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[1] 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.

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

EDITOR'S NOTES

A new look for the IJAAS.

As you have already noticed, the IJAAS has a new look and format. To support the FAA's efforts to reduce costs, the IJAAS will only be available from our website at http://www.faa.gov/about/office_org/headquarters_offices/arc/programs/academy/journal/. The new size and double column format will make printing from the web more economical and environmentally friendly for our readers. We hope you are as pleased with the new look as we are.

Papers

Our lead article, *The Pilot-Into-The-Loop Problem: Joining or Rejoining Flights in Progress* examines the ability of pilots to join or rejoin a flight already in progress. Casner focuses on the levels of workload and awareness between pilots who flew continuously and pilots that joined or rejoined the flight with or without time to prepare.

In Mitchell, Kristovics, and Bishop's *Glass Cockpits in General Aviation: A Comparison of Men and Women Pilots' Perceptions* research suggests that though both men and women were positive toward the new glass cockpit technology the reasons underlying the use of the technology were quite different.

In *Controlling Practical Drift in High Reliability Organizations,* Stolte, Vogt, and Weber suggest that practical drift can be addressed directly by reactive, preventive, and predictive strategies. They present a guideline to create awareness of unanticipated deviances and to use sharp-end-operators' knowledge when designing and redesigning rules and procedures.

Avers, Hauck, Blackwell, and Nesthus applied a unique strategy to identify key attributes of an effective fatigue countermeasures training program. In *A Qualitative and Quantitative Analysis of Fatigue Countermeasures Training in the Aviation Industry,* fatigue countermeasure programs were reviewed and content was analyzed to identify critical dimensions across industry programs.

In *An Assessment of General Aviation Advanced Composite Aircraft Repair Methodologies,* Mitchell's study is an examination of composite repair methods used with the top three GA composite aircraft manufactures. The focus of this study is a review on how each OEM's Aircraft Maintenance Manual or Structural Repair Manual differs in the repair of similar damage in composite sandwich core wing damage.

In *Teaching Maintenance and Inspection Aspects of the Rotax 900 Series Aircraft Engine at a Traditional Part 147 Airframe and Powerplant Technician School,* Hannon and Harrison suggest that a factory approved maintenance courses may be viable additions to traditional Part 147 A & P programs. This paper examines some of the engine's characteristics and provides some suggestions for development and inclusion of Rotax engine familiarization material in such a program.

KC

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Volume 10, Number 2 2010

REVIEW PROCESS iii
POLICY AND DISCLAIMERS iv
PUBLICATION AND EDITORIAL STAFF v
PHILOSOPHY STATEMENT xii
EDITOR'S NOTES xiii

Papers

The Pilot-Into-The-Loop Problem: Joining or Rejoining Flights in Progress
Stephen M. Casner 1

Glass cockpits in general aviation: A comparison of men and women pilots' perceptions
Jim Mitchell, Alexandra Kristovics, and Ron Bishop 11

Controlling Practical Drift in High Reliability Organizations
Wilhelm Stolte, Joachim Vogt, and Christoph Weber 31

A Qualitative and Quantitative Analysis of Fatigue Countermeasures Training in the Aviation Industry
Katrina Avers, Erica L. Hauck, Lauren V. Blackwell, and Tom Nesthus 51

An Assessment of General Aviation Advanced Composite Aircraft Repair Methodologies
Keven R. Mitchell 67

Teaching Maintenance and Inspection Aspects of the Rotax 900 Series Aircraft Engine at a Traditional Part 147 Airframe and Powerplant Technician School
Dennis R. Hannon and Matthew W. Harrison 77

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Delivering Tomorrow's Training Today

The Pilot-Into-The-Loop Problem: Joining or Rejoining Flights in Progress

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Abstract

This study examines pilots' ability to join (or rejoin) a flight that is already in progress. These situations naturally arise when pilots work in shifts or are removed from active participation due to distraction or complacency. Twelve pilots assumed control of an airplane in the midst of two instrument approaches and were asked to fly the remainder of the approach and missed approach procedure. During one approach, pilots were given a two-minute period to look about, review the instrument approach procedure, and prepare themselves to take over the controls. During a second approach, pilots were given no time to prepare, handed the approach procedure, and asked to assume control of the airplane immediately. As a control, pilots also completed a third approach and missed approach during which they flew continuously, without interruption. Surprisingly, there were no differences in the number of errors committed by pilots in any of the three conditions. Pilots who were given no time to prepare reported significantly higher levels of workload, but there was no difference in reported workload when pilots had time to prepare and when they flew continuously. Pilots who flew continuously reported comparatively greater awareness, but these differences narrowed over time when pilots had two minutes of preparatory time. The results encourage further study of the pilot-into-the-loop problem and the development of aids to support pilots more effectively in situations in which participation is intermittent.

The Pilot-Into-The-Loop Problem: Joining or Rejoining Flights in Progress

Consider the case of a captain of a 14-hour-long, transoceanic flight from New York to Tokyo. Six hours into the flight, with landing still more than eight hours away, this captain hands control of the aircraft over to an international relief pilot, retires to the crew bunk quarters, and takes a nap. Two hours later, the captain returns to the cockpit, reassumes his position in the left seat, and politely asks the on-duty pilots to fill him in on what has happened while he was away.

Now consider the case of a pilot of a small advanced cockpit airplane who, on a long cross-country flight, has allowed his attention to drift. Throughout the flight, this pilot has cast an occasional glance at a colorful panel that has presented him with the planned route, his position along the route, surrounding terrain and weather, the time of arrival and fuel remaining at each point along the way, and the current status of most every system on board. An anomaly with the electrical system has now presented itself and the pilot realizes that he must become more actively engaged and continue the flight "the old-fashioned way" to an alternate destination.

What do these two pilots have in common? Both pilots find themselves in a situation in which they are "out of the loop" and must now take up a position that is "in the loop." In other words, both pilots must piece together an understanding of the current state of affairs and take control of an ongoing task in a dynamic environment that will not stop and wait for them.

The challenge of joining or rejoining a control or decision-making loop is not a new one in aviation. Pilots have been switching seats on international flights for as long as crew rest requirements have been in place (Rosekind et al, 1996). Reports of degraded pilot awareness while monitoring cockpit automation systems are commonplace (Casner, 2005; Endsley and Kiris, 1995). Interruptions such as emergencies distract pilots from primary flying tasks for extended periods of time (Burian, Barshi, and Dismukes, 2005). The efficacy of strategic cockpit naps, leaving one wakeful pilot on duty during less critical phases of flight, has been investigated (Graeber, Rosekind, Connell, and Dinges, 1990) while aircraft manufacturers have advanced proposals for single-pilot cruise operations (Flight Safety Foundation, 2008). Meanwhile, technologies for remotely piloting several aircraft at once, as well as aircraft that can be intermittently supervised, continue to be developed (Hobbs, 2010; Cooke, Pringle, Pedersen, and Connor, 2006; Jones, Whelan, and Wenberg, 2009).

