated in this study. Participants ranged from 20 to 57 years in age ($M = 24.47$, $SD = 7.57$). Total flight experience ranged from 140 hours to 5,000 hours of logged flight time ($M = 868.37$, $SD = 1250.10$). All participants were current pilots, as they all reported logged flight time within the past six months. All participants had previous flight simulator experience and were familiar with the Frasca FTD. None of the participants had previous experience with CPDLC.

Analysis of Errors in Pilot Recall/Execution

This first hypothesis was constructed to examine the effects of conditions in air traffic control commands (voice, text) on the accuracy of pilot recall/execution in a single-pilot general aviation simulated flight deck environment. A sub-hypothesis was also constructed to examine effect of loads (high, moderate, and low) of commands. The dependent variable consisted of numbers of participant errors in pilot recall/execution as recorded by the observer. The research hypothesis stated that:

> H_1: Pilots flying in single-pilot general aviation operations would have fewer pilot recall/execution errors when conducting flights using CPDLC (text) commands than when conducting flights using the conventional voice ATC commands.

The null hypothesis used in the statistical analysis was that:

> H_{01}: The mean score for overall pilot recall/execution errors on trials conducted under the text condition will be greater than or equal to the mean score for pilot recall/execution errors on flights conducted under the voice condition.In this analysis, along with the major hypothesis, was a sub-hypothesis involving levels of ATC command block loads. The sub-hypotheses regarding load level of ATC commands was:

> Sub-Hypothesis$_1$: Pilots flying in single-pilot general aviation operations would have fewer pilot recall/execution errors when conducting flights using CPDLC (text) commands than when conducting flights using the conventional voice ATC commands across the High and Moderate load ATC command blocks, and there would be no difference in errors at the Low load ATC command blocks.

The null hypothesis for the quantitative analysis of this sub-hypothesis regarding load levels of ATC commands was:

> Null Sub-Hypothesis$_1$: The mean score for pilot recall/execution errors on trials conducted under the text condition will be greater than or equal to the mean score for pilot recall/execution errors on flights in the voice condition across levels of High and Moderate load ATC command blocks, and these error mean scores will not be equal in the Low load ATC command blocks.

A *3* X *2* X 2 mixed-design ANOVA was analyzed to compare the scores for errors in pilot recall/execution of the participants in the text and voice conditions. The results for the within-subjects effects are depicted in Table 1.

A significant main effect of condition (voice, text) was found *F*(1, 28) = 113.42, $p < 0.05$. The null hypothesis was rejected. Numbers of errors in pilot recall/execution in the text condition (*M* = 0.44, *SD* = 0.66) were less than in the traditional voice ATC command condition (*M* = 1.36, *SD* = 0.37).

Table 1

ANOVA Table of Within-Subjects Effects for Errors in Recall/Execution

Source	*df*	*F*	η^2	*p*
Condition (C)	1	113.42	0.80	0.00
Load (L)	(1.46)	30.82	0.52	0.00
C x L	(1.59)	13.12	0.32	0.00

Note. Values enclosed in parentheses represent degrees of freedom corrected using Greenhouse-Geisser estimates of sphericity.

A main effect of load (low, moderate, high) was found *F*(1.5, 40.9) = 30.82, $p < 0.05$. Numbers of errors made in pilot/recall execution were effected by ATC command parameter loads of low (*M* = 0.38, *SD* = 0.41), moderate (*M* = 0.68, *SD* = 0.56), and high (*M* = 1.63, *SD* = 1.02).

An interaction effect of Condition (voice, text) X Load (low, moderate, high) on numbers of pilot recall/execution errors was present *F*(1.6, 44.6) = 13.12, $p < 0.05$. The null sub-hypothesis was rejected for conditions in high and moderate loads.

As predicted, numbers of errors in pilot/recall execution in the high load text condition (*M* = 0.87, *SD* = 0.86) and moderate load text condition (M = 0.30, SD = 0.47) were less than errors in the high load voice condition (*M* = 2.40, *SD* = 1.35) and moderate load voice condition (*M* = 1.07, *SD* = 0.83). However, the researcher failed to reject the sub-null hypothesis regarding the low parameter conditions. The researcher predicted that there would be no significant difference in errors at the low parameter commands. However, a difference was found as the low parameter text errors (*M* = 0.17, *SD* = 0.38) were less than the low parameter voice errors (*M* = 0.60, *SD* = 0.62).

Upon examination of the data (refer to Figure 1), it appeared that the higher load ATC commands had the greatest difference in errors regarding conditions of text and voice. However, this appeared to diminish at the low loads of ATC commands. Additionally, no main effects or interactions for the between-subjects effect of order were found. The numbers of errors in pilot recall/execution across condition and load were not significantly affected by the order of trial.

A *post hoc* analysis was calculated by conducting multiple protected dependent *t* tests. The researcher conducted three paired samples *t* tests, thereby inflating the Type 1 error rate. A Bonferroni correction to the alpha level was applied and a significance level of 0.017 (0.05/3) was used for analysis instead of 0.05.

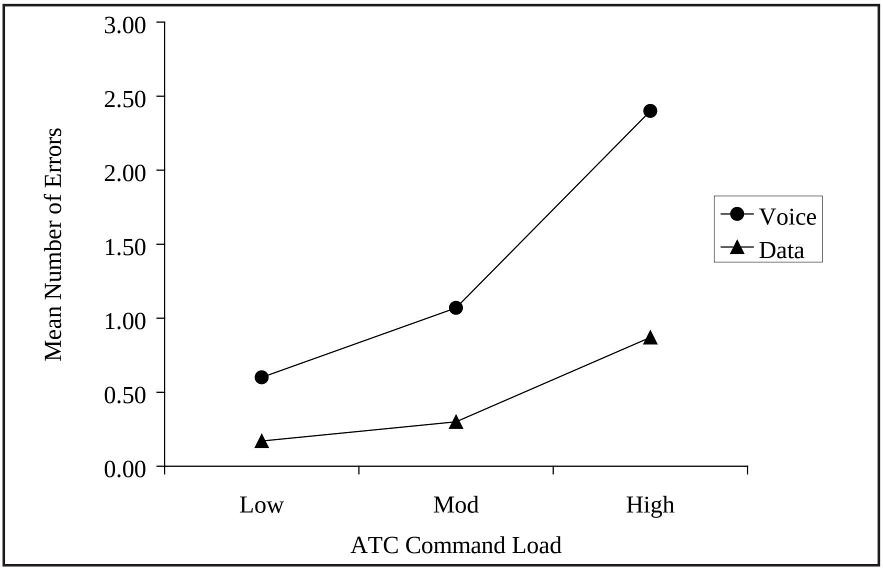

Figure 1. Errors in pilot recall/execution across command loads in voice verses text.

Follow-up protected *t* tests revealed a decrease in errors (*M* = 1.53, *SD* = 1.07) from the voice to text condition at the high load ATC command level (*t* (29) = 7.82, *p* < 0.017). There was a decrease in errors (*M* = 0.77, *SD* = 0.77) from the voice to the text condition at the moderate load ATC command level (*t* (29) = 5.43, *p* < 0.017). There was also a decrease in errors (*M* = 0.43, *SD* = 0.63) from the voice to the text condition at the low load ATC command level (*t* (29) = 3.79, *p* < 0.017). The results of the paired samples *t* test are presented in Table 2.

Table 2

Paired Samples t Test for Errors in Recall/Execution.

Source	*M*	*SD*	t	*DF*	*p*
ErVoiceHi - ErTextHi	1.54	1.07	7.82	29	0.00
ErVoiceMo - ErTextMo	0.77	0.77	5.43	29	0.00
ErVoiceLo - ErTextLo	0.43	0.63	3.80	29	0.00

Note. A Bonferroni correction to the alpha level was applied and the significance level is 0.017 (0.05/3).

Analysis of Response Times to ATC Commands

A second hypothesis was constructed to examine the effects of CPDLC (text) and voice air traffic control commands on pilot response times to commands in a single-pilot general aviation simulated flight deck environment. A sub-hypothesis was also constructed to examine effect of loads (high, moderate, and low) of commands. The dependent variable consisted of a measure of response times rounded to the nearest second. Response time was measured from the beginning of the controller command to the participant's initiation of the execution of that command. The research hypothesis stated that:

> H_2: Pilots flying in single-pilot general aviation operations would have faster pilot response times to commands when conducting flights using CPDLC (text) commands than when conducting flights using the conventional voice ATC commands.

The null hypothesis used in the statistical analysis was that:

> H_{02}: The mean score for overall pilot response time on trials conducted under the text condition will be slower than or equal to the mean score for pilot response time on flights in the voice condition.

The sub-hypothesis regarding load level of ATC commands was:

> Sub-hypothesis$_2$: Pilots flying in single-pilot general aviation operations would have faster response times when conducting flights using CPDLC

> (text) commands than when conducting flights using the traditional voice ATC commands in the High and Moderate load ATC command blocks, and there would be no difference in response times at the Low load ATC command blocks.

The null hypothesis for the quantitative analysis of this sub-hypothesis regarding load levels of ATC commands was:

> Null Sub-Hypothesis$_2$: The mean score for pilot response times on trials conducted under the text condition will be slower than or equal to the mean scores for pilot response times on flights in the voice condition across levels of High and Moderate load ATC command blocks, and these response time scores will not be equal in the Low load ATC command blocks.

The *3* X *2* X 2 mixed-design ANOVA was analyzed to compare the pilot response time of the participants in the text and voice conditions. Table 3 depicts the results for the within-subjects effects.

Table 3

ANOVA Table of Within-Subjects Effects for Response Times

Source	*df*	*F*	η^2
Condition (C)	1	61.30	0.69
Load (L)	(1.39)	267.63	0.91
C x L	2	17.89	0.39

Note. The value enclosed in parentheses represents degrees of freedom corrected using Greenhouse-Geisser estimates of sphericity.

A significant main effect of condition (voice, text) was found *F*(1, 28) = 61.30, $p < 0.05$. The null hypothesis was rejected. Response times in the text condition (*M* = 121.69, *SD* = 25.93) were faster than in the traditional voice ATC command condition (*M* = 152.98, *SD* = 25.95).

A significant main effect of load (low, moderate, high) was found *F*(1.39, 38.93) = 267.63, $p < 0.05$. Response times were significantly affected by ATC command parameter loads of low (*M* = 79.68, *SD* = 15.98), moderate (*M* = 116.20, *SD* = 26.47), and high (*M* = 216.12, *SD* = 42.69).

An interaction effect of Condition (voice, text) X Load (low, moderate, high) on pilot response times was present *F*(2, 56) = 17.89, $p < 0.05$. The null sub-hypothesis was rejected for conditions in high and moderate loads. As predicted, response times in the high load text condition (*M* =184.43, *SD* = 54.98) and moderate load text condition (*M* = 110.767, *SD* = 33.73) were less than respective times in the high load voice condition (*M* = 247.80, *SD* = 50.25) and moderate load voice condition (*M* = 121.63, *SD* = 29.20). However, the researcher failed to reject the sub-null hypothesis regarding the low parameter conditions. The researcher predicted that there would be no significant difference in response times at the low parameter load commands. However, a significant difference was found as the low load text response times (*M* = 69.87, *SD* = 19.28) were faster than the low load voice response times (*M* = 89.5, *SD* = 20.75).

Upon examination of the data (refer to Figure 2), it appeared that the higher load ATC commands had the greatest difference in response times regarding conditions of text and voice. However, this effect for response times appears to diminish at the moderate and low loads of ATC commands. Additionally, no main effects or interactions for the between-subjects effects of order were found. Response times across condition and load were not significantly affected by the order of trial.

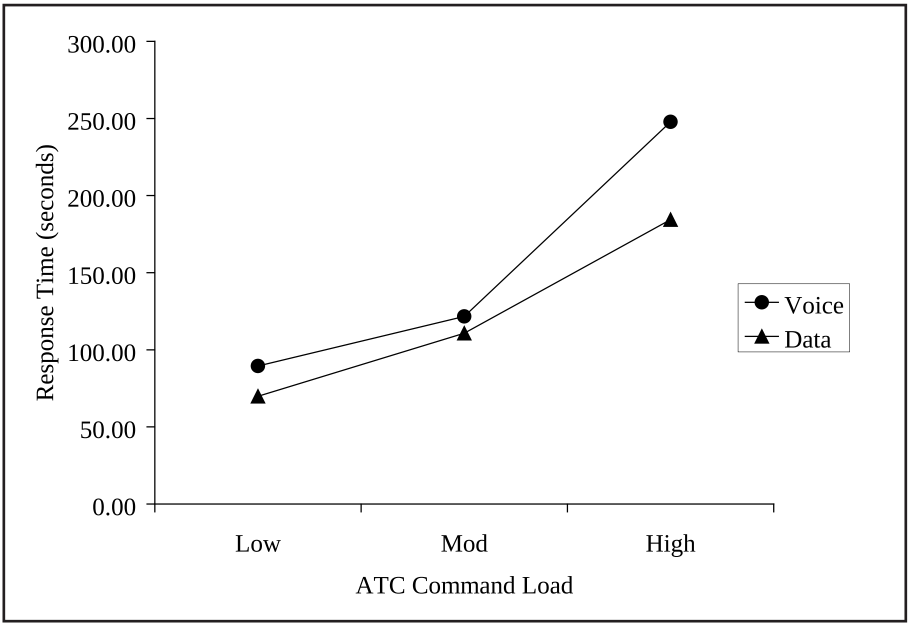

Figure 2. Response times across command loads in voice verses text.

A *post hoc* analysis was calculated by conducting multiple protected dependent *t* tests. The researcher conducted three paired samples *t* tests, thereby inflating the Type 1 error rate. A Bonferroni correction to the alpha level was applied and the researcher used a significance level of 0.017 (0.05/3) instead of 0.05.

Follow-up protected *t* tests revealed a decrease in response time (*M* = 63.37, *SD* = 60.71) from the voice to text condition at the high load ATC command level (t (29) = 5.72, $p < 0.017$). There was also a decrease in response time (*M* = 19.64, *SD* = 22.35) from the voice to the text condition at the low load ATC command level (t (29) = 4.82, $p < 0.017$). However, there was no significant difference in response time (*M* = 10.87, *SD* = 34.25) from the voice to the text condition at the moderate load ATC command level (*t* (29) = 1.74, *p* > 0.017). The results of the paired samples *t* test are presented in Table 4.

Table 4

Paired Samples t Test for Response Time.

Source	*M*	*SD*	t	*DF*	*p*
RtVoiceHi - RtTextHi	63.37	60.71	5.72	29	0.00
RtVoiceMo - RtTextMo	10.87	34.25	1.74	29	0.09
RtVoiceLo - RtTextLo	19.63	22.35	4.81	29	0.00

Note. A Bonferroni correction to the alpha level was applied and the significance level is 0.017

Discussion of the Results

The purpose of this human-technology interaction research was to provide empirical evidence for evaluating human performance regarding innovative air traffic control communications for single-pilot general aviation operations within the initiatives of the Next Generation Air Transportation System (NGATS). The results of this study revealed a statistically significant decrease in both human performance measures of errors in pilot recall/execution and response times in moving from the conventional voice ATC commands to the CPDLC text commands for pilots operating an FTD that simulated the single-pilot general aviation work environment. It was also shown that results were significant across all levels of air traffic control command loads (high, moderate, and low). However, a conservative *post hoc* analysis revealed no significant decrease in the human performance dependent variable of response time at the moderate load ATC command level.

The results of this study support the view that human performance can be improved when complex information is presented in visual form and users can refer to the text again. Data analysis revealed that the high parameter load ATC commands had both significantly fewer errors and reduced response times in the CPDLC (text) condition. However, this performance effect appears to diminish at the moderate and low loads of ATC commands.

These findings are consistent with those of Risser et al. (2006), where results demonstrated a human performance advantage in text commands with longer messages. Taken together, these findings indicated that CPDLC provides an improvement in human performance, especially with regard to high parameter load communications from ATC such as Automatic Terminal Information Services (ATIS), initial clearances, and detailed route changes. However, the evidence from this study, and previous research with multi-crew airline operations, generally endorses the roll of the dual modalities of voice and text over a preemption of one modality of communication.

The conclusions as well as the limitations of this study also bring forth possible avenues for future research that might be needed in relation to introducing single-pilot general aviation text communications within the framework of the NGATS. An avenue for future research lies in continuing the exploration of the dual modalities of the communication process. A more thorough understanding of flight deck communications from a human performance perspective could be achieved by considering the heads down time of the pilot, scanning priorities in both visual and instrument conditions, and the interplay of the dual modalities of voice and text. However, in this research the decision was made to explicitly separate the modes of communication so that they each could be examined individually. This detachment can be seen to provide an initial step towards developing a more complete model for understanding the emerging CPDLC system from the single-pilot general aviation perspective. The next step would be to identify the interconnections between the human performance elements and to model the actual human factors process as an interaction of these elements.

Implications of the Results

One of the improvements needed within the NGATS initiative is to increase the efficiency and accuracy of pilot-controller communications (Baik & Trani, 2005; Erzberger, 2004; Hellerberg & Wickens, 2003). The results of this study demonstrated that a communication technology, which included text-based communications, might extend pilot's working memory, thereby improving both accuracy and efficiency in performing complex flight tasks.

The results of this study provide a data point supporting the advancement of CPDLC technologies for the single-pilot general aviation flight deck through applied laboratory research with qualified instrument-rated pilots. CPDLC technology's implications for multi-crew airline operations have been documented in previous studies (Billings & Cheaney, 1981; Lee, 1989; McGann et al., 1998). The findings of this study and the findings from previous studies for multi-crew airline operations suggest at least two implications for CPDLC. First, the parameter load of the information (high, moderate, low) affects the integrity of instructions in pilot's working memory. Therefore, the recall and execution of tasks is an important human performance concern and suggests that pilots exercise caution when coordinating multi-task instructions. A second implication is that the permanence of CPDLC text messages can significantly overcome this memory resource problem. These implications lend support for the incorporation of CPDLC technology for single-pilot general aviation operations in the NGATS.

In terms of general implications, the results of this study contribute to the growing body of research on pilot-controller communications and provide needed direction in development of policy for the introduction and application of CPDLC within the National Airspace System (NAS). Stakeholders seeking empirical evidence from experimental research may consult the results of this and similar studies to serve as a framework for a multi-stakeholder dialogue to incorporate the CPDLC technology system within the NGATS initiative. The results indicate the usefulness of text-based pilot-controller communications technology for high workload commands. However, the evidence from this study, in conjunction with studies by Midkiff and Hansman (1993) regarding party-line information and Wickens et al. (1998) regarding automation issues, generally supports the roll of the dual modalities of voice and text over a preemption of voice commands.

Acknowledgements

I wish to acknowledge the Aviation Technology Departments at both Indiana State University and Purdue University for allowing me to use their flight simulator labs and flight training devices. I thank Mr. Bruce Welsh, Mr. Harry Minnier, Dr. John Young, Mr. Larry Gross, and Mrs. Patty Keen for their parts in helping me with the flight simulator data collection process. I also thank those who kindly volunteered to participate in this study.

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International Journal of Applied Aviation Studies, Volume 9, Number 1
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Evaluation of a Mobile Horizontal Radar Display Filter for Air Traffic Controllers

Simone Sporer-Fellner, Holger Flühr, Martin Haider,

FH JOANNEUM GmbH
Department of Aviation
8020 Graz
Alte Poststrasse 149, Austria
simone.sporer-fellner@fh-joanneum.at

Peter Kappertz

BARCO Orthogon GmbH
Stuttgart, Germany

and

Horst Hering

EUROCONTROL Experimental Centre
Brétigny sur Orge, France

Abstract

A novel concept to support air traffic controllers, the mobile horizontal radar display filter WHEELIE allows controllers to quickly select and change the requested flight level by scrolling an Operational Display System (ODS) mouse wheel. Aircraft on the selected flight level are graphically highlighted without masking other traffic. An experimental simulation study of human factors was conducted initially to investigate WHEELIE. A multi-method approach revealed reduced perceived mental workload as a consequence of using WHEELIE. The controllers who assessed WHEELIE pointed out the positive effects of the rapid perception of conflicts as well as the better overview of the respective flight level.

Requests for reprints should be sent to Kay Chisholm, FAA Academy, AMA-800, P.O. Box 25082, Oklahoma City, OK 73125. E-mail to kay.chisholm@faa.gov.

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Evaluation of a Mobile Horizontal Radar Display Filter for Air Traffic Controllers

An air traffic controller's task is to guarantee the safe separation of aircraft in controlled airspace. This may be done in a horizontal or a vertical direction, by speed change, or a combination thereof. Experienced controllers are able to recognize horizontal separation simply by glancing at conventional two-dimensional radar displays – Operational Display Systems (ODS). In the case that horizontal separation is no longer guaranteed, vertical separation has to be assured instead. Vertical separation is based on flight level (FL) data which are represented in numerical mode on the ODS because the 3D traffic is graphically projected into a 2D horizontal plane. The controllers have to continually scan, memorize, and compare the actual FL values of the tracks under their responsibility on the ODS in order to create a mental representation of the traffic.

Hering (2004) at EUROCONTROL Experimental Centre (France) proposed the concept of WHEELIE. WHEELIE is based on the idea that in case of vertical separation, it is important for the controllers to know whether the aircraft are flying on the same or on different FLs. The mobile horizontal filter tool WHEELIE enables the controllers to answer this question quickly (Hering, 2004). The tool permits the requested FL to be selected and changed quickly by scrolling the ODS mouse wheel (…, 180, 190, 200, …), hence the name WHEELIE. Aircraft on the selected FL are graphically highlighted without masking other traffic – the aircraft symbol on the ODS gets a virtual source of light behind it which creates a yellow aureole around the symbol (idea was developed and evaluated by Tavanti and Flynn, 2003). To capture aircraft which are also descending or climbing to the selected FL, a range of tolerance (FL + 499 ft, - 500 ft) was defined. Aircraft within this range are highlighted too to show impending conflict. In addition, the FL is displayed on the screen in an unobtrusive way by coloring the FL in a lighter grey than the background of the ODS and by positioning it in the centre of the display in numerals big enough to enable fast recognition (Figure 1).