While much has been written about human in-the-loop performance and the problem of humans drifting out-of-the-loop (Wickens and Hollands, 1999), the challenge of getting back into-the-loop has only begun to be addressed. Some research has been directed at the problem of shift handoff in the medical (Bogenstatter et al, 2009; Wears et al, 2004; Wears et al, 2003; Hardey, Payne, and Coleman, 2000; Lamond, 1999) and aircraft maintenance domains (Reason and Hobbs, 2003; Jiang, Master, Kelkar, and Gramopadhye, 2002). In the field of business management, researchers have investigated the problem of bringing new-hire employees up to full performance levels as quickly as possible (Rollag, Parise, and Cross, 2005). Linguists have looked at the process of joining a conversation that is already in progress (Pillet-Shore, 2009). Meanwhile, studies of pilot into-the-loop performance are scant (Sheridan, Burki-Cohen, and Corker, 2006).

This article describes a simple experiment designed to take a first look at pilots' ability to assume control of a flight that is already in progress. The experiment was designed with three simple research questions in mind:

1) Can pilots successfully assume the controls of an aircraft in the midst of a busy instrument flight procedure?

2) How does perceived workload, awareness, and the number of errors committed by transitioning pilots compare to that of pilots who fly the same procedure, from start to finish, without interruption?

3) How is performance affected when pilots are given a brief period to mentally prepare for an into-the-loop transition?

Method

Twelve pilots completed an instrument approach and missed approach procedure in each of three experimental conditions (a within-subjects design). In the Control condition, pilots flew the instrument procedure, from start to finish, presumably in-the-loop at all times. In the remaining two conditions, pilots were handed the controls of the airplane after a period of being out-of-the-loop. To create the out-of-the-loop experience, the experimenter took the controls of the airplane while pilots were unplugged from the airplane console and asked to watch (and listen to) a comedy movie presented on a handheld media device. In the Preparation condition, pilots were interrupted from the movie-watching task and asked to plug back into the airplane console. Pilots were then given a two-minute period to review the relevant charts for the instrument approach procedure they were being asked to fly and to look around the cockpit to see how the navigation equipment had been thus far configured for the procedure. In the No Preparation condition, pilots were handed the airplane controls along with the instrument approach charts

and asked to assume control immediately, with no time for review or preparation.

During these approaches, no surprises or hidden circumstances were introduced. For these approaches, pilots had only to avail themselves of the details about where they were, which steps had been already taken, which steps remained to be done, and finish the procedure. The goal of the experiment was to discover to what extent such a transition is possible during a complex instrument procedure, the effect on the number and types of errors that pilots commit, and the way in which pilot workload and awareness changes as the transition process unfolds. The approach and missed approach procedure was chosen because of it is known to be among the busiest of normal procedures (Casner, 2009).

As pilots flew in each condition, the experimenter recorded any errors made, collected subjective workload ratings, and asked pilots to rate their own awareness of the status of the flight.

Participants

Twelve U.S.-certificated pilots participated in the study on a volunteer basis. Ten pilots held a commercial pilot certificate, while two pilots held airline transport pilot certificates. Eleven pilots additionally held flight instructor certificates. Pilots ranged between 500 hours and 30,000 hours of total flight experience yielding a median of 1,588 hours.

Apparatus

The experiment airplane was a Cessna 172S (not a simulator) equipped with VOR radio navigation receivers and conventional course deviation indicators (CDI). An installed GPS receiver and autopilot were not used during the experiment. The presence of electronic navigation, guidance, and control equipment was deliberately minimized to avoid their known effects on pilot error, workload, and awareness. Pilots were furnished with the instrument approach charts that would be needed for the experiment. Pilots wore a view-limiting device to simulate instrument meteorological conditions. A hand-held media player, with a custom aviation headset adapter, was used to present the comedy movie. Paper forms and pens were used to record errors pilots made along with their subjective ratings for workload and awareness.

Procedure

Pilots completed the experiment in a single session that was scheduled at the convenience of both the pilot and the experimenter. At the beginning of the sessions, the experimenter briefed each pilot about the experiment. Pilots were told that the agenda for the flight consisted of a series of three instrument approach procedures. Furthermore, each procedure would consist of two phases: (1) an approach procedure, and (2) a missed approach procedure. Pilots were told that they would fly during some portions of each procedure, and the experimenter would fly during others. Pilots were told that during the times that the experimenter operated the controls, the pilot would be "removed from the loop" and given a movie to watch on a hand-held media device. Pilots were told that the experimenter was interested in various aspects of their experience while flying in each condition such as perceived workload and perceived situation awareness. Pilots were told that the experiment would prompt the pilot to provide estimates of their workload and awareness periodically during the flight.

To create the situation in which pilots were removed from the control loop, pilots were unplugged from the airplane console and connected to the handheld media player to view excerpts from the comedy movie Airplane! (Davison et al, 1980). Any instrument charts that were being used by the pilots were taken away at this time. Pilots were asked to keep their attention on the movie while they were relieved from their flying duties and to refrain from looking at the instruments or the actions of the experimenter. Pilots were told that they would eventually be notified when they would be needed to take control of the

airplane and that instructions would be provided at that time.

In the Control condition, pilots flew the approach procedure followed by the missed approach procedure, without interruption, as they would during any normal flight operation.

In the Preparation condition, the experimenter took the controls of the airplane and asked the pilot to unplug from the console and watch the movie. Pilots were not provided with any approach charts or permitted to see any preparatory actions taken by the experimenter that might reveal which approach or airport would be used. With the pilot removed from the control loop, the experimenter then set up and commenced the approach procedure. Three minutes prior to reaching the missed approach point (MAP), pilots were interrupted and instructed to turn off the movie and plug back into the airplane's console. Pilots were then handed the instrument procedure chart for the approach and airport and given two minutes to review the chart and how the airplane's navigation equipment had been thus far configured. After the two-minute review period, the pilot was asked to take the control of the airplane, complete the remaining thirty seconds of the approach, and then fly the entirety of the missed approach procedure.

In the No Preparation condition, all of the same actions were taken except that pilots were interrupted from the movie one minute prior to reaching the missed approach point. After turning off the movie and plugging back into the airplane's console, pilots were handed the approach chart and asked to assume control of the airplane immediately, with no time for preparation.

The order in which pilots saw the three conditions was randomly determined.

As pilots assumed control of the airplane, the experimenter began asking pilots for verbal estimates of their overall workload. The instantaneous self-assessment (ISA) workload measurement scale (Tattersall and Foord, 1996) was chosen to minimize the intrusion on pilots as they worked during this busy time. Using the ISA technique, pilots provided a numerical estimation of their overall workload using a scale of 0 to 100 in increments of 5. Pilots were asked to provide a workload rating when they first assumed control of the airplane, and then every sixty seconds as they finished the approach and missed approach procedure.

At the conclusion of all three instrument approaches, as the pilot and experimenter flew home, pilots were asked to complete a self-assessment of their awareness during the three different experimental conditions. The awareness self-assessment instrument is a comparative ratings form first used by Vidulich and Hughes (1991). The form asks participants to compare each possible pairing of the three experimental conditions, indicating the dominance relationships among each possible pair.

Results

The data gathered from the twelve pilots were analyzed to determine whether or not differences existed in the number of errors committed by pilots, the levels of workload they experienced, or pilots' perceptions of their own awareness as they completed the instrument approaches in the three experimental conditions.

Errors Committed

Eight types of errors committed by pilots were recorded during the instrument approach and missed approach procedures:

1. Failure to recognize that the missed approach point had been reached.
2. Descent below minimum descent altitude (MDA) for the approach.
3. Wrong frequency tuned for VOR station.
4. Failure to identify a VOR station.
5. Wrong course dialed into course deviation indicator.
6. Deviation of more than 100 feet from an altitude prescribed by approach or missed approach procedure.

7. Deviation of more than 10 degrees from a heading prescribed by missed approach procedure.
8. Full-scale deviation from course deviation indicator.

Figure 1 shows the mean number of errors (of all eight types combined) committed by pilots, along with the standard deviations, for the three experimental conditions.

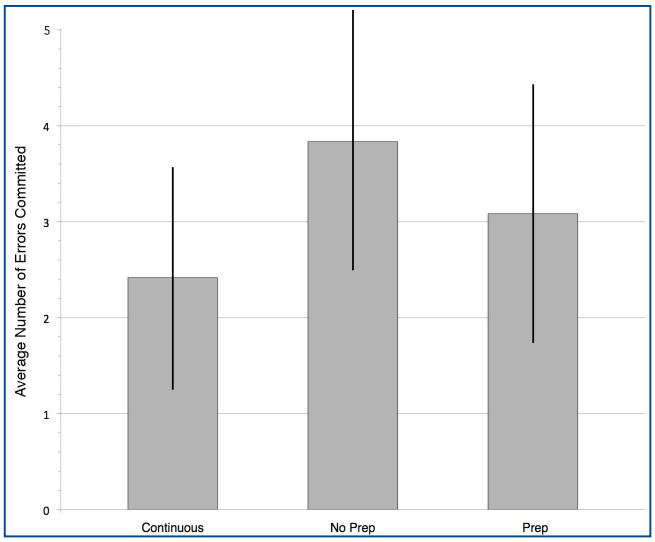

Figure 1.

An analysis of variance revealed no significant differences in the number of errors committed by pilots between any of the three conditions. The standard deviations shown in Figure 1 indicate a large variability in the number of errors committed by individual pilots.

These results show that pilots performed the into-the-loop task with roughly the same success, regardless of what they may have experienced as they worked through the procedure.

Workload Ratings

The next step was to compare the levels of perceived workload that pilots experienced as they completed the instrument procedure. Figure 2 shows the workload ratings provided by pilots in each of the three conditions. Recall that workload ratings were solicited from pilots at sixty-second intervals while they assumed control of the air-

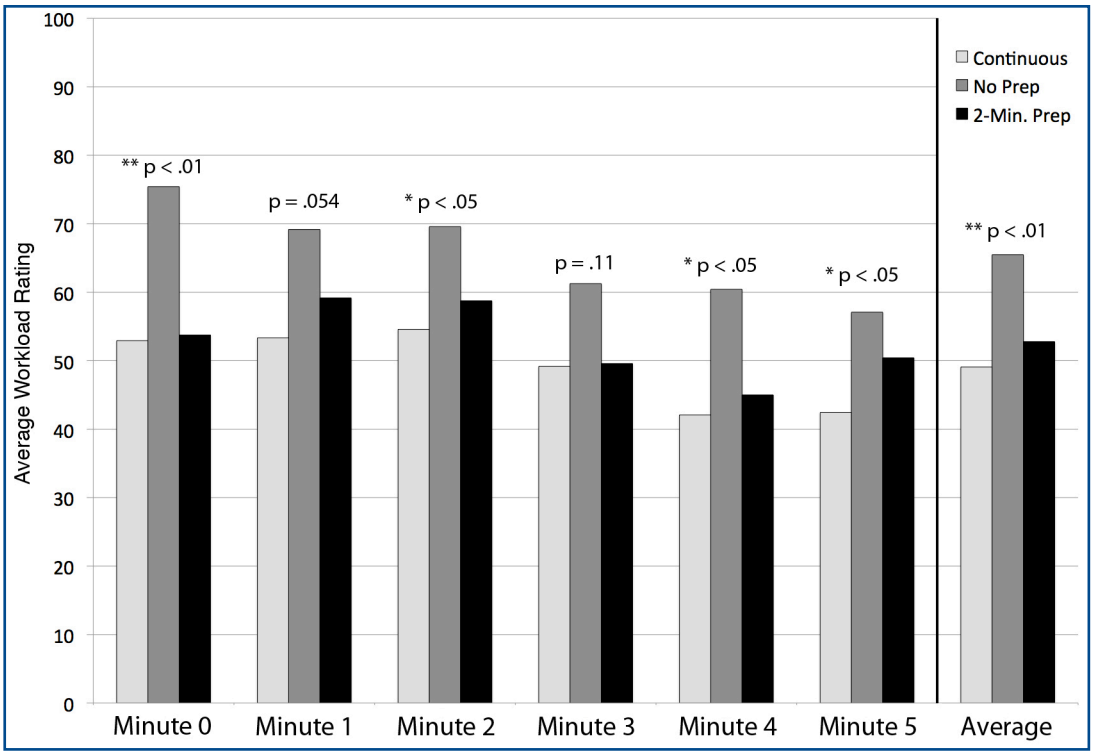

Figure 2

plane. The first six groupings of bars in Figure 2 represent the workload ratings provided by pilots for the first six sixty-second intervals, while the seventh grouping summarizes the average workload rating provided across the six intervals.

The data depicted in Figure 2 suggest that pilots experienced significantly higher workload while flying in the No Preparation condition than they did in the other two experimental conditions. Indeed, a repeated measures analysis of variance (ANOVA) revealed an overall main effect due to treatment condition: $F(2,12)=23.581$, $p < .01$.

Looking at the workload ratings provided at each sixty-second interval, six repeated measures ANOVAs revealed significant or marginally significant differences between the three conditions. The details of these statistical comparisons are depicted above each set of bars in Figure 2. It seems that the higher workload experienced by pilots in the No Preparation condition did not subside over time.

These results suggest that the two minutes pilots were given to look about and mentally prepare effectively eliminated any increases in workload that they might have otherwise experienced when they assumed control of the airplane.

Although reported workload levels appear to somewhat decline across the five minutes during which measures were solicited, this trend was not significant.

Awareness

Recall that pilots were asked to make relative comparisons of their subjective awareness for each of the three experimental conditions at two times during each leg: (1) when they first assumed control of the airplane, and (2) after they finished the missed approach procedure. Our last analysis compared these awareness ratings across the three experimental conditions. Figure 3 plots the geometric means for the awareness ratings supplied by pilots.