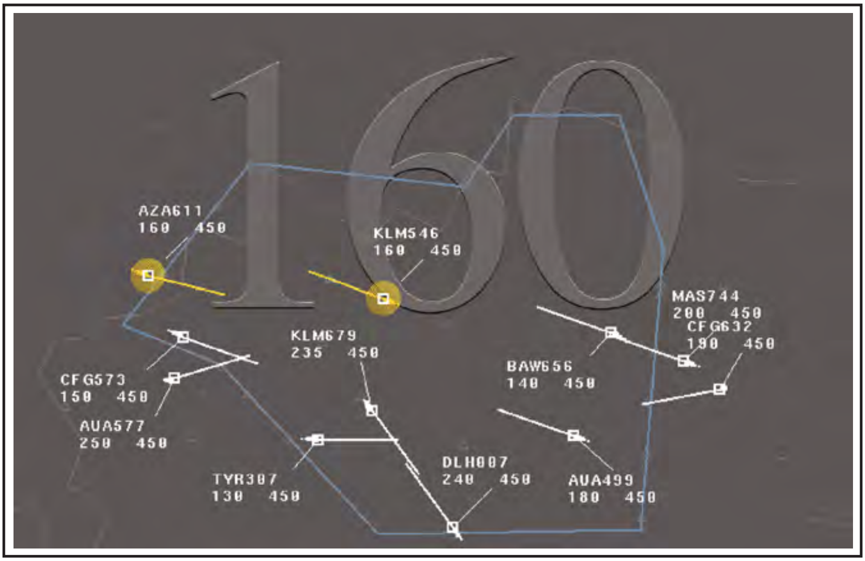


Figure 1. WHEELIE active on FL 160 in Operational Display System

At first glance, the controllers can identify potentially conflicting aircraft on the horizontal level flying on the reference FL (i.e. highlighted traffic). All other aircraft are flying on different FLs and are out of conflict with the aircraft selected by WHEELIE. To limit its influence on the ODS, the tool works on demand only. WHEELIE is normally asleep, but turning the mouse wheel wakes it up; if no further activity is taken, the displayed FL disappears after five seconds. Already implemented filters work as pre-settings for the ODS, and only filtered aircraft are displayed. Further vertical filtering was proposed by David (1997) and David and Bastien (2001). WHEELIE does not suppress information shown on the ODS screen. It is designed for permanent dynamic use to support the controllers in their actual work rather than as a new technology driven tool. It was hypothesized that WHEELIE would positively influence air traffic controllers' mental workload and performance in the areas of safety and efficiency.

The aim of this study was to evaluate the mobile horizontal radar display filter tool WHEELIE in terms of human factors to obtain initial results concerning mental workload of the controllers, changes in safety and efficient performance as well as the acceptance of the WHEELIE software tool. For this reason, a prototype of the mobile horizontal radar display filter tool WHEELIE as well as an adequate operational simulation environment including air traffic service (ATS) routes and simulation scenarios were developed (Sporer, Kinzner, Flühr, Kappertz, Dilly, & Hering, 2006).

METHOD

Subjects and design

A 2 x 2 x 5 (software functionality x scenario x task load) within-subject design was applied. Both the experimental factors software condition (WHEELIE functionality vs. standard) and scenario (scenario 1 vs. 2) were counterbalanced. In each scenario, the variable task load increased as a function of time and resulted in five task-load levels. For the sake of clarity, the different task-load levels are not indicated separately in the table showing the experimental design (Table 1).

Table 1

Experimental design with factors "Software condition" and "Scenario" crossed

Run / group Software condition x scenario (including task-load level changes)				
	group 1	group 2	group 3	group 4
run 1	W 1	W 2	S 1	S 2
run 2	S 2	S 1	W 2	W 1

Note. W = Wheelie Condition, S = Standard Condition; 1 = Scenario 1, 2 = Scenario 2;

Nine male and three female air traffic controllers (en-route controller as well as controller working on approach and tower control) aged 22 to 53 years (mean = 30.8 years, s = 9.4) were randomly assigned to one of the four experimental groups. Each subject participated in two experimental settings. These experimental settings consisted of two different scenarios in combination with both the software functionality WHEELIE and the standard condition (without WHEELIE) in varied sequence depending on the experimental group (see also Table 1 for group settings). The two different scenarios were developed based on the same logical structure in order to be highly comparable: the same number of aircraft enter the sector at exactly the same time, 30% level changes and 60% route changes were required. Within the framework of each of the two scenarios five task-load levels increasing in difficulty were implemented:

- Task-load level 1: initial traffic plus one aircraft every 50 seconds
- Task-load level 2: one aircraft every 45 seconds
- Task-load level 3: one aircraft every 35 seconds
- Task-load level 4: one aircraft every 25 seconds
- Task-load level 5: activated danger

From task-load level one to four the task load was operationalized by increasing frequency of traffic (aircraft entering the sector). Instead of an increase in traffic at task-load level five, a danger area was activated. Each task-load level lasted 5.5 minutes. The described task-load levels were implemented in both of the two scenarios in the same order by starting with level 1 and ending with level 5. Different methods of partially counterbalancing the task-load levels had been evaluated previously because of a potential confounding of learning effect with workload estimates. The design would have allowed eight different sequences (out of 120 possible ones). However, it might have been a problem when a high task-load level is followed by a quite low task-load level because a poor performance at high task-load levels would affect performance on low task-load levels, e.g. non-resolved conflicts could be transferred. Therefore, the task load was realized in increasing order. The comparability of the scenarios was verified by a preliminary evaluation conducted by an experienced air traffic controller (14 years of experience).

Procedure

The whole simulation study lasted approximately 3.5 hours per participating controller. After a short briefing on the purpose and the process of the study, the subjects were asked to fill in an Initial State Questionnaire (developed in Janke, 1976) to determine the presence of any outside influences or preexisting conditions (e.g. length of sleep, use of medication) that could potentially affect their performance during the experiment. The controller had to participate in two training sessions (first scenario: standard simulation; second scenario: simulation with WHEELIE functionality), to become familiar with the operational simulation environment. Each participant ran each scenario for a minimum of 20 minutes; after this time, they were allowed to go on until they felt familiar with the particular simulation. In the experimental phase, the two scenarios described above, which each lasted 27.5 minutes, had to be enacted. During each experimental setting, the controllers answered the Instantaneous Self-Assessment five times (every 5.5 minutes at the end of each task-load level) in a separate notebook. At the end of each session, the NASA Task Load Index (TLX, Hart & Staveland, 1988) and a post-scenario questionnaire were completed. Finally, a debriefing was conducted with a semi-structured interview assessing the controllers’ acceptance of the WHEELIE functionality.

Operational Simulation Environment

The operational simulation environment was based on a modified graphical user interface of the “ODS Toolbox” by BARCO Orthogon GmbH, Germany, to simulate the WHEELIE functionality (option to highlight radar symbols and display the selected FL on the screen). WHEELIE functionality was added to the standard operational display system by pre-selection for each experimental setting. For the geographical simulation environment, a control sector (NORTH Sector) presently used by Austro Control was chosen and embedded with slight modifications in order to fit the needs of the software (reduction of navigation points and addition of coordination points). Additionally, a virtual restricted area was inserted into the sector activated in task-load level number five. In the restricted area, a separation of at least 5NM horizontally or 500ft vertically (instead of 1000ft vertically for non-restricted area) had to be kept. The upper limit was set at 500ft as in real ATC so that the next FL above could be used without loss of separation. For the sake of clarity, nine air traffic service (ATS) routes of the global ATS network were embedded in the control sector (Figure 2):

- Heading east: M141, M749, L605, L725 (4 big dashed lines)
- Heading west: L850, L851 coming to T161, L856, L610 (4 big solid lines)
- Bidirectional: L604 (1 triple line)

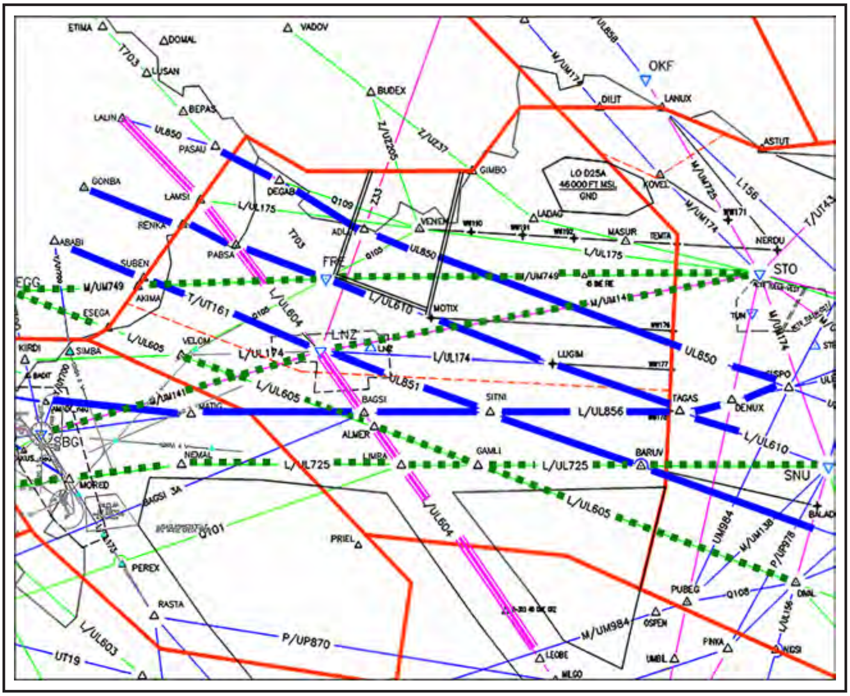


Figure 2. Simplified control sector with restricted area and Air Traffic Services routes

During the simulations, one pseudo-pilot communicated with the air traffic controllers and followed their instructions, adequately navigating the aircraft. Due to the software environment, all possible controller instructions were not executable, e.g. direct routing instructions to any waypoint or the request to a specific climb rate per minute; therefore, adequate rules for the pilot-controller-communication had to be defined. Visual contact between the pseudo-pilot's and controller's working position was prevented to eliminate potential interference.

Dependent Variables

The study is based on a multi-method approach which combines different levels of empirical data with both objective and subjective measures. The subjective evaluation reflects the individual's interpretation of a situation, while the physiological measures complement the representation of a latent construct with data which are considered to be objective. Thayer and Friedman (2000) point out the necessity of analyzing multidimensional complex constructs in multiple areas. This study focuses on the following measures:

- Subjective ratings of mental workload
- Physiological variables of heart rate (HR) and heart rate variability (HRV) as objective parameters for mental workload
- Behavioral indicators to assess performance in the areas of safety and efficiency
- Acceptance of the WHEELIE functionality surveyed by means of a semi-structured interview at the end of the experimental simulation study

Subjective measures. The subjective measurement approach was primarily used to investigate the controller's mental workload during the experimental simulation scenarios. To assess mental workload in each experimental scenario the NASA Task Load Index (TLX, Hart & Staveland, 1988) was employed in a computerized version in German language (Forschungsgesellschaft für Angewandte Naturwissenschaften e.V.; Pfendler & Thun, 1998). Additionally, the Instantaneous Self-Assessment Technique developed by the UK National Air Traffic Services (ISA; Stanton, Salmon, Walker, Baber, & Jenkins, 2005) was used to assess subjective ratings of workload for the ascending task-load levels during the scenarios. Five measurements were taken within one experimental session, one after the completion of each task-load level.

Physiological measures. Physiological reactions on mental workload were assessed by ECG recording using a portable digital Holter recorder (Medilog® AR12, Huntleigh Healthcare, Cardiology Products Division), which the subject carried. The subject's average heart rate (HR) in bpm in 2.75-minute-intervals (10 sections of measurement) and average heart rate variability (HRV) in ms in 5.5-minute-intervals during experimental simulation sessions were computed from data obtained from of a 12-lead ECG.

Performance measures. The experimental sessions were recorded in a log-file (ASCII file) where the position data from every aircraft were saved every five seconds. Due to software conditions it was not feasible to routinely sample every five seconds. The indicators for safety and aircraft delays which emerged from the recordings during the experimental scenarios were data separation losses (<5nm horizontal; <1000ft vertical between two aircraft for non restricted area), wrong exit and entry conditions, and aircraft entries in the activated danger area.

Acceptance measures. At the end of the experimental simulation study, the controllers' acceptance of the WHEELIE functionality was assessed by means of a semi-structured interview in the course of a debriefing. The interview consisted of questions regarding the advantages and disadvantages or rather the improvements of the WHEELIE functionality in general, the impact of the WHEELIE functionality on safety, efficiency, and mental workload as well as the reasons why the WHEELIE tool was applied. In order to minimize the potential risk that participants give the experimenter the answer they think the experimenter wants to hear, particular attention was paid to the development of the questions of the interview, so that no leading questions could be used by mistake.

For statistical data analysis, subjective ratings, physiological variables, and performance indicators were submitted to analysis of variance (ANOVA) for repeated measures since univariate measures are known to have a greater psychometrical power when small-scale samples are used (Maxwell & Delaney, 1990). In case the assumption of sphericity was violated, degrees of freedom (df) were corrected according to the method of Huynh-Feldt. Content analysis as in Mayring (1997) was applied to the qualitative data from the semi-structured interviews. An overall alpha level of .05 was used for statistical tests. The statistical analysis was conducted according to the principles of descriptive data analysis procedures (Abt, 1987).

RESULTS

Mental Workload

The WHEELIE tool had a positive effect on mental workload as perceived by the subjects. The monitoring of mental workload during the experimental sessions by means of the Instantaneous Self-Assessment revealed a significant main effect in the software condition ($F(1, 11) = 6.71$, $p = .025$), demonstrating that less mental workload was perceived continuously during the simulation session with the WHEELIE functionality, as shown in Figure 3. Furthermore, a significant main effect on the task-load levels ($F(3.49, 38.35) = 31.91$, $p = .000$) was found; the subjectively perceived mental workload increased linearly from the first to the last task-load level. Post-tests showed significant differences in perceived workload between the different task-load levels except for the last two levels 4 and 5, which reflects in general the successful manipulation of task-load levels. It was hypothesized that WHEELIE might have positive effects on workload especially at moderate and high task-load levels. However, the findings indicate the overall positive effect of WHEELIE on subjective mental workload.

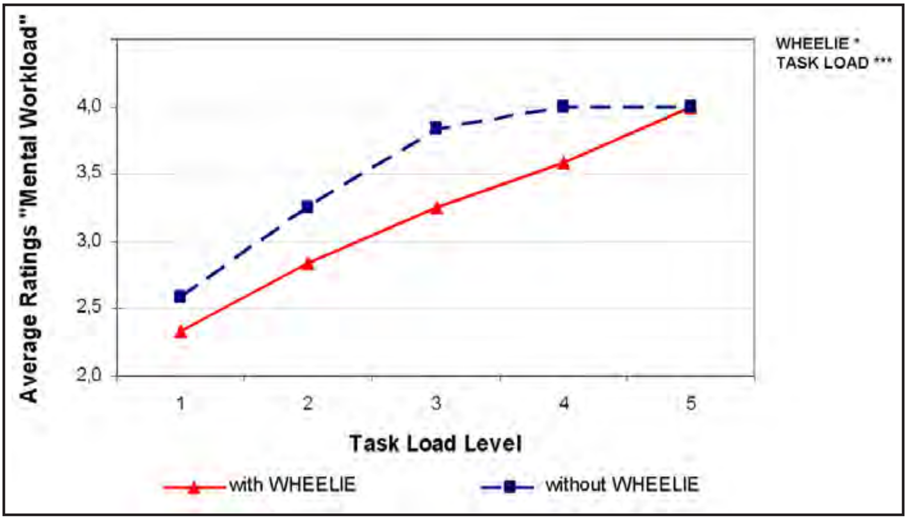


Figure 3. Average ratings of workload in WHEELIE condition and task-load levels

In contrast to the results obtained from the Instantaneous Self-Assessment, no significant differences between the standard and the WHEELIE conditions regarding mental workload were found using the NASA Task Load Index.

Contrary to the findings on the subjective level, no significant effect for the WHEELIE tool was observed in the objective or physiological recording of mental workload (heart rate, heart rate variability). However, the findings revealed a statistical trend at the task-load levels (HR: F(3.67, 40.37) = 2.51, p = .062; HRV: F(4, 44) = 2.35, p = .069). The process of HRV (depicted in Figure 4) suggests that mental workload increased for the task-load levels 2, 3, and 4 but decreased at the end of the measurement, i.e. the end of the last task-load level. Post-tests revealed that task-load level 2 and 5 differ significantly (p = .029). Note that for the analysis of heart rate variability, the statistical method standard deviation of the normal-to-normal interval (SDNN) was calculated for the duration of the task-load levels (5.5 min). In the literature (e.g. Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996), a period of 5 min. is recommended to obtain valid results.

Performance

The WHEELIE functionality had no statistically significant effect on either safety (separation losses, wrong exit and entry conditions, aircraft entries in the activated danger area) or efficiency (aircraft delays). But results denoted an effect of the different task-load levels on the number of separation losses (F(1.40, 15.40) = 5.72, p = .021). A peak at the third level occurred i.e. the most separation losses were committed in this level (post-tests revealed that task-load level 3 differs significantly from the other levels). It is worth noting that in general hardly any separation losses occurred. Within level 3 less than one (M=0.33, SD=0.57) separation loss was committed on average.

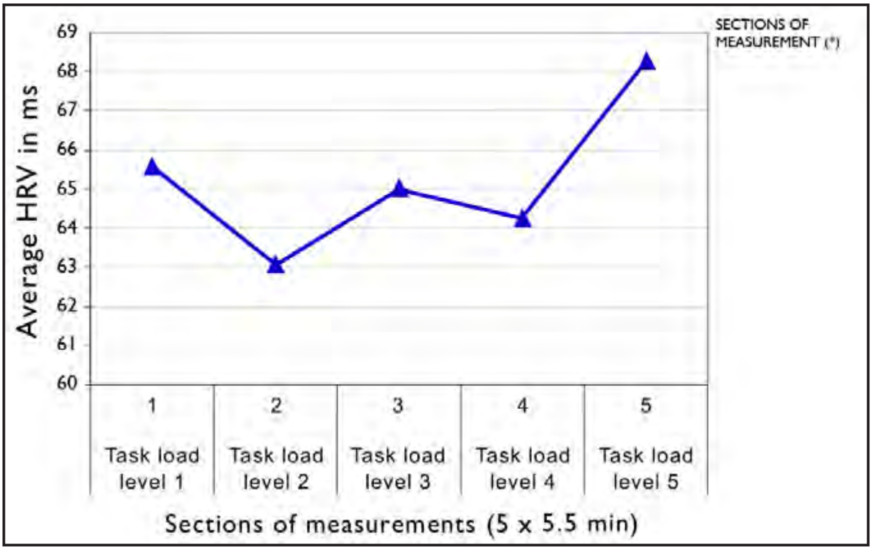


Figure 4. Average HRV in ms in 5.5min periods in task-load levels

Acceptance

Content analysis revealed that the controllers applied the WHEELIE tool in different settings (Figure 5) with most controllers commenting that they used the WHEELIE tool to scan the flight levels for potential conflicts in general and to scan a flight level before a change of altitude or an intercept. Three participants stated that they used the tool to search for aircraft when they could not find a specific one quickly on the screen due to the very high traffic density. It was also asked if WHEELIE may improve the detection of conflicts. Eleven out of twelve controllers answered the question affirmatively. This result was transferred to be analysed by a binomial test, and showed that WHEELIE significantly (p = .006) improves the detection of conflicts according to participants' opinions.

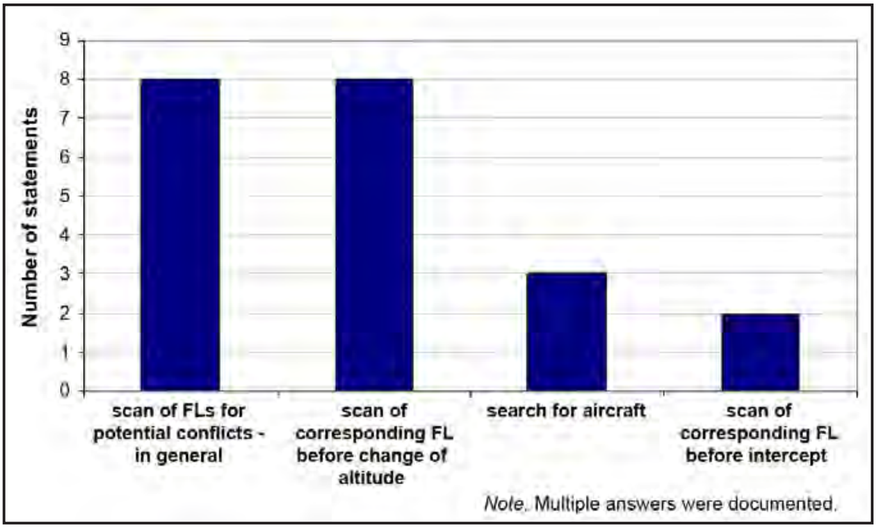
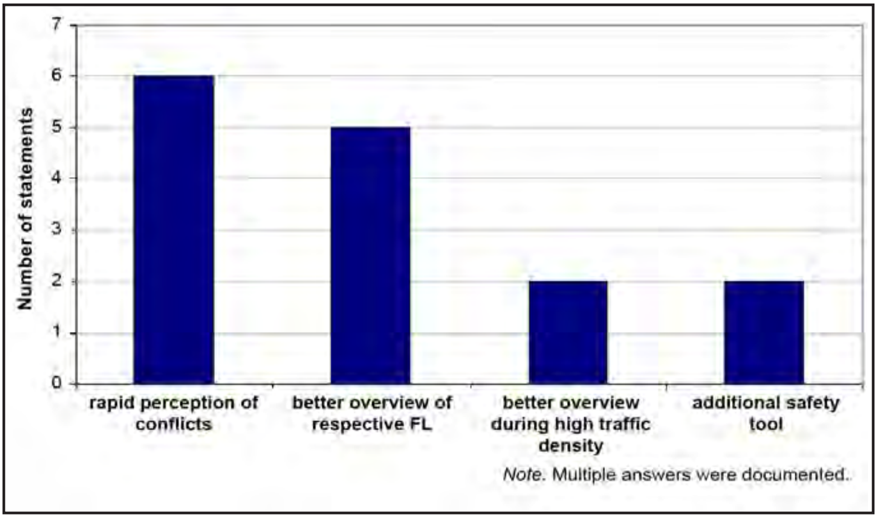


Figure 5. Statements on the reason for applying the WHEELIE tool.