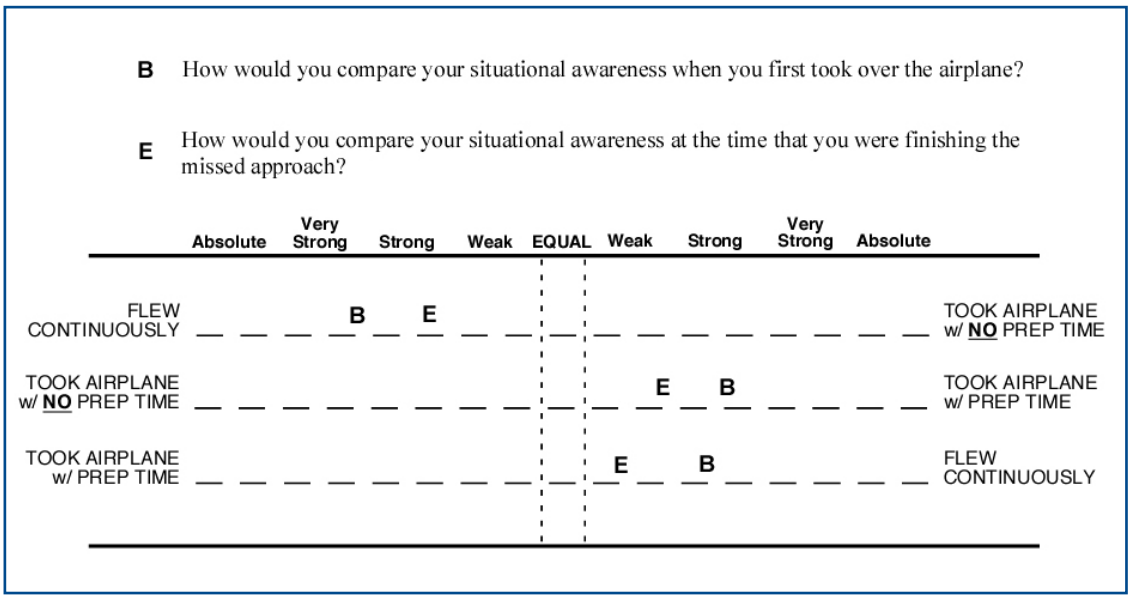

Figure 3.

As expected, pilots rated their awareness during the Continuous condition significantly greater than their awareness during the No Preparation condition, both when they first assumed control ($t(11)=-3.17$, $p < .01$) and after they had finished the procedure ($t(11)=-1.86$, $p < .05$). Similarly, pilots rated their awareness ratings in the Preparation condition significantly greater than in the No Preparation condition, both before ($t(11)=2.51$, $p < .05$) and after assuming control ($t(11)=2.81$, $p < .01$). Interestingly, pilots did not indicate a greater awareness when the Continuous and Preparation conditions were compared.

These results suggest that two minutes to look about and mentally prepare allowed pilots to achieve the same perceived levels of awareness as they reported when flying the procedure from start to finish without interruption. This result has interesting implications for the levels of awareness that pilots maintain while flying under everyday circumstances. It has been suggested by several researchers that awareness is drive by demand: that pilots' level of awareness is largely driven by the extent to which the prevailing circumstances require it (Endsley and Kiris, 1995; Casner, 2005). One pilot participant in the present study reported that being handed the controls of the airplane after viewing the movie was "a good wakeup call."

The proximity of the beginning (B) and ending (E) awareness ratings suggests that pilots' estimation of their own awareness did not change much over the course of the approach procedure. Three comparisons revealed no significant differences between the beginning and ending awareness ratings for any of the three conditions. Any "catching up" that may have occurred as pilots completed the approach and missed approach procedure did not affect their feelings about awareness.

Discussion

The most surprising outcome of this rudimentary experiment was that pilots who assumed control of an airplane in the midst of an instrument approach procedure, after being given two minutes to look about, committed no more errors, experienced no more workload, and reported no less awareness than when they flew the same procedure continuously from start to finish. After taking control of the airplane given no time to prepare, pilots still committed no more errors but did report significantly higher workload and lesser awareness.

Although the results lend initial support to the idea of allowing pilots to be intermittently involved with the progress of a flight, the experimental setting used was simplistic in a number of important ways. Although flying an approach and missed approach procedure is a considerably busy task, it is also a routine and largely predictable one. To generalize the results of this experiment, future studies must be done to look at flight situations that are more complex. For example, many flight situations require pilots to deal with a greater volume of information, to acquire information that is not readily available, to communicate with others to acquire needed information, to make decisions in the presence of incomplete information, or to experiment to gather further information and determine the best courses of action. There have been a number of attempts to characterize the complexity of a task along these and other dimensions (Chechile, Egglestone, Fleischman, and Sasseville, 1989; Kieras and Polson, 1985; McCabe, 1976) and these dimensions might be used as variables in a future experiment. Increasing the complexity of the task may prompt pilots to commit more errors, experience higher workload, lower their perceptions of their own awareness, or any combination of these outcomes.

It must also be noted that pilots in this study performed well for one particular task for which they were given time to survey the situation and mentally prepare. There are many flight situations to which pilots might arrive for which time to prepare is simply not available. Emergencies and recoveries from lapses of attention are the most obvious situations in which pilots must begin to work with little or no time to prepare.

As a further caution, although the spike in workload experienced by pilots in this study who completed the approach without time to prepare

was not associated with a corresponding increase in the number of errors committed, a relationship between workload and error has been reported for other tasks (Wickens and Hollands, 1999). When experiencing high levels of workload, human operators are known to compromise their performance in various ways that can lead to greater error rates, or to simply accept greater error rates in the interest of continuing their performance.

Supporting Pilot Into-The-Loop Performance

Situations that are more complex, unexpected, unpredictable, or that afford little time to prepare invite us to consider techniques that directly support pilots when performing the into-the-loop task. In our study, we offered pilots little more than two minutes to look about. Other researchers have explored ways of providing summary information that details events or changes that have taken place while the human operator was absent. Aside from the techniques that are already in use in the medical and aircraft maintenance industries, other techniques have been proposed and evaluated such as event history lists and instant replays of critical events (St. John, Smallman, and Manes, 2005, 2007). A future study might look at the usefulness of these sorts of information resources in an aviation setting. Another topic for future research might be to design a standardized procedure that systematically helps pilots to apprise themselves of the details of the flight, similar in spirit to the standardized procedure used to diagnose and correct unusual attitudes. How accurate is information transmitted to medical professionals joining a medical emergency? A simulator study. *Human Factors 51*(2), 115-125.

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Glass cockpits in general aviation: A comparison of men and women pilots' perceptions

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Abstract

This research focuses on the perceptions of men and women pilots towards advanced cockpit systems in general aviation. The research used a mixed method approach based on an electronic survey. Multiple-choice questions provided quantitative data, and the qualitative data was drawn from the free comments participants wrote at the end of the survey. The results indicate, as a community of users, both men and women pilots generally have positive perceptions of advanced cockpit systems. Results from the quantitative analyses indicate that men preferred to use advanced cockpit systems significantly more than females. Females also tended to be more concerned about not losing their piloting skills and being dependent on these systems more than men. Qualitative analyses supported these findings. The analyses suggested that although both males and females were positive and had adopted the new technology, the reasons underlying the use was quite different for men and women.

Glass Cockpits in General Aviation: A Comparison of Men and Women Pilots' Perceptions

Commercial, large jet aviation has been utilising an expanding range of advanced technology such as GPS (Global Positioning System), AP (autopilot), MCDU (multi-purpose control display unit), FMC (flight management computer), EFIS (electronic flight instruments system), PFD (primary flight display), and HUDS (heads up displays) on flight decks for over 20 years. This technological application has been labelled the "glass cockpit" and has been the subject of much research over this period (Wiener, 1988; James, McClumpha, Green, Wilson, & Belyavin, 1991; Rudisill, 1995; Singh, Deaton & Parasuraman, 2001; Naidoo, 2008; Mitchell, Vermeulen, & Naidoo, 2009). Similarly, the paucity of women pilots in large commercial jets has been explored (Vermeulen & Mitchell, 2007; Kristovics, Mitchell, Vermeulen, Wilson & Martinussen, 2006; Mitchell, Kristovics, Vermeulen, Wilson & Martinussen, 2005). The new technology continues to be developed and applied to the military, commercial, and general aviation field. General aviation includes all aviation operations but excludes scheduled commercial airlines and military aviation. It includes business flying, agricultural aviation, personal flying for pleasure and sports, bush flying, gliding and flying by flight-training institutions (Kumar, DeRemer & Marshall, 2004). Experimental aircraft and very light jet aircraft are recent additions to general aviation (Cobb, Thomas & Cobb, 2007).

More recently, manufacturers of light aircraft have been introducing versions of this technology, including GPS, AP, and Traffic Alerting System (TAS), into the general aviation (GA) and recreational aviation (RA) sectors. These are referred to as advanced cockpit systems. Advanced cockpit aircraft means any aircraft, old or new, that includes at least a panel-mounted GPS receiver unit and an autopilot. The new cockpit systems might also include electronic flight instruments, a moving map, traffic alerting system, hazardous weather system, terrain-warning system, or a complete glass cockpit. Therefore, general aviation and recreational pilots are being exposed to a new raft of innovations in light aircraft flight deck design. Recent research (Casner, 2005, 2008; Dekker & Nahlinder, 2006) has examined pilots' perceptions of the new technology and some implications for training new pilots. The aim of this research is to develop a greater understanding of the perceptions of pilots, as a community of end users, towards automation on the flight deck of GA and RA aircraft in Australia using this framework. More specifically, the research will address the relationship between women pilots and the new technology, and compare their perceptions with that of men pilots.

Women and "those flying machines"

Within international, domestic, and regional aviation domains, there is a scarcity of women pilots. Estimates put the numbers to be less than 5% of the worldwide total pilot population (Mitchell et al., 2005). In Australia, the current number of licence holders for the piloting of aeroplanes, helicopters, and balloons is 40734 men and 2382 women. Women represent 5.85% of all licence holders (Stewart Cameron, CASA, personal communication 26.02.2010). This is an unfavourable comparison with other non-traditional occupations such as engineering where, for example in Australia, women comprise 10% of the engineering workforce (Engineers Australia, 2006). The reasons for the low number of women entering into the commercial flying field remain unresolved. This is despite more than three decades of affirmative action, equal employment opportunity legislation, and organisations providing opportunities for women. In engineering, Faulkner (2006) indicated that women and girls are not interested in design roles and "that the symbolic association of masculinity and technology must be operating strongly" (p. 143). Similarly, Mitchell et al. (2005) found that Australian data indicated a pronounced orientation towards a masculine culture within piloting. This is despite the evidence of legendary women aviators and their contribution to aviation (Moolman, 1981; Cadogan, 1992; Yount, 1995). Thus, piloting remains less attractive to women than other non-traditional occupations including engineering.

The significance of air transportation cannot be overestimated in terms of the economic and social impact to society. From the early days of powered flight, women have been involved in its development and acceptance. Women pilots (aviatrixes) "fuelled an immense popular passion for flying and captured the imagination and hearts of the masses" (Millward, 1998-99:1). It is from this point that women pilots, having demonstrated that flying was safe, began to be marginalised by the aviation industry. Millward's (1998-99:13) research indicated that women pilots were portrayed either as "woman in pursuit of diversion" or "woman in pursuit of fortitude." Women between World War I and World War II were portrayed as not being serious about the economic rewards of flying but merely flying for sport and pleasure. As a result, many women's contributions to flying were written out of the history of aviation. As Millward (1998-99:14) pointed out "while women can occasionally be incorporated into a masculine discourse, the reverse seldom occurs." Airspace, at that time, came to be and largely remains under masculine control and the domain of men.

Classifying women pilots as seeking either diversion or fortitude helped reinforce the notion that women were not meant to fly aircraft. They were the recipients of gender bias evaluations based on their excursions into a male-dominated occupation and "man's work." These successful women pilots were then subjected to a discourse that favoured male attributes and were therefore criticised for violating gender prescriptive norms (Heilman, Wallen, Fuchs & Tamkins, 2004). For women, stepping outside the bounds of gender-specific stereotypes generates forms of social censure including disapproval, negativity, being cold, poor group members and interpersonally wanting. They can be seen as "bitter, quarrelsome, selfish, deceitful, and devious" as well as counter-communal (Heilman et al.,

2004:417). These negative epithets are usually not applied to the successful man operating in a male gender-specific domain. Prototypically, men are applauded for being assertive, competitive, agentic and controlling while women are stereotyped as pro-social and communal (Lammers, Gordijn & Otten, 2009). This stereotypical bias against successful women pilots led to their contribution to aviation to be downgraded and/or ignored in the development of aviation.

Not only were women "written out" of aviation history, aircraft cockpit design was engineered with a bias against women's bodies. This bias was confined not only to the military but also to commercial aircraft. Aircraft cockpits were designed and built to conform to male anthropometry (Weber, 1997). As Araújo (2008:483) pointed out "[T]he relative subordination of women thus concerns not only the production of technology and science but also its practical utilization." The design of cockpits has acted as a barrier to the inclusion of women pilots in military and commercial aviation and therefore helped to preserve the cockpit primarily as a male domain. However, in light aircraft, cockpit design had fewer physical limitations for women. Cockpit space, although always confining, is personal space whether the cockpit-seating layout is singular, paired, or tandem. Instrumentation, relative to large aircraft, was basic and the required physicality of strength, leg, and arm reach required for large aircraft was generally not an issue except for exceptionally short people. However, flying has a duality of space. There is the envelopment of the pilot within the aircraft and expansiveness of seemingly unlimited airspace surrounding the aircraft. The duality and use of this airspace then depends upon how it is being utilised by the pilots. It could be because of the pilot being employed and engaged in commercial activity, the pilot's participation in a sporting event, or a pilot engaged in leisure or personal flying.

Women and technology

Feminist studies into the relationship between women and technology have spanned several decades. A critical argument in women's relationships with technology is that technology, its development is male dominated, and therefore it enhances men's power. Much of the writing has been based on the premise that "[T]he cultural association between masculinity and technology in Western society is hard to exaggerate" (Grint and Gill, 1995:3). Articles on the "social shaping of technology" or "constructivist" theory of technology emphasise the dominance of masculinity in the development of technology (Wajcman, 2005). Rather than women being the developers of technology, they are mainly consigned to the role of end users, be it in the home or the workplace. Edited books by MacKenzie and Wajcman (1985, 1999), Grint and Gill (1995), Fox, Johnson and Rosser (2006) and Wyer, Barbercheck, Giesman, Ozturk and Wayne (2009) are some of the many contributions to the understanding of that relationship which embeds technology in a masculine frame.