Figure 6 presents the statements on the advantages of the WHEELIE functionality. Rapid perception of conflicts and the improvement of the overview of a single flight level were mentioned most frequently as advantages of the WHEELIE tool. Additional responses indicated the improvement of the overview of traffic during high traffic density and the perception of WHEELIE as a supplemental safety tool.



Note. Multiple answers were documented.

Figure 6. Statement on the advantages of the WHEELIE functionality.

Perceived disadvantages and ideas for improvement of WHEELIE were also assessed (Figure 7). Most subjects stated that the display was suboptimal and they would prefer a more discrete numerical display of the flight levels e.g. on the side of the screen. Moreover, they felt the time of activity (5 seconds for this simulation) should be shortened. Several statements focused on the additional highlighting of labels and the option of displaying several flight levels simultaneously.

In the areas of perceived safety and efficiency, a general increase in safety is mentioned by most of the controllers interviewed. It was specifically mentioned that conflicts are assessable earlier. As for the impact of the WHEELIE tool on efficiency, 7 subjects felt it had little influence on efficiency while 5 subjects reported increased efficiency due to more rapid overview of traffic.

As the variable scenario was included in the experimental design to eliminate memory effects, separate analyses were conducted to investigate its effect. However, no significant results were obtained, which reflects the successful manipulation, i.e. the comparability of the experimental scenarios.

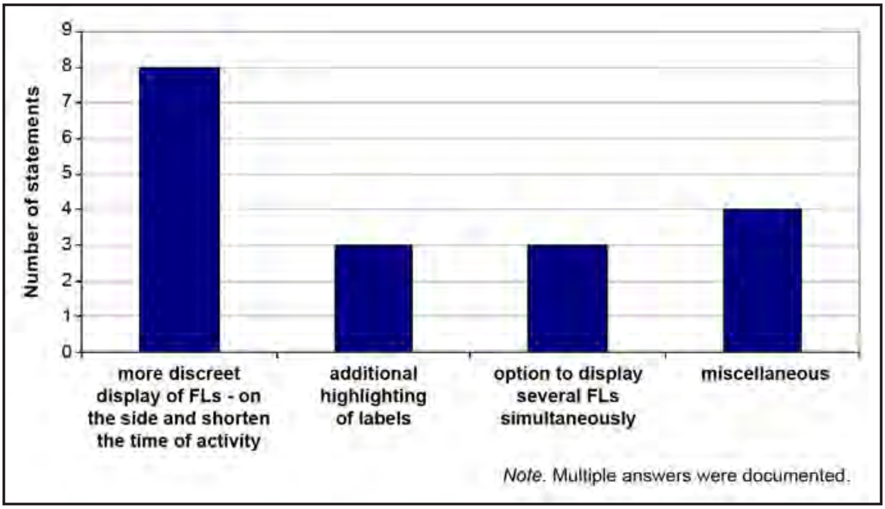


Figure 7. Statement on suggestions for the improvement of the WHEELIE functionality.

Conclusions

In a human factors study, the prototype of the mobile horizontal display filter WHEELIE was initially evaluated in an experimental simulation study to assess the impact of the tool on controllers' mental workload, performance, and acceptance by using a multi-method approach under different task-load levels.

The results of controllers' opinion on the WHEELIE tool showed positive assessment and a general acceptance. WHEELIE was mainly used to scan flight levels for potential conflicts and corresponding flight levels before an intercept or a change in altitude of an aircraft. In particular, controllers pointed out the rapid perception of conflicts, a better overview of respective flight level, as well as the resulting positive impact on safety. Quantitative analyses revealed the positive effects of the WHEELIE functionality. The ratings highlighted reduced perceived mental workload (ISA) as a consequence of the WHEELIE tool. In contrast to the subjective parameters, no effect of the WHEELIE functionality on mental workload and safety could be found with respect to objective parameters (i.e. heart rate, heart rate variability, and performance). Due to the respectively low general heart rate, the conflicting results could be explained by the fact that controllers are trained to keep calm in critical situations. These conflicting results support the need for a multi-method approach to analyze complex latent constructs such as mental workload as described in the literature (e.g. Thayer and Friedman, 2000).

It was hypothesized that WHEELIE might have positive effects on mental workload especially at moderate and high task-load levels. On the one hand, the subjective perceived task load was reflected in a linear increase in mental workload (ISA - Instantaneous Self-Assessment Technique). On the other hand, physiologically assessed mental workload was nearly stable from the second to the fourth level and decreased at the last task-load level (HR, HRV). The conflicting physiological mental workload development to the task load demands might be caused due to the build-up of the task-load levels; frequency of traffic increased except at the last level – activation of a danger area. Without the additional burden of dealing with increased air traffic, the subjects may have been able to devote their attention to the danger area. Another reason might be that the challenge was too high in the last level and the participants resigned. The fact that performance in general was continuously of a high standard speaks against this thesis. The demonstrative increase in mental workload at the beginning of the experimental scenarios may be an example of the orientation effect. Fowler (1980) suggested that air traffic controllers adapt to traffic peaks. Furthermore, one Canadian study on air traffic control found that most incidents occurred during low or even moderate traffic load (Stager, 1991).

The results obtained reveal the positive effects of the WHEELIE functionality particularly in the areas of perceived mental workload and improvement of the overview of traffic. Further investigations are necessary to confirm the positive effects and to assess WHEELIE's impact on other variables not included in this study.

Acknowledgements

This research was sponsored by EUROCONTROL Experimental Centre and supported by BARCO Orthogon GmbH.

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International Journal of Applied Aviation Studies, Volume 9, Number 1
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A Framework for Analyzing Simulated Aircraft Wake Vortex Encounters

Jeffrey A. Boyd and Ellen J. Bass

University of Virginia
Department of Systems and Information Engineering
P.O. Box 400747
151 Engineer's Way
Charlottesville, VA 22904
ejb4n@virginia.edu

James C. McDaniel

Mechanical and Aerospace Engineering
Charlottesville, VA 22904

and
Roland Bowles (retired)

NASA

Abstract

Redefining the current aircraft separation standards could increase airspace capacity while maintaining safety by defining an acceptable wake vortex encounter based on aircraft controllability and pilot acceptance of aircraft response. This work implements an aircraft wake encounter analysis framework that can run on a standard workstation. Two analyses are conducted as a proof-of-concept using a Boeing 757-200 follower aircraft. The first analysis examines parameters that influence follower aircraft response. The second examines the impact of the weight of the generator on the follower aircraft response. The Burnham-Hallock wake flow-field model as adapted by Tatnall defines the wake of a generator aircraft. For the follower aircraft's response, strip theory calculates the wake-induced forces and moments acting on the aircraft. For the follower aircraft-centered wake encounter hazard metrics, this research considers maximum bank angle upset, maximum roll acceleration, and vertical and horizontal flightpath deviations. This work demonstrates the flexibility of the framework's software implementation as its ultimate purpose is to aid researchers studying wake vortex encounters.

Requests for reprints should be sent to Kay Chisholm, FAA Academy, AMA-800, P.O. Box 25082, Oklahoma City, OK 73125. E-mail to kay.chisholm@faa.gov.

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A Framework for Analyzing Simulated Aircraft Wake Vortex Encounters

Wake vortices can create a controllability problem for a following aircraft flying through the wake of the preceding generator aircraft. Most wake encounters are harmless causing a slight upset in the follower aircraft similar to a light or moderate atmospheric turbulence encounter. However, several aircraft accidents have been caused by wake vortex encounters and the pilots' responses to them (c.f., National Transportation Safety Board, 2004).

Current U.S. aircraft wake vortex separation standards include only six distances to space all aircraft operating within U.S. airspace (Table 1) where heavy aircraft are capable of takeoff weights of more than 255,000 pounds, large of more than 41,000 up to 255,000 pounds, and small aircraft at 41,000 pounds or less. The B757 category is reserved for Boeing 757 aircraft, which operate in the large aircraft category but have specific wake separation standards. The FAA spacing criteria related to the A380 are more conservative than those of the International Civil Aviation Organization (ICAO) and implemented by the UK Civil Aviation Authority (UK CAA) (ICAO 2008, UK CAA 2008). The Air Traffic Organization has directed the word "SUPER" to be appended to the call sign of any A380 aircraft (Federal Aviation Administration, 2008).

Table 1

U.S. wake vortex separation standards in nautical miles (FAA, 2007a, 2007b, 2008)

	Lead aircraft				
Following Aircraft	A380	Heavy	B757	Large	Small
A380	6	4	4	2.5	2.5
Heavy	6	4	4	2.5	2.5
B757	8	5	4	2.5	2.5
Large	8	5	4	2.5	2.5
Small	10	6	5	4	2.5

Aircraft spacing has a significant effect on capacity system-wide. If spacing is too conservative, then the capacity of the runway corridors could be increased by decreasing in-trail separation. In an analysis of potential capacity impacts, the Aircraft VOrtex Spacing System (AVOSS) project used a wake predictor algorithm and determined aircraft spacing dynamically based on predicted and observed wake behavior (Hinton, Charnock, and Bagwell, 2000; Rutishauser, Butler, and Riggins, 2004). An analysis using runway traffic mixtures for DFW, Miami, and Seattle yielded an average throughput increase between 6 and 12% using dynamic aircraft spacing.

The work described herein defines an analytical framework and toolset able to inform the development of criteria for acceptable wake encounters. The toolset takes advantage of the latest simulation software enabling the analyst to run wake encounter experiments on a commercial-off-the-shelf desktop computer. The analytical framework includes a mathematical description of the wake flow-field, a follower aircraft response, and hazard metrics. The toolset does not currently contain a pilot or autopilot model so that the results include more severe aircraft reactions than would be encountered with a controlled aircraft.

A commonly used wake vortex flow-field model is the Burnham-Hallock Vortex Model (Burnham and Hallock, 1982, 1997). Using this approach, each vortex is modeled with an equal and opposite circulation such that a downwash is produced between the two vortices. The vortex flow-field is defined in two dimensions with the circulation strength characterized by a non-dimensional unit of time elapsed after the wake's initial roll-up off of the generating aircraft. Assuming an elliptical lift distribution, the flow-field can be calculated requiring only the weight, velocity, and wingspan of the generator aircraft. Because these data are available for a wide variety of aircraft, nearly any generator aircraft can be modeled. Burnham and Hallock (1982, 1997) found that their model produced behavior observed in actual wake data. Their model has also been used in the studies of Tatnall (1995) and Reimer and Vicroy (1996).

Strip theory has been used to model aircraft response (Johnson, Teper, and Rediess, 1974; Stuever and Greene, 1994; Stewart, 1999; Reimer and Vicroy, 1996) and is also applied in this research. One difficulty of applying strip theory is determining the fidelity necessary for the aircraft model. Stewart (1999) examined modeling the aircraft response using progressively more complete descriptions of the aircraft and vortex interaction and showed that modeling an aircraft as a wing and a vertical and horizontal tail includes sufficient detail to calculate roll, pitch, and yaw response. Reimer and Vicroy (1996) examined the response of a Boeing 737-100 aircraft encountering the wake vortices of a Boeing 727 to determine a hazard boundary for the B737-100. With their approach, strip theory is used to calculate the aerodynamic forces and moments acting upon the aircraft where each strip is defined in terms of its area, two-dimensional lift-curve slope, angle of incidence, dihedral angle, and the body axis coordinates of the quarter and three-quarter chord points at the mid-span of the strip.

Adapting the approach of Reimer and Vicroy (1996), strip theory is used to model the follower in this work. The follower aircraft is modeled using the aerodynamic surfaces of the wing, horizontal stabilizer, and vertical stabilizer. Parameters necessary to define the follower aircraft model are the aircraft geometry, spanwise lift distribution, and the inertial tensors.

Tinling (1977), Loucel and Crouch (2005), and Vicroy et al. (1997) examined the maximum bank angle induced by the vortex as a criterion for determining a hazardous vortex encounter. Rossow and Tinling (1988) introduced the roll response, $\dot{p}$ (ratio of the roll acceleration due to the vortex-induced rolling moment to the roll acceleration brought about by a maximum aileron deflection, i.e., roll control authority also called the roll control ratio, RCR). They propose that a rule-of-thumb for defining nonhazardous encounters is $\dot{p}$ values less than or equal to 0.5. Schwarz and Hahn (2006) also consider RCR as a hazard metric and use it to define a simplified hazard area (SHA), an area to be avoided by following aircraft to reduce wake hazard.

In order to demonstrate the framework, two proof-of-concept analyses are conducted (see Boyd, 2008 for more detail). The first is informed by Vicroy et al. (1997) who found that encounter geometry and wake strength impact the encounter. The analysis herein examines 64 combinations of horizontal and vertical encounter angles and leader-follower separation distances in order to analyze follower aircraft response. This work includes encounter scenarios where the follower aircraft penetrates the wake flow-field at a 90-degree angle. As there is no pilot model yet incorporated into the tool, the results are more severe than what might be encountered in an actual aircraft.

The second analysis examines the sensitivity of the follower's response to the generator's weight in order to provide insight into the required precision for the weight of the generator aircraft to inform dynamic aircraft spacing when using the governing equations from Tatnall (1995). Because of the stochastic nature of the generator aircraft weight, this sensitivity analysis sheds light on whether mean weights can be used, or whether the full distribution needs to be considered when determining aircraft spacing.

Methods

Wake Flow-field

The Burnham-Hallock wake vortex model (Figure 1), originally proposed by Rosenhead (1931), can approximate the flowfield from any generator using only its weight, velocity, and wingspan (see Appendix for nomenclature). The inputs are: (a) W_G (weight of the generator), (b) $V_{\infty G}$ (velocity of the generator), (c) b_G (span of the generator), (d) the encounter time t_E (or alternatively the encounter distance $d_E = V_{\infty_G} t_E$), (e) the point (y_L, z_L) defining the center of the left vortex, (f) (y_R, z_R) defining the center of the right vortex, and (g) (y_p, z_p) the position at which to calculate the induced velocities. The output is the velocity vector [u v w]' in inertial coordinates. The point (y_p, z_p) can be substituted into the vortex flow-field equations and the sidewash and downwash values in the inertial coordinate system (v_I, w_I) can be determined. See Reimer and Vicroy (1996) for more details.

Vortex circulation strength at time t=0 (time of wake generation) is calculated (Tatnall, 1995):

$$\Gamma_\infty(t=0) = \frac{W_G}{V_{\infty_G} b_G (\pi/4)\rho} \qquad \text{(Eq. 1)}$$

and the vortex circulation strength decay is:

$$\frac{\Gamma_\infty(T_E)}{\Gamma_\infty(t=0)} = 1 - \frac{T_E}{8} \qquad \text{(Eq. 2)}$$

where T_E is a non-dimensional unit of time:

$$T_E = kt_E = \frac{32W_G}{\pi^4 \rho V_{\infty_G} b_G^3} t_E \qquad \text{(Eq. 3)}$$

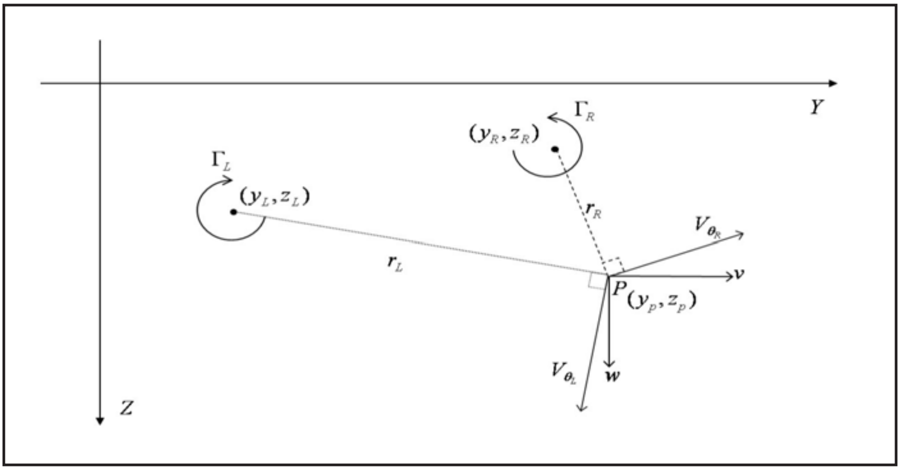

Figure 1. Two-dimensional wake vortex geometry

The vortex circulation strength $\Gamma_\infty(T_E)$ can be varied for a given $V\infty_G$ by varying the encounter time t_E. Defining the vortex circulation in this manner assumes a worst-case scenario for the wake decay. This model should be conservative when compared to most real world scenarios because it assumes atmospheric conditions conducive to a lingering wake (Tatnall, 1995).

Herein we implemented the mathematical framework outlined in Reimer and Vicroy (1996) using a vortex core radius of 2 ft. The wake encounters discussed occur during final approach to a runway. Thus, the air density used for all computations is the air density defined by the U.S. Standard Atmosphere for 400m (NASA, 1976).

Aircraft Response

One follower aircraft, a Boeing 757-200, is modeled using proprietary Boeing data. Inputs for the model include its initial velocity vector, its trim condition for the encounter scenario, and its initial orientation with respect to the inertial frame indicated by the Euler angles (φ, θ, ψ). Outputs are (a) the velocity vector in the inertial frame, (b) the position vector in the inertial frame, (c) the new Euler rotation angles (φ, θ, ψ), (d) the velocity vector in the body frame, (e) the vector of angular rates in the body frame, (f) the vector of angular accelerations in the body frame, and (g) a vector containing accelerations in the body frame.

Strip theory methods are used to model the aerodynamic effect of the wake on the following aircraft. Strip theory divides the aerodynamic surfaces (wing, horizontal, and vertical stabilizers) into small strips along the chord of the surface. Each strip is treated as a two-dimensional wing for which the forces and moments are calculated. Then all of the forces and moments of each strip are summed to get the total forces and moments for the airplane.

Each strip's force and moment contributions are calculated by determining the free-stream and wake-induced velocities at the strip's three-quarter chord point translated from the inertial-axis system to the body-axis system. The free-stream and wake velocities are then summed to get the local body-axis velocities for each strip using the implementation of Reimer and Vicroy (1996).

Each aerodynamic surface was divided into 10 strips – 20 for the wing, 20 for the horizontal tail, and 10 for the vertical tail. The lift gradients used were derived from Boeing proprietary data for the Boeing 757-200. For these analyses, local stall is ignored.

Encounter Scenarios

The final approach phase of flight is hazardous with respect to wake encounters because aircraft are low and slow—operating at the lower edge of their performance envelope. Figure 2 illustrates the encounter scenario considered in this work. The generator aircraft traveling at a TAS of $V_{\infty G}$ has conducted a missed approach/go-around at time t=0 and has departed the glideslope flying level at altitude h_E continuing along the localizer course. The generator leaves a horizontal wake that decays with time but has a fixed position (no transport). The following aircraft is traveling at a fixed true airspeed (TAS) of $V_{\infty F}$ on its final approach on the 3^o glideslope of an instrument landing system (ILS) approach to a runway at an altitude h_0. It vacates its altitude h_0 at the approach velocity $V_{\infty F}$ to reach the encounter point E at the encounter time t_E (from when the follower is at its initial position to when it reaches the encounter point) and at the encounter altitude h_E. The follower aircraft encounters the wake of the generator at encounter point E, an encounter distance d_E from the follower's initial position.

This encounter scenario describes a general parallel wake encounter with the horizontal angle between the wake vortices and the flight path of the follower aircraft equal to 0. Although this encounter is not exactly like a go-around or missed approach (since the generator aircraft continues straight and level), we used it for comparison purposes to Reimer and Vicroy (1996).

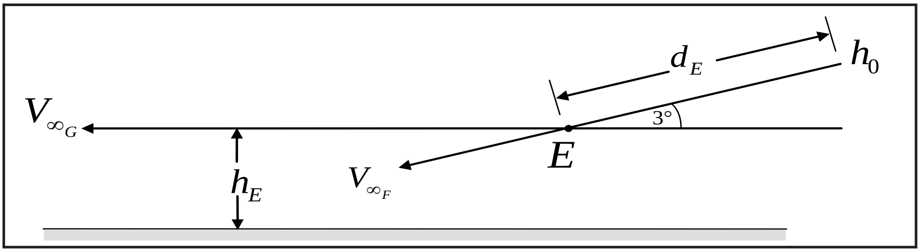

Figure 2. Encounter scenario

This paper also considers non-parallel encounters (i.e. encounters involving a horizontal encounter angle). The horizontal angle is defined by the acute angle observed between the headings of the generator aircraft (and thus, the wake vortices) and the follower aircraft velocity vectors in the X-Y inertial plane.

Apparatus

The experimental simulation apparatus was developed in MATLAB Simulink with the Aerospace Toolkit and Aerospace Blockset. MATLAB is used by industry, government, and research organizations to perform aerospace analyses. Included with the Aerospace Toolkit and Blockset suite is a six-degree-of-freedom solve block. This block integrates the equations of motion by using the parameters: total forces, total moments, and an inertia matrix. At each time step, the aircraft's position is calculated as well as the wake flow-field. Then, the strip calculations are performed and the total forces and moments due to the wake are added to the current forces and moments of the aircraft. See Boyd (2008) for more details.

For each simulation trial, the Euler angles, the angular accelerations, and the position of the center-of-mass in inertial coordinates are recorded. The metrics defining the encounter are the bank angle extremum φ_{ext}, the roll acceleration extremum $\dot{p}_{ext}$, the localizer deviation extremum L_{ext}, and the glideslope deviation extremum GS_{ext}. The metrics φ_i and $\dot{p}_i$ are direct output from the model. The metrics L_i and GS_i are derived from the position vector output. If the desired course (localizer or glideslope) is the vector **c** and the current aircraft is the position vector **p**, then the distance between the point defined by **p** and the line defined by c in two dimensions is

$$D = \frac{|\mathrm{c} \times \mathrm{p}|}{|\mathrm{c}|} \qquad \text{(Eq. 4)}$$

This formula then defines the formulae for L_i and GS_i. For L_i

$$x_0 = x_{l_0}$$
$$x_1 = 0$$

$$y_0 = y_{I_0}$$
$$y_1 = 0$$
$$x_i = x_{I_i}$$
$$y_i = y_{I_i}$$
$$L_i = \frac{\left|(y_0 - y_1)x_i + (x_1 - x_0)y_i + (x_0 y_1 - x_1 y_0)\right|}{\left|(x_1 - x_0)^2 + (y_1 - y_0)^2\right|} \qquad \text{(Eq. 5)}$$

where *i* represents the time step. A similar formula is used for calculating GS_i.

Encounter Geometry and Wake Strength Analysis

For all analyses, a core radius of $r_c = 2$ ft is used to calculate the vortex effects. 64 encounter scenarios were simulated by crossing 4 glideslope angles (2, 3, 4, and 5 degrees), 4 horizontal encounter angles (0, 30, 60, and 90 degrees), and 4 wake strengths equivalent to the follower distances of 2, 3, 4, and 5 nautical miles behind a Boeing 747 aircraft. Note that the resultant wake circulation strength of a 747 could, in fact, be created by several aircraft because an infinite number of generator aircraft weights and wingspans coupled with follower distances can yield a given wake circulation using the Tatnall (1995) model. Table 2 highlights this point.

Table 2

Example aircraft and decay times for circulation strength of 110 m^2/s. Aircraft parameters from Stuever (1996). Note: numbers were generated using the Tatnall (1995) governing equations, which may not be valid for all weight regimes listed here.

Aircraft	Weight (1000 lbs)	Velocity (kts)	Wingspan (ft)	Decay time (s)
B747-100	735.0	140	195.8	120
B777-200	590.0	138	199.9	151
MD-81	140.0	132	107.8	72
DHC-8	41.1	99	90.0	32
Citation X	31.0	126	64.0	3

Another series of simulation scenarios were run such that the vertical angle was fixed at three degrees and the distance was fixed at five nautical miles. Then the horizontal encounter angle was run in increments of 10 degrees from 0 to 90 degrees. This yields a cross-section of how the horizontal encounter angles impact the dependent variables.

Weight Sensitivity Analysis

Three encounter geometries were selected to examine the effect of a B777-200 generator's weight on a follower aircraft on a 3-degree glideslope (standard ILS approach) at a separation distance of five nautical miles as stipulated by FAA regulations. Each encounter had either a 0, 30, or 60-degree horizontal encounter angle. Then, for each encounter geometry, the weight of the generator was varied (Table 3) and the bank angle extremum plotted.

Table 3

Quantiles and weights of B777-200 used in weight sensitivity analysis.

Quantile	0.01	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	0.99
Weight (lbs)	379852.1	397613.6	405092.4	410485.2	415093.1	419400.0	423706.9	428314.8	433707.6	441186.4	458947.9

Dependent Variables

The dependent variables for both analyses were the following aircraft's responses:

- The bank angle extremum.
- $\dot{P}_{ext}$, the extremum wake-induced roll acceleration.
- The maximum glideslope deviation.
- The maximum localizer deviation.

Results

All of the graphs and output from this section were produced using R (R Development Core Team, 2008). For the ANOVA analyses, the results are reported as significant at $\alpha = 0.05$.

Wake encounter geometry and strength

The average computation time required to run one 100-second simulated flight was just over six seconds. The distance and vertical encounter angle impact the severity of the aircraft's response. The shorter the following distance, the stronger the wake, and the larger the response exhibited by the aircraft. The steeper the encounter angle, the shorter the period the aircraft is exposed to the wake and the less the response. Most of the significant flow-field velocities are within about a 75m radius of the center point on a line between the two vortex cores (Figure 3). The longer the aircraft remains in this corridor, the larger the reaction.

The responses are similar for the same horizontal encounter. Thus, the encounters for a two nautical mile following distance and three degree glideslope are presented (see Boyd, 2008, for more results). For the zero degree horizontal encounter, the aircraft is slowly descending into the flow-field directly above the right vortex. With this position in the wake, the left wing is mostly exposed to a downwash while the right wing is mostly exposed to an upwash. As a result, the aircraft has a strong left-turning tendency and never actually gets within about 50 meters of either vortex. None of the 0-degree encounters directly penetrated the vortices (Figure 4). This is because the aircraft begins its left turn well in advance of a direct vortex encounter. Figure 5 shows that for the zero degree horizontal encounter angle, the aircraft exhibits a gradual bank to the left along with a coupling in pitch. The rates, rate accelerations, and body accelerations are plotted in Figure 6. The Y-Z trace in Figure 7 shows that the aircraft does not actually penetrate the wake vortices, but still makes a nearly 400 degree turn followed by large vertical flightpath oscillations.

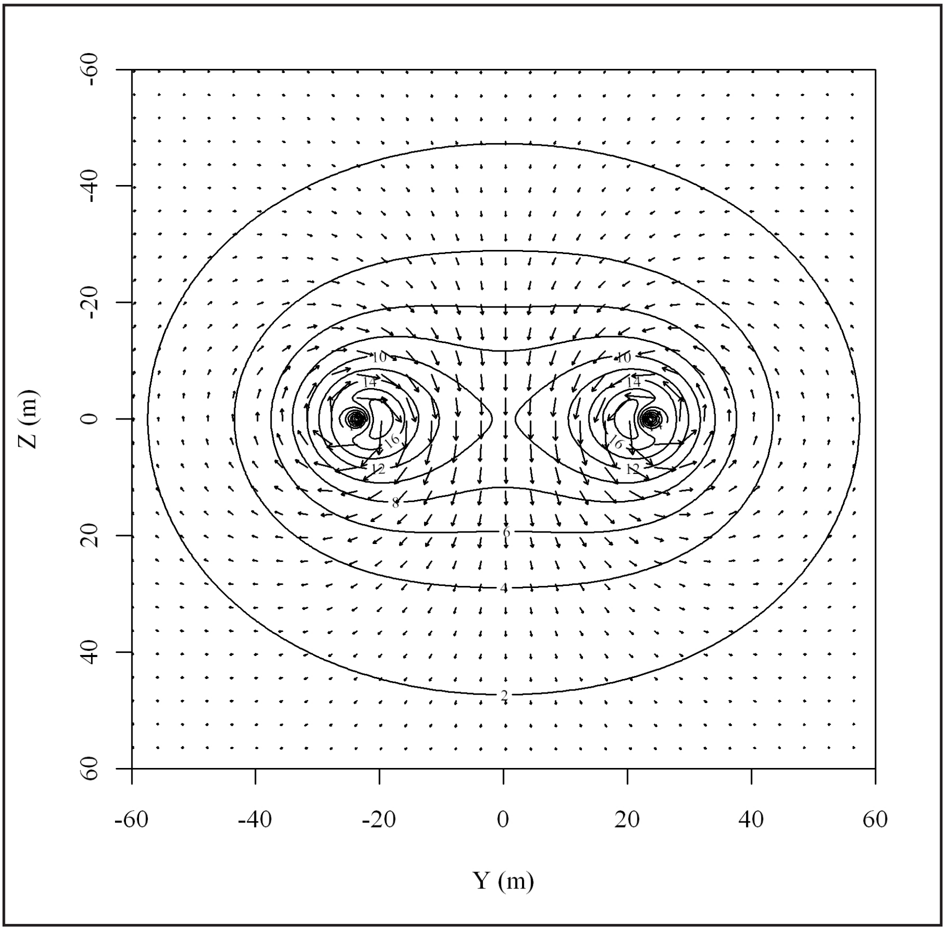

Figure 3. Wake flow-field of 747-100 generator after 56 seconds decay (2nm). Contours depict lines of equal wind velocity (m/s).

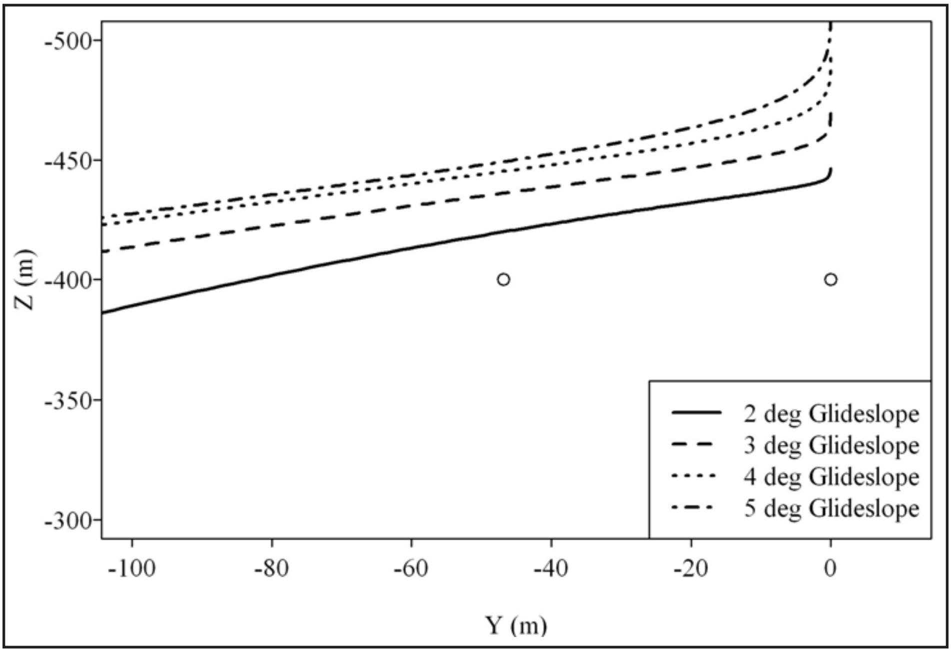

Figure 4. Y-Z traces for 0 degree horizontal encounter angle. (Circles indicate vortex centers)

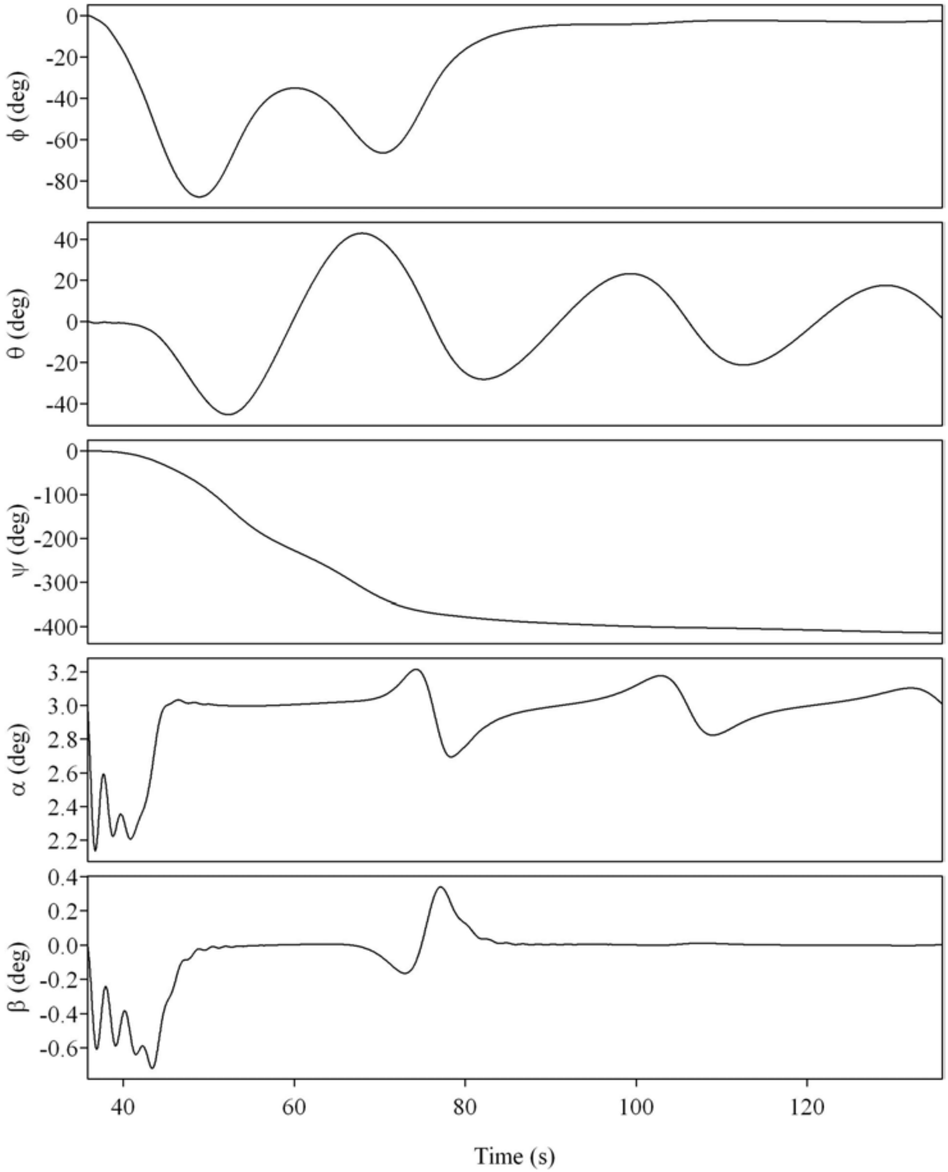

Figure 5. Roll φ, Pitch θ, Yaw ψ, Angle of Attack α, and Sideslip Angle β for 2nm distance, 3^o glideslope, 0^o horizontal angle

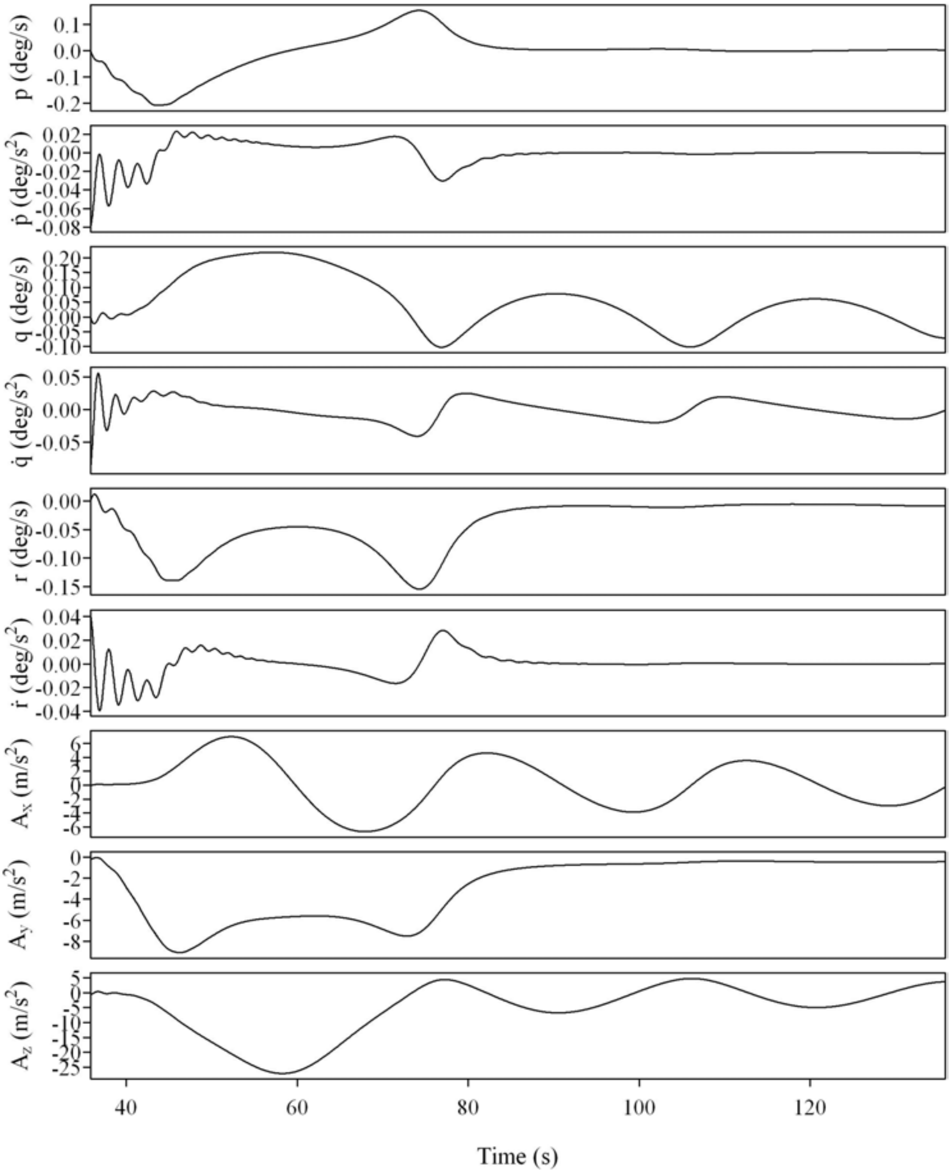

Figure 6. Roll Rate, Roll Acceleration, Pitch Rate, Pitch Acceleration, Yaw Rate, Yaw Acceleration, X-body Acceleration, Y-body Acceleration, and Z-body Acceleration for 2nm distance, 3^o glideslope, 0^o horizontal angle

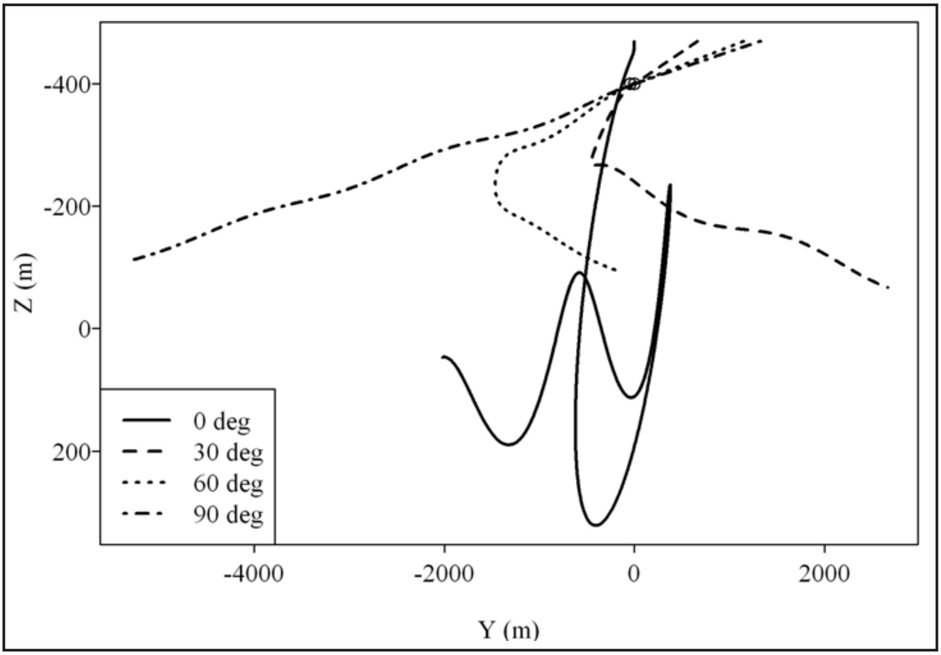

Figure 7. Y-Z traces of the aircraft for horizontal encounter angles of 0, 30, 60, and 90 degrees. (circles at (0, -400) are the vortex locations)

For the 30-degree horizontal encounter angle (Figure 8), the aircraft enters a sharp left bank. Then, as it moves across the wake field from right to left, it is influenced by the left vortex and has a sharp bank to the right. As the aircraft approaches the right vortex, the aircraft pitches up a little, then it hits the zone between the vortices where a strong downwash exists and has a sharp drop in pitch angle. The aircraft then hits the outside of the left vortex causing the pitch to increase again. The rest of the encounter is the damped sinusoid reaction exhibited by the aircraft returning to the trim condition (equilibrium).

Examining the rates, rate accelerations, and body accelerations in Figure 9, Roll Rate, Roll Acceleration, Pitch Rate, Pitch Acceleration, Yaw Rate, Yaw Acceleration, X-body Acceleration, Y-body Acceleration, and Z-body Acceleration for 2nm distance, 3^o glideslope, 30^o horizontal angle shows that this is a more violent encounter than that of the 0 degree horizontal encounter angle. The perturbations have a much higher frequency and pitch, roll, and yaw are all excited. There are also accelerations in all three axes with a lateral acceleration as high as 0.6g's and a vertical acceleration as high as 1g. Most importantly, the jerk, or the rate of change of the acceleration, is much higher than that of the 0-degree horizontal encounter. The Y-Z trace in Figure 7 shows that the aircraft makes a substantial left turn with some large vertical flightpath oscillations.