Feminist writers bring many perspectives to analyses of the interactions between women and technology. Bryson (1999) discussed various approaches and recognised that each approach can be complementary or antagonistic. Similarly, Rosser (2006) recognised that there are many divisions within the feminist approach to understanding the relationship between women and technology. Each perspective brings with it its own "ways of seeing" and interpreting the impact of technology in such terms as patriarchy, culture, class, power, race, inequality, occupations and structural issues relative to gender. Similarly, other approaches, informed by constructivist thought include ways of "doing gender," "performing gender," "positioning gender" and "practicing gender" (Poggio, 2006).

Orlikowski (2000) criticised the social constructivist approach indicating that it does not take into sufficient consideration the role of the end user of technological artefacts, technology-in-practice. She goes on to say:

> ...in both research and practice we often conflate two aspects of technology: the technology as artefact (the bundle of material and symbol properties packaged in some socially recognizable form, e.g., hardware, software, techniques); and the use of technology, or what people actually do with the technological artefact in their recurrent, situated practices (p. 408).

The choice of various technologies and technologies-in-practice involves both choosing the type of technological artefact and identifying how the user will interact with and apply any number

of applications. Accordingly, technologies-in-practice are those "rules and resources" based on the "skills, knowledge and assumptions" held by the user and developed by their ongoing interaction with the properties and norms or protocols of each artefact (Dery, Hall & Wailes, 2006:232).

On a more psychological level, and ones that does not dispute Orlikowski's (2000) argument, are the findings of Venkatesh, Morris and Ackerman (2000) and Venkatesh, Morris, Sykes and Ackerman (2004). They investigated gender differences in individual decision-making processes in technology adoption using the theory of planned behaviour as the basis of their studies. Initially, Venkatesh et al. (2000) found that women tended to have what they termed as a "balanced" approach to adopting new technology: that is, they were most influenced by subjective norm and perceived behavioural control. In contrast, attitude was the only influencing factor for men. Attitude relates to the perceived ease of use and the usefulness of the technological base being introduced. Subjective norm relates to "perceived opinions of referent others" (Mathieson, 1991:176). Perceived behavioural control relates to perceived "perception of the availability of skills, resources, and opportunities" (Mathieson, 1991: 176). As Venkatesh et al. (2000) suggested, these findings support the gender schema theory. Their literature review indicated that men were more inclined towards a preoccupation with work, accomplishment of objectives and eminence, and achievement. Other masculine traits included dominance and assertiveness, being instrumental, task-oriented, more likely to rebel, and more likely to emphasise outcomes over process. In contrast, they related to women having characteristics such as expressive behaviour, being more compliant in receiving and acting on orders, relationship oriented, interpersonal goals, increased awareness to social cues, and having a greater process orientation.

One of the limitations of the findings above was addressed in a later study by Venkatesh et al. (2004) who not only explored the difference between men and women based on biological sex but also incorporated a measure of gender identity. They found that masculine individuals showed the same pattern above for men, that is, influenced by attitude only. Feminine individuals were most influenced by subjective norm and perceived behavioural control and where attitude was not significant. However, for androgynous individuals (where participants exhibited both male and female traits), results indicated that attitude, subjective norm and perceived behavioural control were all significant. Their research also showed that a large percentage of females (67%) in their sample could be classified as androgynous. Also, Venkatesh et al. (2000) found that factors such as income, organisational level, education and computer self-efficacy were all found to be not significant as predictors of intention of use.

Within the context of general aviation and recreational aviation, which may be considered a masculine industry, the implementation of advanced technological developments, represented by a range of artefacts identified above, presents the opportunity to compare what men and women pilots, a community of users, say they do in relation to the new electronic systems being implemented in light aircraft.

The present study

The present study builds on the recent findings of studies (Casner, 2008) carried out by NASA in the USA into GA pilot perceptions of glass cockpits in light aircraft that examined the benefits and limitations of the use of this technology. Casner (2008) identified nine topic areas arising out of the research. These are: (1) General attitudes about advanced cockpit systems; (2) Workload; (3) Situational awareness; (4) Learning; (5) Retention; (6) Error; (7) Safety; (8) Preference for in-flight use; and (9) Overall preferences. The focus of the present study, however, is to examine these issues in relation to women pilots in comparison to that of men's perspectives and is based on data collected from an Australian sample.

The research used a mixed method approach. Quantitative data were drawn from the multiple-choice questions and the qualitative data drawn from the free comments participants wrote at the end of the survey. In this approach, the quantitative and qualitative methods are used in conjunction with one another. Results from both areas are integrated and are aimed to complement each other (Steckler, McLeroy, Goodman, Bird & McCormick, 1992).

Method

Participants

Overall, there were 223 responses. These were from 186 men, 34 women pilots and 3 who did not indicate their gender. Not all respondents completed their survey forms. Incomplete surveys were removed from the database and the final cohort consisted of 100 men and 22 women pilots. Table 1 highlights their biographical details.

Materials

The present study used the identical 52-item NASA survey on pilot attitudes towards glass cockpits. Participants were asked to respond to each item using a 5-point Likert scale, where 1 = strongly agree, 2 = agree, 3 = neutral, 4 = disagree and 5 = strongly disagree. Therefore, the lower the score, the more the pilots agreed with the statement represented by the item. One further

Table 1

Participant details

	Women (N=22)	Men (N=100)
Average age	44.8	51.9
Average flight hours	1289	2679
Average hours in "glass cockpit"	72	403
Average hours with at least a Panel mounted GPS	286	740
Certificates and ratings		
1. Private	12	51
2. Instrument	-	16
3. Commercial	5	23
4. Airline Transport Pilot	2	9
5. Chief Flying Instructor	2	-
6. Chief Flying Instrument-Instructor	1	1
Primary flying activity		
1. Non –schedules charter	6	
2. Scheduled charter operations	-	
3. Airline	1	
4. Private leisure/sport	14	
5. Other	1	
Education		
1. High School Certificate	4	
2. Diploma	5	
3. Bachelor degree	6	
4. Post graduate degree	7	
Computer literacy		
1. Poor	-	
2. Average	5	
3. Above average	5	
4. Excellent	12	

item "How do you think advanced cockpit systems will affect the number of aircraft accidents?" had a different response set. Participants had to choose from six responses, that is, "significantly reduce accidents," "somewhat reduce accidents," "will not affect accidents," "somewhat increase accidents," "significantly increase accidents" and "unsure."

In addition, further items gathered data related to primary flying activity (e.g. private/leisure, scheduled charter operations etc.), age, sex, educational background, certification, and total flight time - including time flying with a glass cockpit. Participants were also asked about their preference between the different advanced systems, such as GPS, autopilot, hazardous weather display, moving map, terrain warning, and traffic alerting system. Further, a space for comments was added to allow pilots to express their views on issues that were or may not have been addressed in the survey questions. These comments were then utilised as the base for the qualitative analyses. The NVivo 8® software package was utilised to analyse the qualitative data.