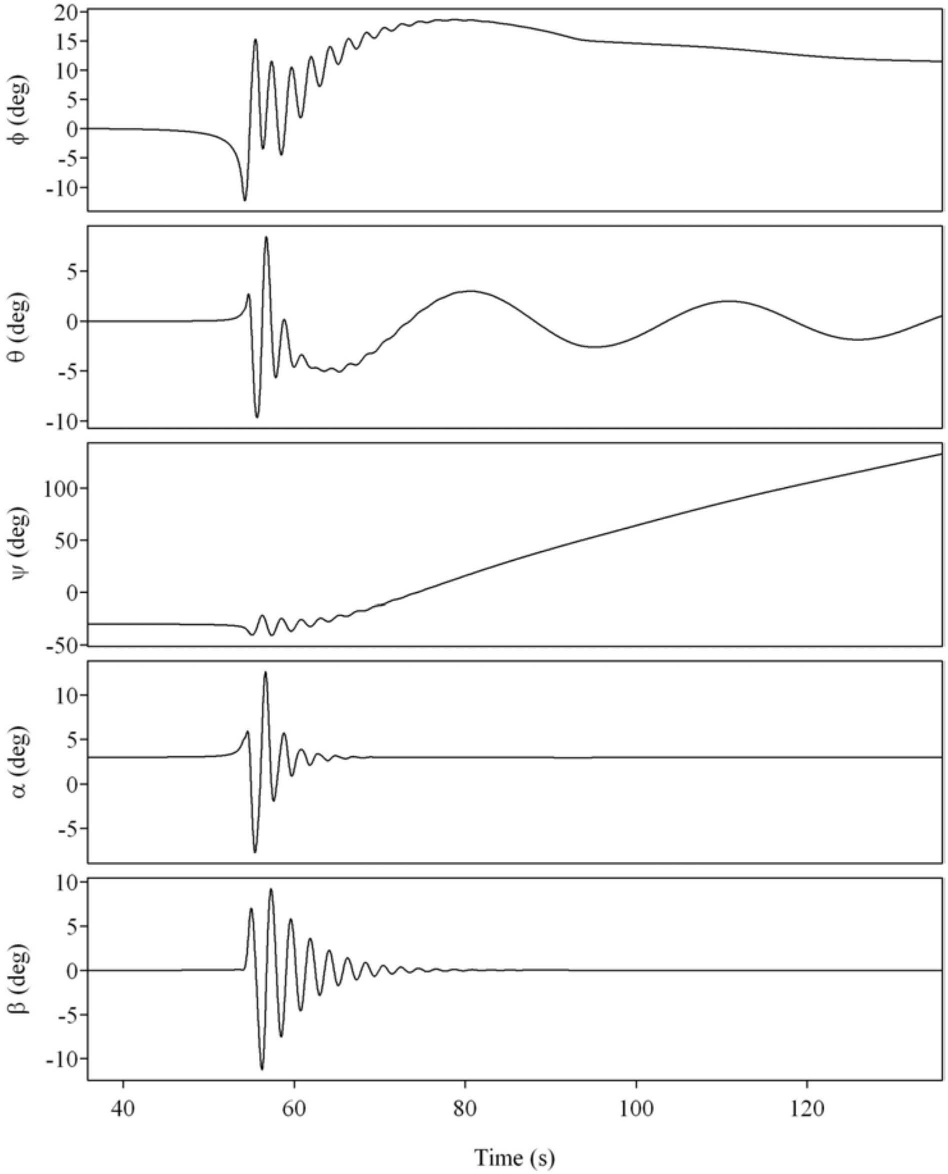

Figure 8. Roll φ, Pitch θ, Yaw ψ, Angle of Attack α, and Sideslip Angle β for 2nm distance, 3° glideslope, 30° horizontal angle

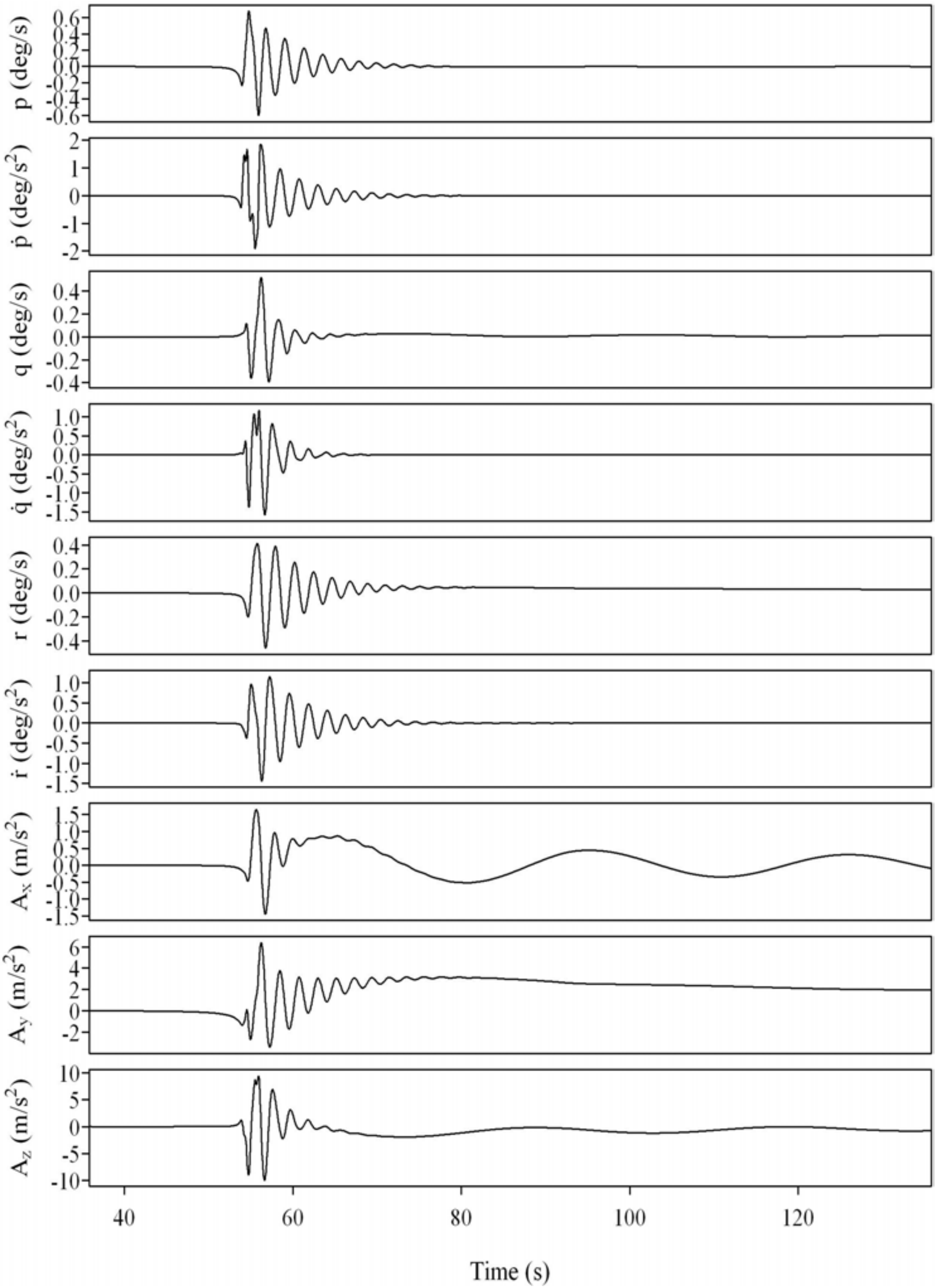

Figure 9. Roll Rate, Roll Acceleration, Pitch Rate, Pitch Acceleration, Yaw Rate, Yaw Acceleration, X-body Acceleration, Y-body Acceleration, and Z-body Acceleration for 2nm distance, 3° glideslope, 30° horizontal angle

The 60-degree horizontal encounter, Figure 10, is similar to the 30-degree encounter, except that the aircraft has less rolling response. This is due to the shorter exposure to the vortices. Figure 11 shows the rates and accelerations of the encounter. The perturbations for the 60-degree encounter are not as large in amplitude as those from the 30-degree encounter, but pitch, roll, and yaw are still excited. There are also accelerations in all three axes. The Y-Z trace is shown in Figure 7.

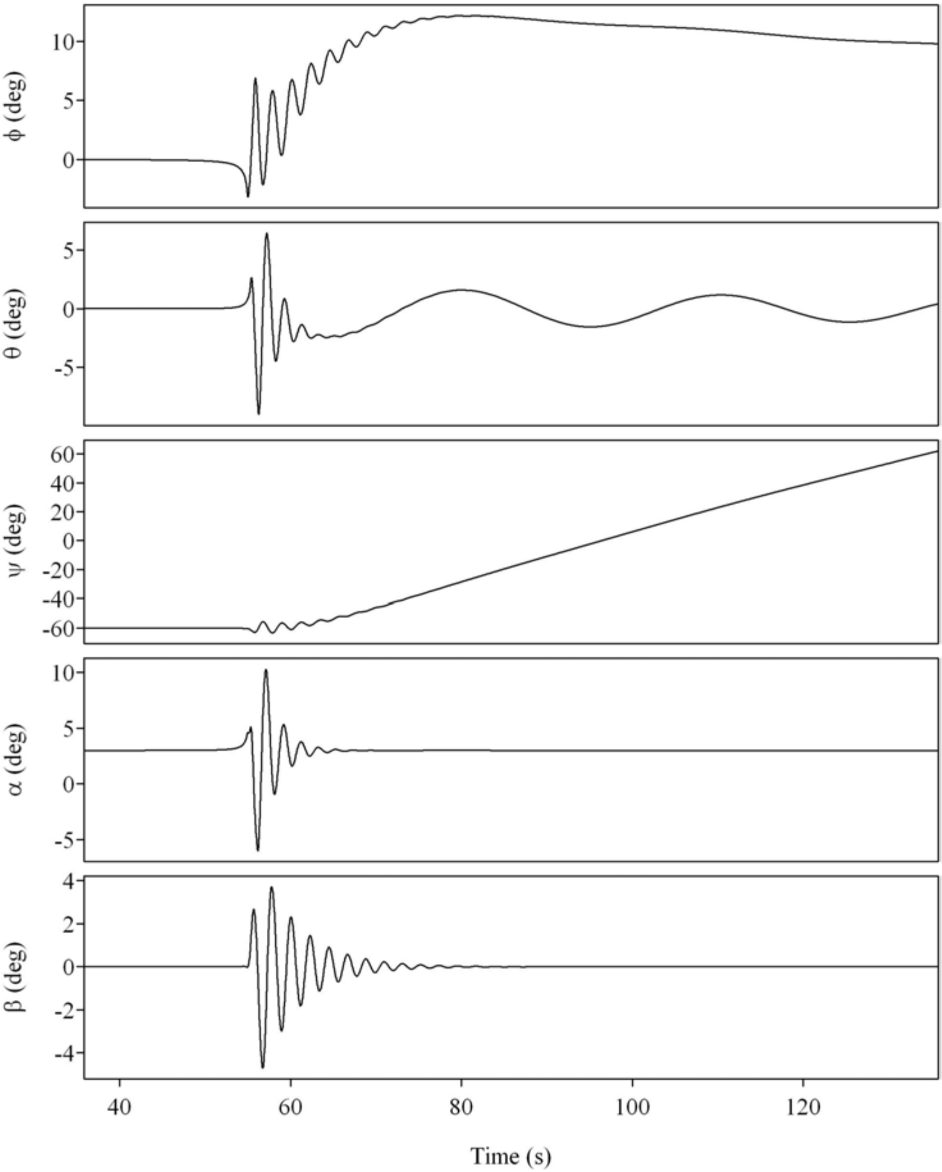

Figure 10. Roll, Pitch, Yaw, Angle of Attack, and Sideslip Angle for 2nm distance, 3^o glideslope, 60^o horizontal angle

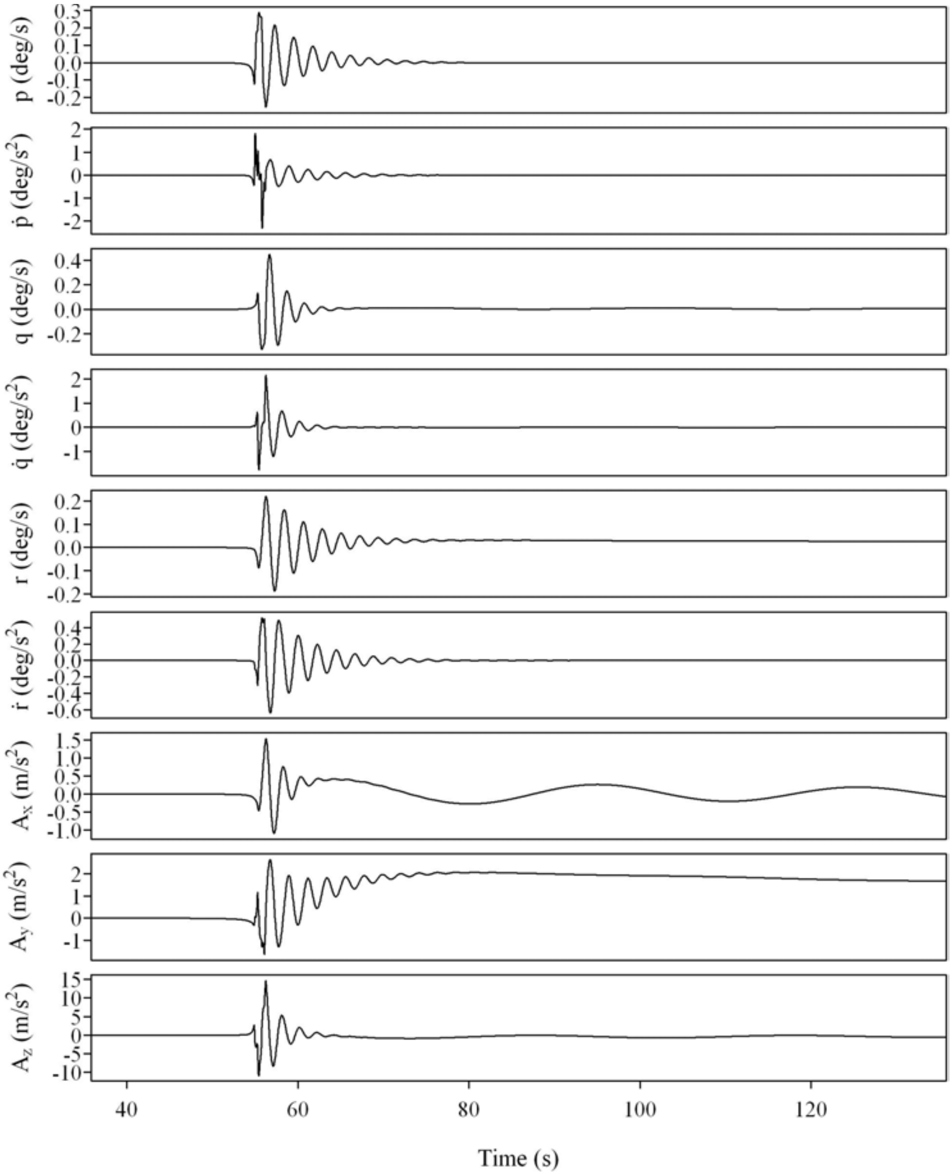

Figure 11. Roll Rate, Roll Acceleration, Pitch Rate, Pitch Acceleration, Yaw Rate, Yaw Acceleration, X-body Acceleration, Y-body Acceleration, and Z-body Acceleration for 2nm distance, 3^o glideslope, 60^o horizontal angle

Finally, the 90-degree encounter in Figure 12 excites only a pitching response. As the aircraft approaches the right vortex, the pitch increases. Between the two vortices, the aircraft has a sharp decrease in pitch, and as it departs the left vortex has an increase pitch. The aircraft then oscillates as it returns to trim. Figure 13 clearly shows that only aircraft pitch is affected by the wake encounter, as there are no lateral accelerations. The Y-Z trace in Figure 7 shows that the aircraft continues its general flightpath after encountering the wake with some vertical flightpath oscillations.

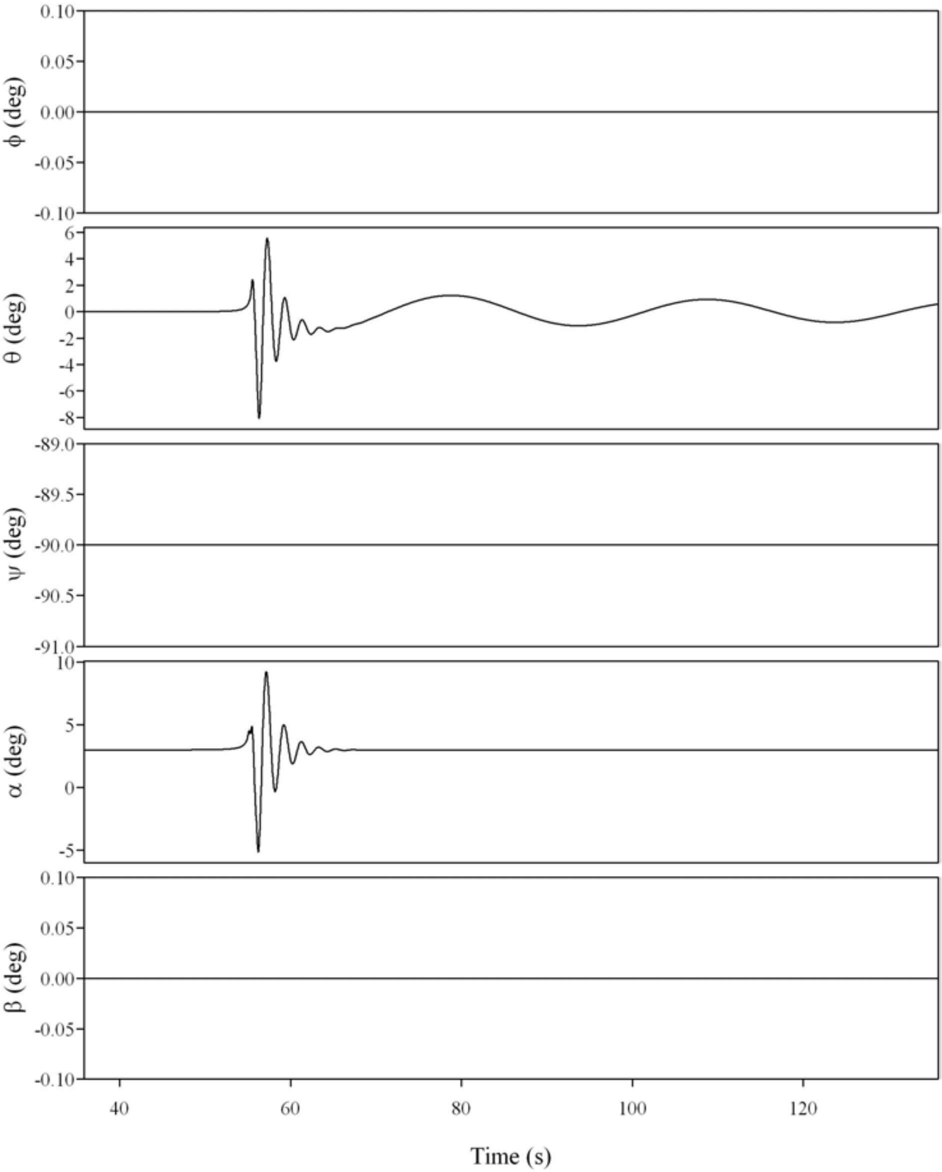

Figure 12. Roll φ, Pitch θ, Yaw ψ, Angle of Attack α, and Sideslip Angle β for 2nm distance, 3° glideslope, 90° horizontal angle

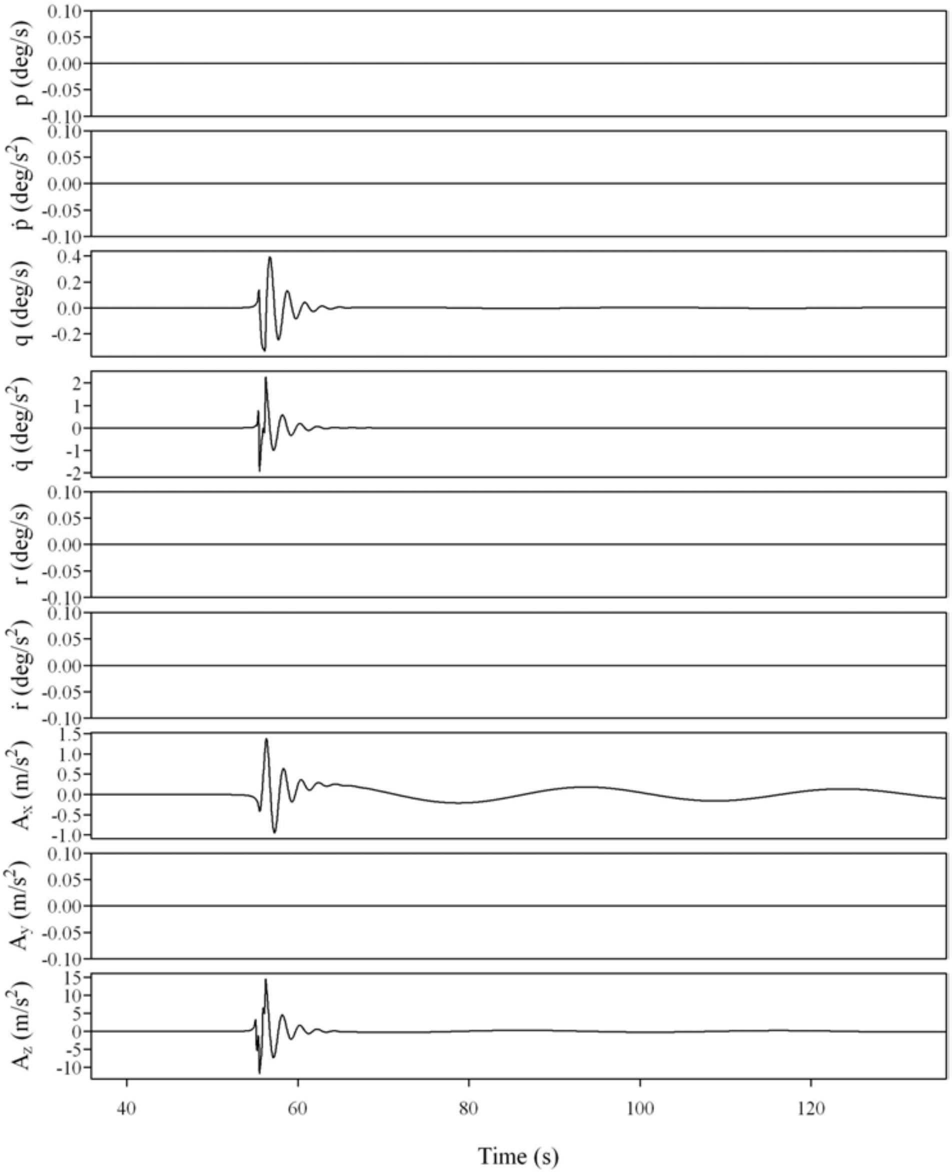

Figure 13. Roll Rate, Roll Acceleration, Pitch Rate, Pitch Acceleration, Yaw Rate, Yaw Acceleration, X-body Acceleration, Y-body Acceleration, and Z-body Acceleration for 2nm distance, 3^o glideslope, 90^o horizontal angle

Demonstrating the sensitivity of the horizontal angle, an encounter was run for a 3-degree glideslope at a distance of five nautical miles for horizontal angles from 0-90 degrees spaced at intervals of 10 degrees. Figure 14 shows that the more perpendicular the encounter, the less the roll response is.

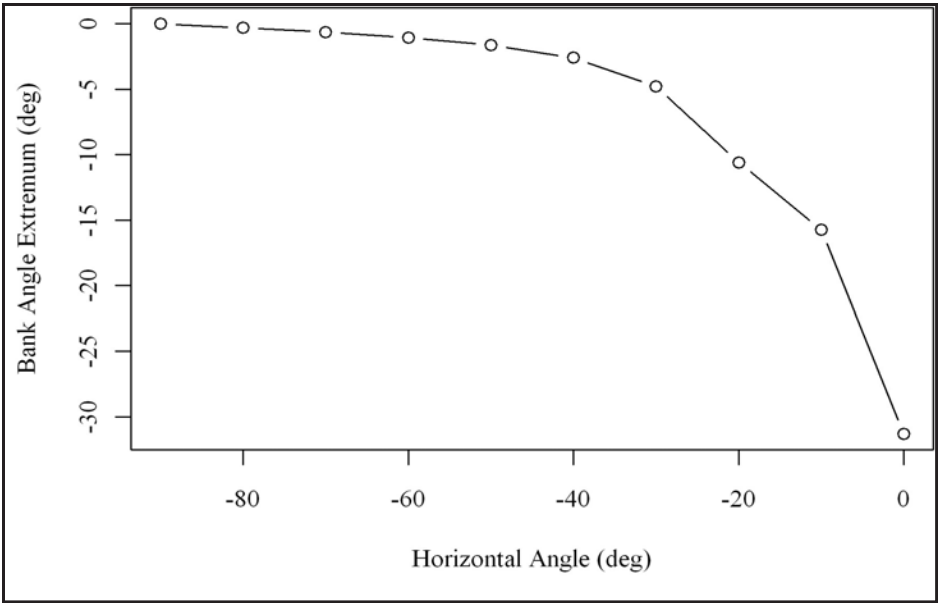

Figure 14. φ extremum against horizontal encounter angle

Table 4 lists the condensed relevant information from the ANOVA tests conducted on the full range of the 64 runs. The results show that encounter distance and horizontal encounter angle have significant influences on the bank angle extremum φ. The interaction of distance and horizontal encounter angle and the interaction of glideslope and horizontal encounter angle are also significant. Additionally, the ANOVA test reveals that the interaction between the distance and horizontal encounter angle and the interaction between the glideslope angle and horizontal encounter angle have statistically significant effects on the bank angle extremum φ.

Table 4

ANOVA Results for Dependent Measures

	Independent Variables					
Dependent Measures	Distance	Glideslope Angle	Horizontal Angle	Dist × Glide	Dist × Horiz	Horiz × Glide
ϕ	F(3,27)=4.92 p =0.0074*	F(3,27)=2.01 p =0.1368	F(3,27)=565.6 p =(<2e-16)*	F(9,27)=0.49 p =0.8653	F(9,27)=16.1 p =1.1e-8*	F(9,27)=22.61 p =2.4e-10*
$\dot{\rho}$	F(3,27)=1.62 p =0.2070	F(3,27)=1.00 p =0.4066	F(3,27)=51.94 p =2.4e-11*	F(9,27)=1.00 p =0.4654	F(9,27)=5.6 p =2.2e-4*	F(9,27)=1.03 p =0.4443
Glideslope Deviation	F(3,27)=94.6 p =1.9e-14*	F(3,27)=67.7 p =1.1e-12*	F(3,27)=1308 p =(<2e-16)*	F(9,27)=0.82 p =0.61	F(9,27)=55.8 p =4.0e-15*	F(9,27)=70.7 p =(<2e-16)*
Localizer deviation	F(3,27)=3.00 p =0.048*	F(3,27)=0.5 p =0.683	F(3,27)=40.3 p =4.1e-10*	F(9,27)=1.43 p =0.225	F(9,27)=2.45 p =0.035*	F(9,27)=0.63 p =0.763

Note: *p < 0.05 (indicates significant results for α=0.05)

For the response variable $\dot{p}$, the ANOVA tests show that of the main effects, only the horizontal encounter angle is significant. This is likely due to the narrow range of values for the roll acceleration extremum. Additionally, the ANOVA test shows that the interaction between the distance and horizontal encounter angle has a statistically significant effect.

All of the independent variables and interactions, except for distance and glideslope, have a significant effect on the glideslope deviation. And for the maximum localizer deviation, the ANOVA results show that encounter distance and the horizontal angle are significant.

Weight Sensitivity Analysis

The simulation was run 11 times for the weight sensitivity analysis, once for each quantile of the generator's weight that was used. The influence of the weight on the bank angle extremum is shown in Figure 15 for a 0-degree horizontal encounter angle. The weights examined covers 98% of the entire weight distribution for the operational weight data of a B777-200 collected. In the lower 50% of the weight distribution, the bank angle response is more sensitive to the weight than in the upper 50% of the distribution. However, over the entire range examined, the bank angle only varies by about six tenths of one degree.

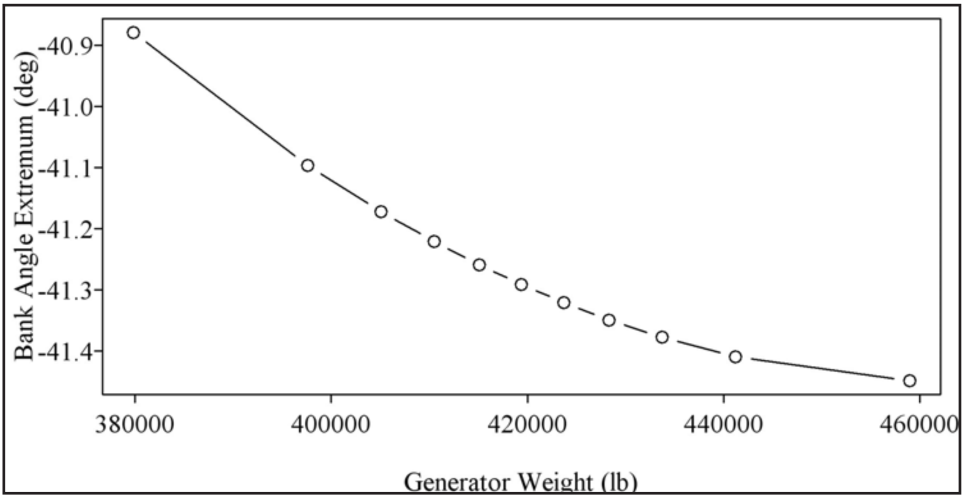

Figure 15. Sensitivity of bank angle extremum to generator weight, 0-degree horizontal encounter angle

The roll acceleration extremum from Figure 16 shows a similar result, except that the sensitivity is more linear across the distribution. The roll acceleration only varies by 0.4 (deg/s) over the range examined.

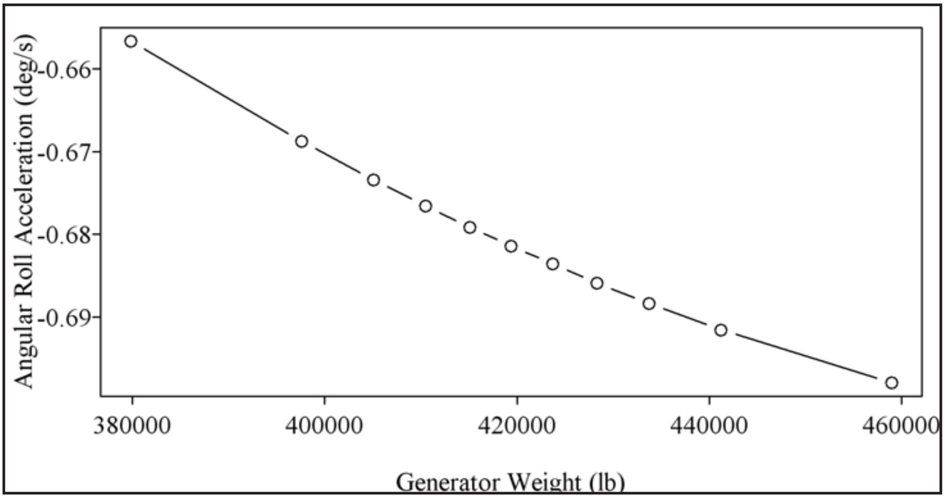

Figure 16. Sensitivity of roll acceleration extremum to generator weight, 0-degree horizontal encounter angle

Discussion

This work provides a framework and methodology to analyze an aircraft wake vortex encounter in an analysis software toolset built using a commercially available software package and can run on a standard desktop computer. The simulation model requires only the aircraft geometry, spanwise lift distribution, and the inertial tensors of the follower aircraft to run. With these data, the model is generalizable to any generator and follower aircraft pairing. Additionally, the wake flow-field model can be easily changed to use a different model or even run data collected from wind tunnels or live flights. Finally, the framework is flexible enough to allow a wide variety of wake encounter geometries.

The empirical results obtained from the proof-of-concept analysis provide insight into the effect wake strength and encounter geometry has on the reaction of the follower aircraft. The results of the sensitivity analysis suggest that the response of the follower aircraft may not be sensitive to the weight distribution of the generator aircraft using the governing equations from Tatnall (1995). However, it should also be noted that the encounters examined are not necessarily worst-case encounters as the aircraft is often kicked out before it is fully influenced by the wake. Future research should follow the guidance of Höhne, Luckner, and Fuhrmann (2004) in determining critical wake encounters using their process Worst-Case-Search (WCS).

The wake strength and encounter geometry analysis results provide an overview of a wide range of encounter geometries. The closest prior research to conduct this type of an analysis is that of Loucel and Crouch (2005). They present results for encounter geometries with the horizontal angles between 0 and 30 degrees and vertical angles between -15 and 15 degrees and their response metric was the maximum encounter bank angle. Their results agree with the results of this research. As the horizontal angle moves from a parallel to perpendicular, the maximum bank angle decreases. Additionally, as the vertical angle moves away from parallel, the maximum encounter bank angle decreases. The difference between the two efforts is that their model included an autopilot that was trying to maintain a given course, so the response was not as oscillatory as the responses presented here. Again, future research needs to include a pilot or autopilot model.

For future work, the aircraft model will have to include some element of control—either a pilot or autopilot model. After this is added, the perturbations should be conducted again to see how the aircraft responds along with the control models. Incorporating control into the model will make the encounters more realistic. The results from this research are more severe than what would occur in a real-world environment since a pilot would certainly not allow his or her aircraft to roll 110 degrees at low altitude. Additionally, a controlled aircraft will be less likely to be thrown from the wake since it will more closely maintain the desired trajectory. Staying on the desired trajectory may expose the aircraft to the influence of the wake for a longer period of time or even cause the aircraft to have a more direct penetration through the wake. Either may subject the aircraft to a larger wake response than would result from a model without control.

Examining the sensitivity of the generator weight on the follower response shows that over the range of operational landing weight data collected for a Boeing 777-200 generator, the bank angle extremum for the Boeing 757-200 follower varies by 0.6 degrees. While this does not seem to be a dramatic result, other researchers (Tinling, 1977; Rossow and Tinling, 1988) have determined that a bank angle as small as 5 degrees defines the boundary layer for wake encounter acceptability at low altitudes. The bank angle sensitivity appears to have a non-linear relationship with the weight of the generator aircraft. At the lower weights, the bank angle appears to be more sensitive. This suggests that future work should conduct a more comprehensive sensitivity analysis. Other aircraft weight distributions should be examined along with other wake strength and encounter geometries. Additionally, the Tatnall (1995) equations should be empirically confirmed for the generator weight regimes this study considers.

To define an acceptable wake encounter such that a new aircraft spacing system can be designed and implemented, an in-depth analysis is necessary that addresses several aspects of the wake encounter event. Several aircraft pairings, encounter geometries, and aircraft spacings must be examined. Also, the effect of environmental conditions on the wake strength and transport could be considered. This search space makes the efficiency and speed of the analytical software quite important.

To make a determination about how to define an acceptable wake encounter, researchers must conduct human subject experiments with air transportation users, as in Luckner, Höhne, and Fuhrmann (2004), (pilots, passengers, air traffic controllers, etc.) since acceptability is typically a subjective assessment. In order to conduct human subject experiments, an analysis tool must exist in order to generate the encounter scenarios that the participants will experience. This research provides the framework and software tool necessary to generate such scenarios.

After the scenarios are generated, researchers need to conduct an analysis to see which response metric (or metrics) has the best predictive quality for determining encounter acceptability. $\dot{P}$ examined in this research tends to indicate the violence of the encounter—if it is a smooth or rough encounter—and how effective the aircraft should be in overcoming the wake-induced roll perturbations. The roll angle extremum tends to indicate the overall severity of the encounter. The parallel wake encounter angles had a lower value for $\dot{P}$ but had a more extreme roll angle than the oblique encounters. This indicates that the aircraft eases into the wake for parallel encounter and stays in longer causing a larger upset. For the oblique encounters, the aircraft is in and out of the wake faster having a more violent (higher jerk) response, but less in magnitude than that of the parallel encounter. The glideslope and localizer deviations are extremely important when making a determination about whether a safe landing can continue. However, the deviations resulting from this research are not very relevant since there was no control in the model and the aircraft was not attempting to maintain a desired trajectory.

Having selected the metrics to determine encounter acceptability, the analysis tool produced from this research or a variant can be used by researchers to determine the wake response for many aircraft pairings, geometries, and separation distances. Collecting these responses in a database, a Monte Carlo simulation can be conducted to determine the Pareto frontier balancing wake encounter acceptability with increased traffic volume building on the example application for WakeScene (Wake Vortex Scenarios Simulation) presented in Holzäpfel et al. (2006).

Acknowledgments

This research was funded in part by the National Institute of Aerospace Contract NAS1-02117 Task Order Statement of Work and NASA Task Order: Wake Hazard Definition (Subtask 3.3 Define Acceptable Wake Encounter) referenced by NASA Task Order Number NNL06AB54T. The NASA Langley Research Center (LaRC) project technical monitors were Dr. Wayne Bryant, Dr. Fred Proctor, and Dr. Edward Johnson. The authors acknowledge guidance provided by Dr. Dan D. Vicroy of NASA LaRC and Dr. Lloyd E. Barrett of University of Virginia's Department of Mechanical and Aerospace Engineering. The authors thank Boeing for supplying the necessary proprietary Boeing 757-200 data required to model the follower aircraft.

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Appendix

Nomenclature

b = wing span, ft
d_E = encounter distance, ft
h_E = altitude of vortex encounter, ft
h_0 = altitude of following aircraft at time 0, ft
r_c = vortex core radius, ft
r = radius from vortex center, ft
t = time, s
T = non-dimensional unit of time
u = velocity component along **X-axis**, ft/s
v = velocity component along **Y-axis**, ft/s
w = velocity component along **Z-axis**, ft**/s**
W = aircraft weight, lb
x = coordinate along **X-axis**, ft
X = longitudinal axis
y = coordinate along **Y-axis**, ft
Y = lateral axis
z = coordinate along **Z-axis**, ft
Z = vertical axis
ρ = atmospheric pressure, slug/ft^3
θ = pitch angle, rad
φ = roll angle, rad
ψ = yaw angle, rad
Γ = vortex circulation strength, ft$_2$/s
h = height
i = time index during navigation

International Journal of Applied Aviation Studies, Volume 9, Number 1
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Moral Development in Pilot Populations

Erica Diels

Gary Northam

and

Brian Peacock

Department of Safety Science
Embry Riddle Aeronautical University

Abstract

Ethical issues are being discussed more frequently in society today and, while most industries are taking steps to improve ethical decisions through education, aviation is lagging behind in both the understanding of ethical issues inherent to the industry and ethics education. In this study three groups of pilots (students, instructors, and faculty) at Embry-Riddle Aeronautical University were examined in an effort to determine moral development level in terms of P score on the Defining Issues Test 2 (DIT2). It was hypothesized that differences would be found among the groups and that the moral development score would increase from students, through flight instructors to faculty. This was found to be the case. The instructor and student pilots scored lower than expected in the DIT2 questions and it is suggested that this may be due to a lack of ethics training in aviation curricula.

Requests for reprints should be sent to Kay Chisholm, FAA Academy, AMA-800, P.O. Box 25082, Oklahoma City, OK 73125. E-mail to kay.chisholm@faa.gov.

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Moral Development in Pilot Populations

In this day and age, many leaders, businesses, and high profile operations have brought to the forefront the issue of ethics and ethics education. Unfortunately, the reason for this is not a positive one. Poor decisions involving ethics have become more and more common, particularly in the business world (e.g. ENRON) and in the aviation field (various airlines in the news for skimping on routine maintenance inspections). In an attempt to counter this problem, the application of ethics education has been increasing in many industries. Many professional schools include ethics courses in their curricula. Aviation, on the other hand, has not seen such an increase.

For the purpose of this paper, morality is defined as a set of (human) laws that seek to assure harmony among individuals and groups. Ethics embraces the study of morality and the practical standards established to define morality more precisely (Peacock, Northam, and Diels, 2008). It follows that “professional ethics” are the behavior standards set by well-defined professional groups, such as medicine, business, engineering, and aviation. Many professional organizations formalize and publish sets of ethical standards. Given that the purposes of all organizations are effectiveness, efficiency, safety, and satisfaction, the ethical dilemma is often found in the tradeoffs among these purposes and perhaps in the different points of view of the various providers and customers of the service.

Because aviation faces high consequences of failure, it has developed as a profession based on stringent selection, training, and oversight. In the early days, given adequate contexts the outcomes of a flight were focused on the pilot in command. The pilot was in turn charged with offering good “aviation decision making.” In more recent years this focus of responsibility has broadened somewhat to include the concepts of “crew resource management,” in which there may be many contributions and contributors to each “aeronautical decision.” Nevertheless, the prime responsibility still lies with the pilot in command.

Thus, the pilot in command may be faced with many dilemmas and tradeoffs between effectiveness, efficiency, safety, and satisfaction. Moreover, the expectations of different groups of providers and customers may differ widely. One recent example of a complex aeronautical decision-making chain, which had a catastrophic outcome, was the weather related crash of Continental Flight 3407 near Buffalo. The finger pointing related to this accident spreads far and wide, way beyond the pilot in command, and many people, policies, and practices were identified as being lacking.

The study of ethics in aviation focuses on the processes by which those involved handle complex decisions and tradeoffs. The development of ethical standards will be based on ethical principles from many sources. The implementation of these principles will be through education.

As aviation moves into its second century, the challenges and issues that face it are beginning to change. Technology in the industry continues to advance, forcing all aspects from flight training to air carrier operations to keep pace. For example, widespread use of unmanned aerial systems is just around the corner (Peacock and Northam, 2007). Regulation must also be implemented in an effort to keep laws current and applicable. This is not always an easy task in such a fast moving, high-risk industry. This risk pertains not only to lives, but to property and business success as well. A large amount of regulation and Standard Operating Practices/ Procedures (SOPs) are an integral part of managing the risk. While these cover most operations within the industry, there are still a few “grey” areas that have little or vague regulation. This requires some application of judgment and/or ethical decision making to achieve a desirable outcome. Even with these grey areas, ethics in the industry and ethical decision-making are rarely addressed in training or in consideration of professional behavior. This may be due to the argument that aviation has so many rules that ethical issues are left to the individual, since as long as one obeys the rules they are doing the “right” thing, but even if one obeys the rules there is still room for unsafe and unprofessional behavior. Even with all the regulation, SOPs, and oversight, accidents occur on a regular basis. Many of these events met the rules, mostly met the rules, or resulted from bad decisions in a “grey area” of legislation. Other events occur due to individuals or groups taking shortcuts for reasons of expedience or personal convenience.

On a day-to-day level in the flight-training environment, flight instructors are required to make decisions regarding the balancing of mission completion, weather, personal finances, operational rules, and student benefit/relationship (Northam & Diels 2007). No strict rules or guidance exist and very little formal training addresses such decisions. Much more time is spent on the technical and regulatory aspects while operational and ethical decision-making is encompassed in what is referred to as “good airmanship.”

Teaching “good airmanship” is usually left to the flight instructor. The Federal Aviation Administration (FAA) has taken many steps to supplement and assist the instructor, but these methods are less concerned with the ethical implications of the actual decision and more concerned with the decision process and reduction of accidents resulting from poor decisions. In General Aviation (GA), poor decisions made by pilots accounted for 52% of all pilot error accidents when Aeronautical Decision Making (ADM) research was introduced by the FAA in 1975.

Six different studies of different pilot groups (based on certificate level) found that using ADM techniques reduced in flight pilot errors from about 50 percent to 10 percent (FAA, 1991). The techniques presented in ADM training for GA pilots focused on understanding the decision making process and avoiding the influence of generalized “hazardous attitudes.” The techniques presented to Commercial and Airline Transport Pilot (ATP) level pilots focused on Crew Resource Management (CRM).

The five hazardous attitudes are presented as a guide on what influences may affect the decision making process (FAA, 1991), but the main focus is that of recognizing a need for a decision, implementing one that does not use a hazardous attitude, and evaluating its effectiveness. The hazardous attitudes include anti-authority, impulsivity, invulnerability, macho, and resignation. These attitudes and their associated behaviors are centered on the masculine culture that is very influential in aviation. While avoiding these attitudes when faced with a decision may reduce the likelihood of an accident, any ethical implications of the decisions are purely coincidental. A study of both male and female flight instructors in New Zealand found that this influence is strong enough to change the values and methods of teaching used by female flight instructors, which include less analytical methods, and achievement oriented results (Ramsey & Ramsey, 1996).