Procedure

The data were collected online via links placed on the websites of the Aircraft Owners and Pilots Association (AOPA), Australian Women Pilots' Association (AWPA), Sport Aircraft Association of Australia (SAAA) and Recreation Aviation-Australia (RAA). Each of these associations advised members of the research and requested that they complete the survey. Responses were submitted online and collated on Excel spreadsheets.

Results

Quantitative

The data from the 52-item questionnaire were analysed using SPSS 17. The original intention of performing a factor analysis on the questionnaire was not possible owing to the small size of the sample. In reviewing the required sample sizes for factor analyses, Mundfrom, Shaw and Ke (2009) stated that the absolute minimum that has been suggested was three per item, which for the 52-item questionnaire would be a minimum of 156 participants. Unfortunately, the present sample of 122 prohibited analysis for the factor structure. Therefore, the following analyses were undertaken on an item-specific basis.

Another reason the data were analysed on an item-specific basis was the difficulty in establishing a good reliability coefficient among Casner's (2008) proposed factors. For example, coefficient alpha for the first factor, general attitudes, was .50, with a more acceptable .79 when items 17 and 48 were removed. The coefficient alpha for the awareness factor, however, was .24. When examining the items on the awareness factor (see Table 2), one can see that items 4, 15, 23, 24, 25 and 29 relate to one's own perceptions whereas the remaining items relate to perceptions of other pilots. Other proposed factors also had similar problems. Therefore, the above findings reinforce the decision to undertake analyses on individual items in an attempt to explore initial data for differences between males and female pilots.

When sample sizes are uneven, as in this case of the present study where there are 100 men and 22 women, many statisticians recommend the use of non-parametric tests such as Mann-Whitney U test (e.g., Urdan, 2010). Some researchers have also argued that Likert scales are non-parametric and should be analysed using non-parametric tests (Jamieson, 2004; Seaman and Allen, 2007). However, other researchers have argued that in some instances, parametric tests such the t-tests, more specifically, the Welch test, can outperform the Mann Whitney U test except in cases where there is severe violations from the test assumptions (e.g., Ruxton, 2006; Kikvidze and Moya-Laraño, 2008; de Winter and Dodou, 2010). De Winter and Dodou state that for both the t-test and the Mann Whitney U test,

> "the Type I error rate deviates from the nominal value when unequal variances are combined with unequal sample sizes

or when unequal variances are combined with non-normal distributions (Fagerland & Sandvik, 2009; MacDonald, 1999; Stonehouse &Forrester, 1998; Zimmerman, 2006). In such cases, separate-variance procedures such as the Welch test are recommended as being more Type I error robust (Cribbie & Keselman, 2003; Ruxton, 2006; Zimmerman, 2006)" (2010: 2).

However, Kikvidze and Moya-Laraño (2008) add, "non-parametric tests could complement parametric tests when testing samples of une¬ven size" (2008:67). Therefore, the following analyses will be undertaken using both Mann-Whitney U tests and the Welch test when comparing the differences between male and female pilots.

In relation to which advanced cockpit system males and females preferred, the majority of both males and females preferred the GPS. For females, 63.6% preferred the GPS, 9.1% selected autopilot and 9.1% selected the moving map. Males showed a similar pattern, where 54% chose the GPS, 19.0% selected autopilot and 19.0% selected the moving map. More females (13.6%) preferred the traffic alerting system than men (4%). Hazardous air display systems were preferred by 3% of males and 4.5% of females.

The item of whether advanced cockpits would increase or decrease accidents was scored from 1 = significantly decrease accidents to 5 = significantly increase accidents. The result from the Welch test and Mann Whitney U test revealed no significant difference between males and females; $t(28.04) = .47$, $p = .76$. The mean for men was 2.70 (SD = 1.84) and the mean for women was 2.86 (SD = 2.17), indicating that both men and women thought that advanced cockpit system would "somewhat" decrease accidents to "will not affect accidents." Mann Whitney U test results were $z = .03$, $p = .97$.

Table 2 shows the items of the questionnaire and the difference between the means for men and women pilots. As can be seen from the Table, 10 of the items showed a significant difference between males and females. All analyses on the items below were undertaken using the Welch test with α set at .01, as well as the Mann Whitney U test.

There were four items in which the men and women's scores were significantly different, indicating that men agreed more with the statement than women did on the following items:

Item 1. Using the autopilot lowers my workload, Welch test: $t(35.77) = -3.019$, $p = .005$; Mann Whitney U Test: $z = 3.10$, $p = .002$.

Item 4. My situational awareness is better in an advanced cockpit, Welch test: $t(33.07) = -2.18$, $p = .037$; Mann Whitney U Test: $z = 2.31$, $p = .021$.

Item 12. I prefer to use the autopilot during a missed approach procedure, Welch test: $t(37.14) = -2.32$, $p = .026$; Mann Whitney U Test: $z = 2.04$, $p = .041$.

Item 34. I feel safer in an advanced cockpit aircraft than I do in a conventional aircraft, Welch test: $t(32.89) = -2.43$, $p = .021$; Mann Whitney U Test: $z = 2.37$, $p = .018$.

The Mann Whitney U test but not the Welch test identified significant differences between the next two items.

Item 18. I prefer to use the autopilot during periods of high workload, $z = 2.09$, $p = .036$.

Item 21. I prefer to use the autopilot when flying en route, $z = 2.16$, $p = .031$.

Women's scores were significantly different from men's scores on six of the items. Women agreed more with the statement than men did on the following items:

Item 2. New pilots that learn to fly only in advanced cockpit aircraft are going to be lacking in some important piloting skills, Welch test: $t(34.88) = 2.68$, $p = .011$; Mann Whitney U Test: $z = 2.49$, $p = .013$.

Item 3. I am concerned that I might become too dependent on GPS, autopilots, and other advanced cockpit systems, Welch test: $t(29.24) = 2.36$, $p = .027$; Mann Whitney U Test: $z = 2.32$, $p = .020$.

Item 8. CASA should publish a new pilot handbook to cover advanced cockpit systems,

Welch test: t(43.14) = 3.33, p = .002; Mann Whitney U Test: z = 2.59, p = .009.

Item 26. I need to fly more often to maintain proficiency in an advanced cockpit than I do in a conventional aircraft, Welch test: t(38.12) = 3.26, p = .002; Mann Whitney U Test: z = 2.72, p = .007.

Item 43. For some pilots, turn off their GPS and moving map during a flight, and they might be lost, Welch test: t(51.75) = 3.13, p = .003; Mann Whitney U Test: z = 2.14, p = .032.

Item 48. Advanced cockpit systems can get you into trouble just as easily as they can get you out of trouble, Welch test: t(38.52) = 2.94, p = .006; Mann Whitney U Test: z = 2.55, p = .011.