Flight instructors are forced to balance mission completion, weather, personal financial implications, operational rules, and student benefit/relationship (Northam & Diels, 2007) with no strong guidance from their experience as a student pilot. Flight instructors, who have learned how to make ethical decisions elsewhere, may have an easier time making better decisions, similar to the students in Latif's (2001) study on perception of difficulty in ethical decisions in pharmacy students. Many times, if the ethical decision involves basic needs like income to support food, shelter, and lifestyle, the instructor is more likely to make less ethical decisions (Northam & Diels, 2007). This same influence was also noted by Ponemon (1992) in auditors' under-reporting of time to their employer. The most common reasons presented by the auditors for under reporting time on a project included maintaining income levels by keeping certain clients and career advancement. Reporting time in a normal fashion could prevent the auditor from keeping lucrative contracts or advancing in the firm because another auditor could be seen as taking less time to do the same job thus getting better contracts (Ponemon, 1992).

The career goal of a large number of flight instructors is to move on to fly for an air carrier. This means that any problems or weak areas in the flight instructor population will at some point show up in the air carrier environment as the instructors' careers progress. More so in the past, but still present currently, is the problem of the decision making skills and ethical decision making skills from the instructor and student level, (or lack thereof), showing up in the air carrier environment.

The implementation of CRM training was an effort to combat poor judgment/decision making accidents and incidents (FAA, 1991, 2001). As in the case of GA decision making training, the attempt to increase crew coordination and decision making training at the air carrier level focuses more on efficiency/effectiveness at meeting safety/regulatory goals and reducing fatal accidents as opposed to formal ethical ones (FAA, 2001). Ethical decision-making is still left up to the individual, with no formal guidance.

Oderman (2002), in a multi-part study, found that there is very little formal ethical decision making training in aviation. While there is little training, numerous aviation accidents and management mis-decisions indicate a need for formal ethics training (Oderman, 2002). This may indicate that the aviation industry is lagging behind many other industries in teaching ethics. This is quite interesting as the acquisition and application of specialized skills requires highly ethical behavior (Latif, 2001). Highly specialized skills are required in aviation, which would imply that a large amount of ethics and ethical training should be present.

When examining codes of ethics for different industries and practices compared to aviation, aviation is lacking in number of codes and in content in the codes. Examples of codes examined both from inside and outside aviation include statements from the Association of Administrative Professionals, National Society of Professional Engineers, Principles of Medical Ethics as used by Physicians, Airline Pilots Association (ALPA), and National Association of Flight Instructors (NAFI) (IIT, n.d.). Of these five codes of ethics, the aviation codes use less formal language and structure. The ALPA code is an example of one of the few aviation codes that is comprehensive, albeit without detailed specification language. The

NAFI code is similar to many of the codes present in aviation, overly broad in scope and not as elaborate as others are. Many occupational areas in aviation do not even have a code of ethics.

Currently, formal teaching of ethics has been recognized as an important component of education in many industries and professions including business, medicine, engineering, and law. This was not as prevalent in the past, possibly due to values and ethical standards being more commonly taught to children by their communities, families, and religious institutions. As communities and families have become more decentralized, this may be one reason for the need for ethics education (Vincent and Meche, 2001).

To determine if formal ethical education is necessary in any one area of aviation, research needs to be conducted to measure the moral development level for select populations. In the present study, three different pilot populations, including student pilots, flight instructors, and faculty pilots, were examined to determine moral development level. Given that moral development normally increases with age and education (Bebeau & Thoma, 2003), this study hypothesized that student pilots would have the lowest moral development levels, flight instructors the mid levels, and faculty the highest moral development level. The method of measuring and scoring moral development was the University of Minnesota Defining Issues Test Two (DIT2).

Background

Moral development is the level at which an individual gives order to the interests, roles, and moral principles, that govern their lives (Beabout & Wennemann, 1994). Conflicts encountered in everyday activities help shape these decisions and increase moral development levels. Kohlberg introduced the idea of measurable moral development levels in 1969 in an attempt to organize several ethical concepts. Kohlberg created the levels of moral development using participants' answers to certain moral dilemmas. The most famous is the Heinz dilemma (Beabout and Wennemann, 1994). In this dilemma, a man steals a drug for his dying wife and the reader must decide if the man's action is morally right. The responses to this and other dilemmas indicate the individual's moral development level.

Kohlberg's theory is the most widely used way to define moral development level. Prior to Kohlberg, Jung and Freud described moral development in terms of identifications and/or attachments with the family, while Piaget incorporated it into his stages of development as a function of peer development (Needle & Lecker, 1997). Kohlberg's theory of moral development is based on a cognitive-development approach made up of three levels, with two stages per level. This approach is part of the larger personality development of an individual (Kohlberg, 1984). Kohlberg's theory of moral development is similar to Piaget's developmental stages of reasoning and intelligence. In fact, advancement in Piaget's stages of development is required to advance in Kohlberg's levels of moral development (Kohlberg 1984). As the levels and stages increase, so do the amount of information, processing, and complexity of factors that influence moral decisions (see Table 1).

Table 1

Kohlberg's levels of Moral Development (Kohlberg, 1984)

Levels	Stages	Definition
Level I Pre-conventional (Child)	Stage 1 Heteronomous Morality	Egocentric point of view. Doesn't consider the interests of others or recognize that they differ from the actor's; doesn't relate two points of view. Actions are considered physically rather than in terms of psychological interests of others. Confusion of authority's perspective with one's own.
	Stage 2 Individualistic, Instrumental Purpose, and Exchange	Concrete Individualistic perspective. Aware that everybody has his own interest to pursue and these conflict, so that right is relative (in the concrete individualistic sense).
Level II Conventional (Adolescent)	Stage 3 Mutual Interpersonal Expectations, Relationships, and Interpersonal Conformity	Perspective of the individual in relationships with other individuals. Aware of shared feelings, agreements, and expectations, which take primary over individual interests. Relates points of view through the concrete Golden Rule, putting yourself in the other person's shoes. Does not yet consider generalized system perspective.
	Stage 4 Social System and Conscience	Differentiates societal point of view from interpersonal agreement or motives. Takes the point of view of the system that defines roles and rules. Considers individual relations in terms of place in the system.
Level III Post Conventional (Adult)	Stage 5 Social Contract or Utility and Individual Rights	Prior to society perspective. Perspective of a rational individual aware of values and rights prior to social attachments and contracts. Integrates perspectives by formal mechanisms of agreement, contract, objective impartiality, and due process. Considers moral and legal points of view; recognizes that they sometimes conflict and finds it difficult to integrate them.
	Stage 6 Universal Ethical Principles	Perspective of a moral point of view from which social arrangements derive. Perspective is that of any rational individual recognizing the nature of morality or the fact that persons are ends in themselves and must be treated as such.

Maturity plays a large factor in moral development as shown in Table 1 and by Duffield and McCuen (2000) in his discussion of leadership. He explains that maturity is not necessarily a function of age. He also notes that a person in a leadership position can advance more quickly in maturity. Higher maturity leads to higher moral development. Moral development is an indicator of the cognitive moral capacity of an individual (Thorne, 2000) and ethical decision making and/or the action the individual takes regarding the ethical dilemma can be considered the behavior resulting from cognitive moral processing and the influence of other factors.

Ethical dilemmas demonstrate ethical decision capabilities. Robbins suggests that ethical dilemmas define right and wrong conduct (Robbins, as cited in Latif, 2001). Ethical decision-making is also a process that relies on a building block concept of knowledge acquisition to solve more advanced dilemmas (Rest, as cited in Latif, 2001). In other words, high-level decisions cannot be made with low-level ethical decision-making skills.

Moral development plays a large role in ethical decision-making and is commonly the primary indicator of an individual's ethical decision-making capacity. Moral judgment determines moral action (Kohlberg & Candee, 1984). High levels of moral development are a significant indicator of clinical performance in the medical professions in many studies (Krichbaum, Rowen, Duckett, Ryden, & Savik, 1994; Latif, 2001; Sheehan, 1979). Those scoring higher on moral development tests have better success in treating patients, meeting their patients' needs, and participate less in dysfunctional behaviors like lying and cheating than their lower scoring counterparts do (Latif, 2001). A recent replication study conducted by Bay and Greenburg (2001) concludes that this is not always the case, and may be because different populations responded to the selected instrument differently due to biases in the instrument. Overall, moral development is considered one of the best indicators of ethical decision-making and is most widely used to demonstrate such.

Other factors along with moral development can influence ethical decision-making, including a person's needs, level of competition, and environmental contexts. Kohlberg (1984) in his study relating moral judgment to moral action states that even with the demonstration of understanding at a certain moral judgment level, an individual may act on a lower level in a given situation. In 1979, Rest described two types of moral reasoning and/or ethical decision-making (Rest, as cited in Thorne, 2000). These include prescriptive reasoning and deliberative reasoning. Prescriptive reasoning is the individual's ideal ethical outcome to the situation, while deliberative reasoning is the individual's intention to act.

One of the most common measures of moral development in the United States is the Defining Issues Test (DIT) and the newer Defining Issues Test Two (DIT2) developed by Rest (1979) and the Center for the study of Ethical Development at the University of Minnesota. Although the DIT test is better established than the newer DIT2 test, the two tests show a 0.79 correlation (Bebeau & Thoma, 2003).

Two areas of concern with the DIT and DIT2 are that of political bias and type of moral reasoning employed by the subject. A study by Fisher and Sweeney (1998) indicated that an individual answering the DIT with a liberal bias would produce a higher P score than one with a conservative bias. This argument was countered by the producers of the test who state that while political bias, moral judgment, and religious fundamentalism are similar concepts, one cannot be determined from another (Narváez, as cited in Bebeau & Thoma, 2003). Ishida (2006) compared the DIT and Moral Judgment Test (MJT), the more common moral development measure used in Europe. The study concluded that if the subject taking the tests used mostly moral absolutes to come to ethical decisions they were more likely to score high on the DIT and low on the MJT. If the individual used mostly moral relativism and situational specific moral rules, they were more likely to score higher on the MJT and lower on the DIT. This may present a difficulty when interpreting DIT scores as the results may not indicate a lower or higher moral development score, but rather a tendency to use one type of moral reasoning over another.

Self and Ellison (1998) used the DIT and DIT2 tests in a pre/post test arrangement in an effort to determine the effectiveness in a particular ethics curriculum. They investigated the effectiveness of an ethics course on raising the moral development level of engineering students and found that there was a significant increase in scores on the DIT test after the ethics course, and that this was dependent on how the ethics course was presented. Role-playing and scenarios provided more effective results than lectures on moral principles.

In an effort to determine where aviation managers stand in relation to other industries, Reese (2000) conducted a study of aviation managers across several areas in aviation to include airline, regulatory, and military. He found that the moral development scores of these groups of individuals were lower than that for comparable high-risk fields and lower than that of adults in the general population, but higher than high school students' scores. He also suggests that highly structured SOPs and regulations may interfere with moral development levels in individuals in aviation management, since there are very few areas that require the application of ethical decision making and that straying from the established procedure could lead to punishment and/or loss.

Oderman (2003) set out to gain an understanding of the current condition of ethics education in aviation university programs throughout the United States. He found that very little ethical training was being given in aviation management programs, though the interest of faculty and departments in ethics training was present. He also stated that many of the university programs do not address ethics and ethics education at all. This suggests to aviation students and others in the aviation community that ethics is of marginal importance. Even in the departments at the universities that showed interest in ethical education no steps were formally taken to implement ethics training.

In a small survey of flight instructors at an aviation university flight program, it was found that some ethical decision making skills were present in the population and that most of the answers to the survey followed a consistent answer pattern of addressing safety, efficiency, outcome of the action, and personal beliefs/gut instinct (Northam & Diels, 2007). Flight instructors responded that financial issues were a factor in their ethical decisions. Without the ability to maintain shelter, food, and lifestyle from finances the flight instructors were focusing on maintaining basic needs before meeting higher ethical ones. The present, more comprehensive study attempts to compare the moral development level of aviation students, flight instructors, and faculty members.

Methods

Three different groups of pilots were selected for this study. All the participants were currently enrolled or employed at Embry-Riddle Aeronautical University. Participation was voluntary. The student pilot group consisted of 40 Aeronautical Science program students who were taking a CRM class. The flight instructor group consisted of 24 currently employed at the university flight line. The faculty pilot group consisted of 10 professors from both the Aeronautical Science and Safety Science departments.

The Defining Issues Test 2 (DIT2) test was selected for the study due to its reported higher validity and reliability scores and the large amount of research already conducted with both it and its predecessor the Defining Issues Test (DIT). Ease of test administration and scoring was also a factor. The DIT2 test is a paper and pencil measure that consists of five ethical dilemmas that are based on Kohlberg's dilemmas, with the option to add two more dilemmas. Each dilemma has 12 rating questions using a Likert scale and four ranking questions relating to the most important rated questions. The test may be administered in a classroom setting, on an individual level, or in small groups, though the most common is the individual method (Nichols & Day, 1982, Bebeau & Thoma, 2003).

Test administration to students was conducted during one of the normal scheduled meeting times for the CRM class whereas the flight instructors and faculty were requested to complete the survey in their own offices. The test packet contained test instructions and answer sheet.

All completed test answer sheets were returned to the University of Minnesota Center for the Study of Ethical Development for scoring. Raw data listings were provided along with common indices used in the interpretation of the data such as P score and N2 score.

Comparisons were then conducted between the three groups using the P scores and N2 scores from the DIT2 test using conventional parametric methods (Analysis of Variance, regression, and post hoc tests of differences between means.)

Results

The data from this study were first transferred to an Excel spreadsheet for a survey analysis and the development of graphical descriptions of the results. Selected data were then transferred to SPSS for a detailed analysis. The initial hypothesis was that moral development would be simply related to age and education. However, as seen in Tables 2 and 3 these expected relationships were not significant.

Table 2

Linear regression of P Score on Age and Education

	Non-standardized Coefficients		Standardized Coefficients		
Model	B	Std. Error	Beta	t	Sig.
(Constant)	8.507	17.805		.478	.634
Age	.233	.202	.174	1.152	.253
Education	1.997	2.140	.141	.933	.354

Table 3

Linear regression of N2 Score on Age and Education

	Non-standardized Coefficients		Standardized Coefficients		
Model	B	Std. Error	Beta	t	Sig.
(Constant)	.136	17.839		.008	.994
Age	.090	.203	.067	.443	.660
Education	3.097	2.144	.219	1.444	.153

The graphical analyses of the group (faculty, instructor, and student) effects on P and N2 Scores are shown in Figure 1. Table 4 shows the descriptive statistics of the P and N2 scores by subject group. These show the predicted relationship among these three groups with faculty pilots showing the highest level of moral development and the students the lowest. However, it should be noted that there is considerable within group variation.

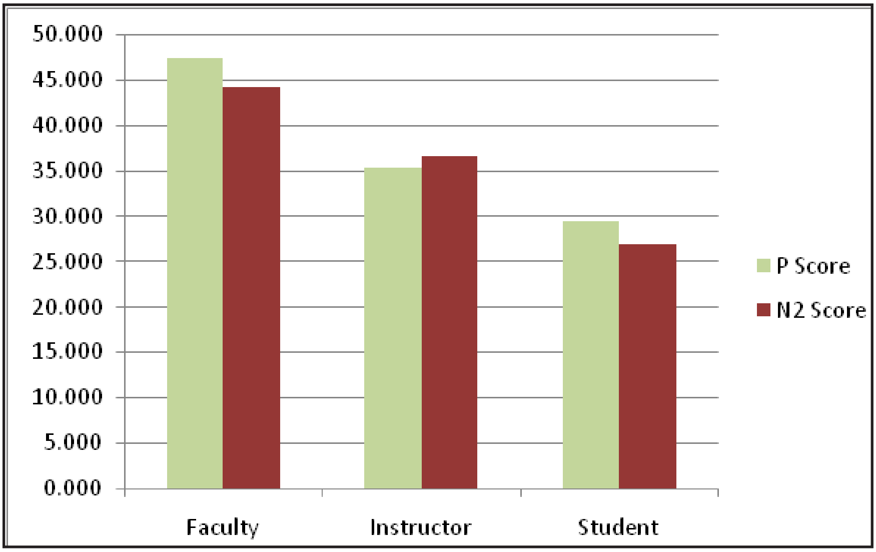

Figure 1. Graphical depiction of the relationship between subject group and P and N2 score.

Table 4

Descriptive statistics of P and N2 Scores by subject group (Note that some subjects did not report their ages)

	Faculty			Instructors			Students		
	Age	P score	N2	Age	P score	N2	Age	P score	N2
Count	9	10	10	21	24	24	40	40	40
Average	53.67	47.46	44.31	26.95	35.28	36.56	21.50	29.55	26.93
STD Dev	14.37	18.53	15.44	8.02	14.26	13.76	1.71	14.55	14.82
Maximum	77.00	66.00	60.15	58.00	74.00	69.58	27.00	58.00	57.57
Minimum	34.00	20.45	20.85	21.00	8.00	9.15	19.00	2.00	4.80

Tables 5 and 7 show the analysis of variance results for the effect of subject group on P and N2 score respectively. These analyses show significant between group effects. Tables 6 and 8 show the post hoc tests (Tukey HSD) results of the differences between the mean scores of the faculty, instructor, and student groups. These analyses show significant differences between the faculty and student groups for both the P Scores and the N2 scores. However, the mean P scores for students and instructors are not significantly different. Also, for the N2 scores both the students and flight instructors and flight instructors and faculty do not show significant differences.

Table 5

Analysis of variance showing the significance of the relationship between subject group and P Score.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2625.458[a]	2	1312.729	5.813	.005
Intercept	75589.150	1	75589.150	334.731	.000
Group	2625.458	2	1312.729	5.813	.005
Error	16033.258	71	225.821		
Total	103321.000	74			
Corrected Total	18658.716	73			

Table 6

Post hoc tests (Tukey HSD) of the differences among group subsets for P Score.

Group	N	Subset	
		1	2
S	40	29.55	
I	24	35.29	
F	10		47.40
Sig.		.489	1.000

Table 7

Analysis of variance showing the significance of the relationship between subject group and N2 Score.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3032.604[a]	2	1516.302	7.145	.001
Intercept	69722.516	1	69722.516	328.551	.000
Group	3032.604	2	1516.302	7.145	.001
Error	15067.046	71	212.212		
Total	95782.845	74			
Corrected Total	18099.651	73			

Table 8

Post hoc tests (Tukey HSD) of the differences among group subsets for N2 Score.

Group	N	Subset	
		1	2
S	40	26.93	
I	24	36.56	36.56
F	10		44.31
Sig.		.124	.254

The P Score results from this survey of aviation faculty, instructors, and students were compared with the tables of different occupational groups published by Rest and Narváez (1994). These comparisons (Table 9) indicate that flight students are not significantly different from high school students (Student's T >0.1) and flight instructors score significantly below college students (Student's T <0.05). It should also be noted that the flight instructors in this sample score only marginally greater that flight students (Student's T, p<0.1)

Table 9

P Score results from this survey inserted into table from Rest and Narváez (1994)

P-score	Group
65.2	Moral Philosophy and political science graduate students
59.8	Liberal Protestant Seminarians
52.2	Law Students
50.2	Medical Students
49.2	Practicing Physicians
47.6	Dental Students
47.46	*Flight Faculty*
46.3	Staff Nurses
42.8	Graduate students in Business
42.3	College Students in general
41.6	Navy Enlisted Men
40.0	Adults in general
35.28	*Flight Instructors*
31.8	Senior High School Students
29.55	*Flight Students*
23.5	Prison Inmates
21.9	Junior High School Students

Discussion and Conclusions

Other research (Rest and Narváez, 1994) indicates that P scores generally increase with educational and maturity level. Flight instructors have a marginally higher educational level than flight students, although many flight instructors are themselves seniors or recent graduates so it is consistent with other research that they have only a slightly higher P score than flight students. Faculty pilots however have higher scores. It should be noted that flight students scored lower than high school students and flight instructors scored lower than college students in general. This is a cause for concern as the behavior of pilots, particularly related to risk taking with passengers, would expect a higher level of concern for others than is indicated by these results. These findings indicate a need for ethics training in college flight schools.

Very little research has been done regarding aviation and moral development. In an effort to examine aviation P scores of different groups to non-aviation P scores (Rest & Narváez, 1994), the data in Table 9 are of interest. Both the student group (average P-score 33.8) and the flight instructor group (average P-score 36.5) fall lower than adults in general and college students, but higher than senior high school students do. The student group was significantly lower than the college students, while the flight instructors group was only marginally lower. These findings may be due to the lack of formal ethics training, the higher technical focus of aviation education, and/or the focus on regulation as a guide for decisions as opposed to other methods. The faculty group had a slightly higher average P score (50.1). This finding is more in line with expectations than that of the flight instructor results.

With the validated dilemmas on the DIT2, it can be concluded that significant differences in moral development in this study were observed between the student and faculty groups. The flight instructors scored marginally lower than expected in the P scores. The P score differences may be due to the lack of formal ethics training and/or the more technical/regulatory focus in aviation. If this is the case, then this study indicates that more attention needs to be given to ethics training in this collegiate aviation-training program. The technical/regulatory focus may cause some to conclude that since we are strongly governed by rules and regulations, there may not be a need for ethical training. The lower than expected P scores, however, seem to indicate that these pilots would benefit from a classroom emphasis on ethical decision making.

This study provides a starting point for further research in this area. Future research should include larger sample sizes, different groups for comparison, refinement of additional questions, and comparisons of moral development of groups with other assessment tools. There is the further indication that the profession as a whole needs a greater focus on ethical issues and that flight students, who rapidly move on to become flight instructors could benefit from formal ethics training. As shown clearly by the Continental Flight 3407 incident the push must come from the top. Good airmanship, aeronautical decision-making, and crew resource management must be complemented by attention to ethical issues throughout the industry by development of standards and ethics education. However, more than in any other context, the pilot in command—the ultimate decision maker—must be equipped with high moral standards and this must start with improved ethics education.

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International Journal of Applied Aviation Studies, Volume 9, Number 1
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Integration of a Fiber Optics Mini-Course into an Existing Aviation Electronics Technology Curriculum

Dennis R. Hannon

Southern Illinois University
Department of Aviation Technologies
636 Flightline Road
Carbondale, Illinois 62901
dhannon@siu.edu
618-453-9208

Abstract

As fiber optic technologies are gaining more widespread usage in aircraft, relevancy of educational instruction in this area has become important for students in avionics programs. The benefit to both the electronics technology and the aviation maintenance technologies student of learning these systems can be significant, especially for those going into networking, communications, corporate and transport airframe or general avionics maintenance. In order to incorporate the study of fiber optics into an existing avionics curriculum, a number of conditions had to be satisfied. Initially, an appropriate course needed to identified and adjusted to accommodate the additional material. Secondly a suitable source for the training material had to be examined. Finally the material needed to be packaged and integrated into the course curriculum. Ultimately, a suitable mini-course was chosen and the material successfully introduced into the Southern Illinois University avionics program. This paper examines the process of integrating fiber optics training into the avionics curriculum and comments on its methods and results.

Requests for reprints should be sent to Kay Chisholm, FAA Academy, AMA-800, P.O. Box 25082, Oklahoma City, OK 73125. E-mail to kay.chisholm@faa.gov.

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Integration of a Fiber Optics Mini-Course into an Existing Aviation Electronics Technology Curriculum

The Department of Aviation Technologies avionics curriculum at Southern Illinois University Carbondale has traditionally included extensive instruction in solid state devices including amplifiers and digital electronic control systems. An electronic digital data bussing and flight information systems (EFIS) course has served as the venue for the study of Aeronautical Radio Incorporated (ARINC) and Military Specifications (MIL-STDs) in that realm for a number of years. Recently, this course has begun examination of state-of-the-art hardware and methods for achieving reliable data transfer in an airborne environment. While a working knowledge of all of these aspects is necessary to the understanding of the techniques used in converting electrical signals into optical signals and vice-versa, specific instruction in fiber optic systems, optical data bussing techniques and troubleshooting was lacking. The need to take the existing electronics technology training a step further into a somewhat comprehensive study of fiber optics became apparent with the trend of the aerospace industry toward increased usage of optical signals in data transfer (Green, 2006).

A recent article in Science Daily reported that flight control systems applications of fiber optics in addition to those already incorporated in contemporary aviation electronics are on the horizon (Optical Society of America, 2006). Conventional data bussing techniques and standards, both in aerospace and elsewhere, using typical twisted pair copper wiring are gradually giving way to these newer optical systems. The Boeing 777 aircraft for example, in addition to being one of the first to be designed exclusively using computer aided design (CAD) systems, incorporated fiber optic technology into a number of its systems (Kerr, 1995). The 787 Dreamliner is expected to contain even more fiber optic pathways as the technology has proved effective and reliable (Keller, 2007). The trend toward optical data transfer appears to be similar in the realm of corporate aviation.

As a prelude to the understanding of fiber optics technology, students needed to become familiar with a fiber optic data link arrangement typically consisting of a transmitter, the fiber optic data link, and a receiver. In the transmitter, circuitry may consist of the following: a) An analog to digital converter; b) a modulator utilizing a transistor semiconductor; c) an infrared visible or laser light source, which is often a light emitting (LED) or laser diode; and d) a connector to couple and maintain alignment of the fiber optic cable to the light source.

The receiver likewise contains a) a coupling connector, b) a detector that is a semiconductor device such as a photodiode or phototransistor, and c) an amplifier (U.S. Navy, 1998). The receiver may also incorporate a digital to analog converter to drive an actuator, transducer, or human interface device as appropriate.

While either analog or digital signals may be sent along fiber optic links, the latter is the method most commonly employed with newer airborne data bussing techniques (Adams, 2003). In civilian aviation, specific Aeronautical Radio Incorporated (ARINC) specifications such as those contained in the ARINC 600 and 800 series address the nature of these digital signals as well as the quality, installation and maintenance of cables utilized. The military standard is MIL-STD-1773. Non-aviation based data transfer regimens likewise have their own standards and specifications. A typical fiber optics installation may also contain devices such as signal multiplexers, couplers, splitters and other devices as needs dictate (Hannon and Ramsundar, 2007).

Fiber optics lends itself well to digital technology as rapid switching on/off or higher/lower intensity is relatively easy to accomplish using common digital logic gates and readily available light emitting diodes (LEDs) for developing and launching low to moderate bit rate signals into fiber optic cables. Reception of the data is likewise straightforward in that a photodiode or phototransistor can accomplish the conversion from optical to electronic signals.

Discussion

In the Southern Illinois University Aviation Technologies Department, meeting the requirement of a venue for introducing fiber optics instruction was straightforward because the avionics specialization curriculum already contained a six credit hour digital data bussing and electronic flight information systems (EFIS) course. Prerequisites to this course included study in aircraft electricity and electrical systems, an introductory course in solid state electronics technology, digital electronics, and another course in traditional aircraft communication and navigation systems. Since fiber optics in aircraft applications at present are primarily involved in data transfer applications, the logical place to integrate the instruction was late in the digital data bussing and EFIS course after ARINC and MIL-STD military specifications and electronic signal processing techniques were covered. Fortunately, certain introductory course material relating to the study of programmable logic devices, controllers, and microprocessors could be shifted to the digital control systems course freeing up time for fiber optics in the EFIS course.

The next phase of the undertaking was to establish sources of material from which to put together a condensed, but still somewhat detailed fiber optics instruction module. One good source of information was found to be Industrial Fiber Optics, Incorporated of Tempe, Arizona, which markets an extensive line of fiber optics educational materials and supplies. Their Fiber Optics Mini-course, Catalog number IF MC-10, appeared to meet our needs and an instructor’s version of the material was ordered for evaluation (Industrial Fiber Optics, 2007). The mini-course does an excellent job of detailing a short history of fiber optics followed by discussion of modulation and demodulation coupled with concepts such as wavelength, bandwidth, noise, etc. common to general communication systems. The material then goes into more depth as to light and fiber optics technology through discussions of light propagation through cable, attenuation, coupling, cable splicing and signal conversion. Included with the course is a laboratory project wherein students construct a basic but fully functional digital fiber optic communications system consisting of an encoder, transmitter, cable link, receiver, and decoder. We were also able to acquire an inexpensive fiber optic training VHS video from UCANDO Educational Products Corporation of Greenview, Ohio. The video was used as an introduction to the Industrial Fiber Optics material and provided some information on signal splitting and cable splicing, which was not covered in other aspects of the course.

Implementation

The fiber optics source materials were arranged for classroom presentation in a logical order: 1) PowerPoint® presentations on the nature of light, 2) Fiber Optic

Association's presentation on Understanding Fiber Optic Communications (Professional Society of Fiber Optics), 3) the UCANDO video, and 4) lecture material from the Industrial Fiber Optics (IFO) Mini-Course. While some of the material in the PowerPoint® presentation and video was redundant with that covered in the mini-course, the latter served as a handy written reference for the students.

Our presentation outline for fiber optic technology study in an aviation control system or a digital data bussing and electronic flight information system (EFIS) course is depicted in the appendix.

In addition to the lecture material, a demonstration presenting fiber optic analog and digital signal transmission was developed utilizing a fiber optic transmitter and receiver capable of processing both signal types (Figure 1). Further, the Industrial Fiber Optics Mini-Course included a laboratory project consisting of the construction and testing of a fiber optic digital transmitter and receiver with which each student was able to conduct experiments. A typical fiber optic test set (Figure 2) was also demonstrated. A short video delineating fiber optics cleaning techniques was shown, which discussed cleaning and measuring techniques. A lack of available class time precluded integration of extensive hands-on fiber optic splicing techniques into the course material; however, it was felt that emphasis should be on background and troubleshooting rather than complex splicing procedures. Splicing techniques were covered briefly in the UCANDO video.

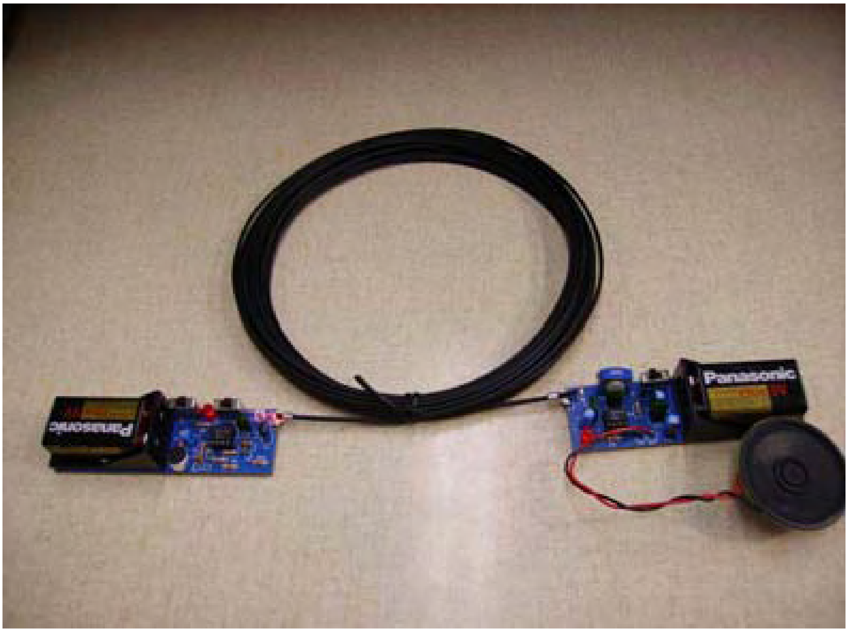

Figure 1. Fiber optic transmitter/receiver set up

Figure 2. Fiber optic test set with cable

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Appendix

Fiber Optic Presentation Outline

- I. The Nature and Properties of Light
  - A. History
  - B. Electromagnetic Spectrum
  - C. Nature of Light
    - 1. Wave Theory
    - 2. Particle Theory
  - D. Wavefronts and Rays
  - E. Refraction and Reflection
    - 1. Index of Refraction
    - 2. Snell’s Law

- II. Fiber Optic Communication
  - A. Early Work
  - B. Total Internal Reflection
  - C. How Light Travels in Optical Fibers
  - D. Fiber Optic Cable construction
    - 1. Core
    - 2. Cladding
    - 3. Buffer
    - 4. Jacket
    - 5. Single and Multi-mode Fibers
  - E. Light Transmission via Fiber Optics
    - 1. Modulation
    - 2. Amplification
    - 3. Transmission
    - 4. Reception
    - 5. Demodulation
    - 6. Processing
  - F. Time and Frequency Division Multiplexing
  - G. Applications
    - 1. Inside and Outside Plant
    - 2. Computers and LANs
    - 3. Aircraft
  - H. Installation and Splicing

- III. Fiber Optic Cable Testing and Cleaning
  - A. Testing Standards
  - B. ARINC and MILSTD Fiber Optic Standards
  - C. Optical Time Domain Reflectometry
  - D. Fiber Optic Cable Cleaning
  - E. Troubleshooting

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International Journal of Applied Aviation Studies, Volume 9, Number 1
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Book Reviews

The Multitasking Myth: Handling Complexity in Real-World Operations

by

Loukia Loukopoulos, Key Dismukes, and Immanuel Barshi

Reviewed by

Barbara K. Burian

NASA Ames Research Center

The demands of modern life require the completion of multiple tasks at the same time. This is true in most occupational settings as well as in personal life. Many a parent has described with pride the ability to multitask: make dinner, help a child with homework, fold a load of laundry, and pay bills – all at the same time. An astounding accomplishment to be sure until upon further examination one discovers that part of the dinner is burned, an incorrect homework answer goes unidentified, the folded socks are mismatched, and two bill payments are switched and enclosed in the wrong envelopes.

This outcome of trying to manage several overlapping tasks may bring a smile of recognition to the lips, but the failure to adequately accomplish multiple tasks concurrently can have devastating consequences as well. A control room operator in a nuclear power plant does not complete a set of system maintenance procedures after being interrupted to assist a colleague leading to an emergency shutdown of the system. A parent unloading groceries inadvertently forgets a sleeping infant in the back seat of the car on a hot day – a mistake that leads to tragedy. An airline pilot neglects to extend the takeoff flaps during a rushed and busy taxi to the runway resulting in the aircraft crashing as it fails to climb during takeoff.

Requests for reprints should be sent to Kay Chisholm, FAA Academy, AMA-800, P.O. Box 25082, Oklahoma City, OK 73125. E-mail to kay.chisholm@faa.gov.

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In *The Multitasking Myth*, Loukopoulos, Dismukes, and Barshi lucidly examine why competent, skilled, dedicated, and conscientious individuals are vulnerable to making these types of errors when managing multiple tasks. Using the work world of airline pilots, they illustrate how this can only be understood through "careful analysis of the nature of cockpit tasks, the operational environment in which the are performed, the demands those tasks place on human cognitive processes and the inherent vulnerability of these processes to characteristic forms of error in particular situations" (pg. 2).

After a thorough exploration of what is meant by multitasking, and whether true multitasking—the simultaneous completion of two or more tasks—really even truly occurs, the "nature of cockpit tasks and the operational environment in which they are performed" are examined in great detail in chapters three and four. Chapter three painstakingly provides the picture of these cockpit tasks through the lens of the operating procedures to be followed by pilots. As written, the procedures lead one to believe that the tasks are linear (i.e., they always follow a fixed sequence), predictable, and that the timing and pace of their execution is under the control of the flight crews. In chapter four, this picture of the ideal world painted by the procedures is shattered as the real world, the one in which these procedures must actually be carried out, is examined. The significant divergence of the ideal and real worlds of airline pilots is startling and these two chapters could serve almost as a template or exemplar for those in other complex and high-risk occupations wishing to undertake a similar examination of the true structure of tasks in their operational settings.

Chapter 5 extends the analysis of the nature of airline cockpit tasks and distills from this analysis four prototypical situations in which the adequate management and completion of concurrent tasks often fail. Two highly readable sections describing the cognitive aspects of concurrent task management and their application to cockpit operations tie all that has come before it in the book together and serve as the foundation for understanding why humans are vulnerable to error when multitasking. It is precisely this type of discussion and analysis—comprehensible, compelling, and detailed but not daunting to non-scientists or those who lack backgrounds in cognitive psychology—that is often found wanting when work or task analyses are performed.

The main text of The Multitasking Myth concludes in chapter six with a thorough description of the real-life application of the findings of the multiple studies that were completed and serve as the basis of this book—a fine example of applied research findings actually applied. The domain knowledge of the authors, as well as their close collaboration with numerous dedicated professionals in the aviation industry, resulted in a real-world success story shared with us, the readers, to further illustrate how the concepts in the book might be employed. The chapter ends with a number of recommendations for ways to decrease human vulnerability to error when managing concurrent tasks and is aimed at both those in the aviation industry as well as those in other complex, high-risk occupational settings.

The main text of the book is augmented with several helpful figures, particularly in the "ideal" and "real" chapters (3 and 4) and excerpts from incident and accident reports nicely illustrate the various points being made throughout the text.

This book is based upon the findings of multiple studies using a variety of methods which are described in one of several helpful and interesting appendices.

It is not often that one comes across a book that is interesting, tractable, expands our understanding about important concepts and issues, and has such obvious and useful application in real life. The Multitasking Myth is just such a book.

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International Journal of Applied Aviation Studies, Volume 9, Number 1
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The Multitasking Myth: Handling Complexity in Real-World Operations

by

Loukia Loukopoulos, Key Dismukes, and Immanuel Barshi

Reviewed by
John C. Di Renzo Jr.
Joint Interagency Task Force South
US Southern Command

The Multitasking Myth, written by Loukopoulos, Dismukes and Barshi, uncovers the myth surrounding the idea that operators of complex systems can multitask without degrading performance and increasing risk of inadvertent omission or error. To do this, the authors skillfully examine human factors research, analyze airline training programs, observe routine commercial airline flights, and analyze NASA's Aviation Safety Reporting System (ASRS) data to provide practical insights into concurrent task management in complex work settings. While the research focuses on aviation, the implications are equally relevant for any complex work environment such as that found in the petroleum or nuclear power industries. The book is extremely well organized and can be easily read by seasoned airline pilots as well as by those unfamiliar with the aviation industry.

In the first two chapters, the authors do an excellent job of presenting the issues under investigation and make clear the complexities involved in what is commonly referred to as multitasking. Additionally, key concepts and terms are well defined in the first two chapters as a prelude to further discussion and analysis throughout the book. The authors outline their methodology -- an excellent discussion of the methodology can be found in Appendix A. The three major components of their research include:

Requests for reprints should be sent to Kay Chisholm, FAA Academy, AMA-800, P.O. Box 25082, Oklahoma City, OK 73125. E-mail to kay.chisholm@faa.gov.

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- An ethnographic study where researchers participated in airline flight training and analyzed company Flight Operations Manual (FOMs) and Flight Reference Manuals (FRMs) at two major airlines. This part of the study focused on two person crews flying the Boeing 737.
- An incident report analysis using voluntarily submitted airline pilot reports to NASA's Aviation Safety Reporting System (ASRS).
- A literature review component focusing on cognitive psychology and human factors research to produce a cognitive account of how even highly skilled pilots are prone to inadvertent errors or omissions when performing highly practiced tasks.

The authors make a clear distinction between multitasking (the appearance of completing more than one task simultaneously) and concurrent task management. In reality, pilots perform all but highly practiced automated tasks sequentially, not simultaneously. The authors use the term *concurrent task management* to describe pilot responsibility, acknowledging that multiple tasks are not performed simultaneously, but they are managed concurrently. Simultaneous task performance can only pertain to highly practiced tasks that have become automated and do not require significant attentional resources. Non-automated tasks, those that are not automatic due to continuous use, require individual processing focused on only one task at any given time.

For Loukopoulos, Dismukes, and Barshi, the issue is to understand how pilots monitor and complete concurrent tasks. Pilots are prone to error when managing concurrent tasks because they are interrupted and forget to resume the interrupted task. Pilots in the cockpit must devise strategies to handle these perturbations. Managing disruptions which cause disorder in the cockpit may be accomplished by interleaving the execution of several tasks, deferring or suspending tasks and/or using external agents (often automated agents) to monitor task.

Chapter 3 focuses on how flight training is done at most airlines. The training is largely based on learning procedures found in airline Flight Operations Manuals (FOMs). Much of the learning process is by rote memory and is highly structured. The FOMs portray cockpit tasks as linear, predictable, and controllable. However, real-world operations are not linear; they are often interrupted by other more urgent tasks. Interruptions are not predictable and they certainly are not under the exclusive control of the flight crew.

The authors describe the flight operation of a routine flight in accordance with a generic airline FOM. The reader is guided through the many phases of flight from pretakeoff procedures through takeoff, climb and cruise, decent and approach, landing, taxi and shutdown. While airline pilots may find this discussion a bit dry, readers who are not airline pilots, may be fascinated by the nature and complexity of cockpit work even as described in an ideal environment. The authors lay the groundwork for a comparison between an idealistic flight and the much more complex and dynamic tasks management required in real-world flying.

Their study extends previous studies of concurrent tasks management and thoroughly describes the challenges aircraft crews must address. A significant number of real-world examples are described in chapters 4 and 5. The book also addresses the most common form of error – inadvertent omission of intended actions caused by prospective memory error. Prospective memory is the cognitive process involved in remembering or forgetting to perform an action postponed until a later time. It is how human operators remember, or do not remember, to complete tasks they had intended to do at a later time.

To study this phenomenon, Loukopoulos, Dismukes, and Barshi collected data on pilot omissions and errors caused by a demonstrated latent memory vulnerability to error. The data collection method allowed for a large and representative sample. Inadvertent omission and error data was collected from the following sources:

- Direct observation of flight crews performing normal operations and in Line Operations Safety Audits (LOSA)
- Flight simulation, where direct observation was supplemented by video, audio and data recording, and extensive de-briefings to understand vulnerability to error
- Incident reports provided voluntarily by pilots using the Aviation Safety Reporting System (ASRS) and/or airline company databases

The authors summarize the reasons concurrent task management in real-world flight operations increases pilot vulnerability to errors and omissions. From this data, the authors concluded that most flight operations are perturbed in diverse ways, but most include:

- Interruptions and distractions
- Tasks that cannot be executed in normal sequence
- Unanticipated new task demands
- Multiple tasks that must be performed concurrently

Pilots typically respond to one or more of these situations by deferring tasks or interleaving tasks (performing part of a task, then doing one or more other tasks, and then returning to the original incomplete task). The problem is pilots sometimes forget to perform intended tasks.

Chapter 6 summarizes the findings and describes how the study was used to review and improve upon airline procedures. The authors partnered with the airlines and a broad representation of airline personnel were selected to participate. These airline participants included: pilots, training center personnel, safety department personnel, pilot union personnel, engineering department personnel, scheduling and dispatch department personnel, and customer service personnel. This review team worked to analyze exiting procedures and to find *hidden traps* that may contribute to perturbations causing inadvertent omissions and errors.

To illustrate this point, the authors describe the existing FOM procedures for setting flaps prior to takeoff. The team noted several opportunities for omission and error. New procedures sought to improve crew coordination. Finally, Crew Resource Management (CRM) classes were recommended because CRM teaches pilots techniques for managing workload and recognizing signs of task overload.

The authors note, value, and encourage the use of personal environmental cues -- a *Post-it Note* type strategy to assist memory recall. For example, a pilot may place a checklist between the throttles as a reminder that the check list was interrupted and requires completion. The authors also suggest training pilots to recognize circumstance conducive to making omissions and errors, and then developing strategies as aids for prospective memory task recall. Training can help pilots avoid errors arising from the four prototypical situations disused above.

This book is particularly well written and appropriate for anyone with an interest in avoiding perturbations leading to prospective memory error that is likely to occur in any complex undertaking. It also provides an excellent basis for future scientific investigation.

Aviation professionals will find this book informative and enlightening, but it is just as appropriate and relevant for readers from any discipline with an interest in learning how humans manage complex operations in stressful, highly complex, and dynamic environments.

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