Table 2

Differences between male and female responses

Variables	Males (100) Mean	SD	Females (22) Mean	SD	Sign
General attitudes					
9 Advanced cockpit systems are becoming too complicated	3.18	1.09	3.05	.90	ns
14 They've gone too far with advanced cockpit systems	3.77	.98	3.59	.91	ns
17 I look forward to new kinds of advanced cockpit systems	2.14	.93	2.41	.96	ns
22 The advanced cockpit does not make good use of my basic piloting skills	3.07	1.11	2.77	1.15	ns
30 In an advanced cockpit, sometimes I feel more like a 'button pusher' than a pilot	3.35	1.11	2.91	1.11	ns
48 Advanced cockpit systems can get you into trouble just as easily as they can get you out of trouble	2.46	.98	1.91	.75	p = .006
Workload					
1 Using the autopilot lowers my workload	1.62	.69	2.05	.57	p = .005
7 There are too many alerts and warning noises in the advanced cockpit systems	3.36	1.00	3.09	.92	ns
28 I can better control my workload in an advanced cockpit	2.43	.91	2.73	.93	ns
37 I sometimes spend more time setting up and monitoring the autopilot than I would just hand-flying the aircraft	3.29	.98	2.82	1.05	ns
42 Navigating using GPS lowers my workload	1.87	.66	2.27	.93	ns
Awareness					
4 My situational awareness is better in an advanced cockpit	2.33	1.21	2.91	1.20	p = .037
15 I always know what mode the GPS and autopilot are in	2.25	.95	2.32	.84	ns
23 The pilot that uses pilotage (a sectional chart) is going to have better navigational awareness than one who uses a GPS and moving map display	3.15	1.18	2.77	.97	ns
24 It worries me that the GPS, autopilot, or other systems may be doing something that I don't know about	3.38	1.00	3.00	.93	ns
25 When I have a traffic alerting system on board, I look out the window less often	3.51	.99	3.23	.92	ns

Variables	Males (100) Mean	SD	Females (22) Mean	SD	Sign
Awareness cont.					
29 If you turn off my GPS and moving map during a flight, I may be lost	3.95	.88	3.77	1.11	ns
33 Pilots who use traffic alerting systems have a tendency to look out the window less often	3.00	.98	2.68	.78	ns
43 For some pilots, turn off their GPS and moving map during a flight, and they might be lost	2.43	1.04	1.91	.61	p = .003
Learning					
2 New pilots that learn to fly only in advanced cockpit aircraft are going to be lacking some important piloting skills	2.51	1.08	1.91	.92	p = .011
8 CASA should publish a new pilot handbook to cover advanced cockpit systems	2.63	1.14	1.95	.78	p = .002
16 There are many things about advanced cockpit systems that can only be learned through experience flying the aircraft	2.01	.77	2.09	.87	ns
19 The practical test standards need to be expanded to include skills specific to advanced cockpit aircraft	2.26	.92	2.00	.87	ns
20 There is more for me to learn and remember in an advanced cockpit aircraft	2.34	.90	2.00	1.02	ns
38 There are still features of the advanced cockpit that I don't understand	2.53	1.06	2.09	.92	ns
39 I found everything that I needed to know about advanced cockpit systems in the manufacturer's technical manuals	3.07	1.08	3.27	.88	ns
41 Students learn to fly GPS approaches more quickly than they learn to fly VOR, VOR/DME, and localizer approaches	2.81	.71	2.64	.49	ns
44 The CASA pilot knowledge test (aka 'written exams') should include questions about advanced cockpit systems	2.54	1.00	2.77	1.02	ns
47 The CASA has provided pilots, students, flight instructors, and examiners with sufficient guidance about flying advanced cockpit aircraft	3.35	.78	3.59	.67	ns
51 Pilots should not be allowed to act as PIC in advanced cockpit aircraft unless they get an endorsement similar to the one required for high-performance and complex airplanes	2.79	1.16	2.32	1.09	ns
Retention					
3 I am concerned that I might become too dependent on GPS, autopilots, and other advanced cockpit systems	3.12	1.05	2.50	1.14	p = .027
26 I need to fly more often to maintain proficiency in an advanced cockpit than I do in a conventional aircraft	3.00	1.08	2.32	.84	p = .002
32 I am concerned that flying advanced cockpit aircraft will cause my basic flying skills to deteriorate	3.33	1.10	3.00	1.02	ns
36 I am concerned that today's pilots may become too dependent on GPS, autopilots, and other advanced systems	2.70	1.07	2.50	1.14	ns

Variables	Males (100) Mean	SD	Females (22) Mean	SD	Sign
Error					
5 Advanced cockpit systems are going to reduce the number of errors pilots make	2.85	1.09	3.05	1.13	ns
6 Using GPS is going to result in fewer accidents	1.98	.91	2.09	.92	ns
10 Incorrect data entered by mistake is easy to detect in the advanced cockpit	3.27	.95	3.50	.74	ns
11 I am less likely to make a navigational error or bust an altitude in advanced cockpit	2.44	1.10	2.50	.96	ns
31 Advanced cockpit systems create opportunities to make new kinds of errors	2.22	.94	2.00	.62	ns
Safety					
13 I feel safer in any aircraft that has a parachute (ballistic recovery system) for the airframe	3.08	1.14	3.00	1.23	ns
34 I feel safer in an advanced cockpit aircraft than I do in a conventional aircraft	2.84	.98	3.36	.90	p = .021
45 Terrain displays in the cockpit are going to reduce the number of controlled flight into terrain (CFIT) accidents	2.44	1.05	2.50	.86	ns
46 Some pilots will misuse advanced cockpit systems to stretch the boundaries of safety	2.21	.87	2.05	.84	ns
49 Traffic alerting systems are going to reduce the number of mid-air collisions	2.44	.97	2.32	.72	ns
50 Cockpit weather systems are going to reduce the number of weather-related accidents	2.39	.97	2.36	.85	ns
52 GPS is going to reduce the number of accidents	2.92	.98	3.14	1.04	ns
Preference for in flight use					
12 I prefer to use the autopilot during a missed approach procedure	3.17	.92	3.59	.73	p = .026
18 I prefer to use the autopilot during periods of high workload	2.00	.94	2.36	.85	ns
21 I prefer to use the autopilot when flying en route	2.09	.93	2.55	1.01	ns
27 I would rather use GPS than VORs to navigate	2.05	1.02	2.00	.97	ns
35 I prefer to use the autopilot when flying an instrument approach	2.86	.93	3.14	.71	ns
40 I prefer to hand-fly the aircraft (autopilot off) during periods of low workload	2.68	.99	2.32	.89	ns

Qualitative

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. This 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. NVivo 8® is a software program for qualitative text analysis and is designed to assist researchers organise, manage, code, and analyse qualitative and mixed-methods research data. This program can be used to facilitate the uncovering of the multifaceted themes hidden in the data or to allocate the data to predetermined categories.

Written responses by men (63/185: 34%) and women (13/34: 38.2%) were extracted from the survey. The qualitative analysis was conducted through NVivo 8®. Casner's (2008) categories were entered as tree nodes and the content of the comments allocated to the various nodes. In addition to the tree nodes, "child nodes" or subcategories were added to the tree nodes of General Perceptions, Retention, and Safety. These child nodes were Positive and Negative Perceptions, Reduced Skill Levels, and Decreased Safety respectively. These were added to reflect the varying perspectives that were identified within the comments.

Comments made by both men and women pilots tended to be brief and focussed on particular aspects of the technology and its application. This amount of qualitative data has limited the analysis and therefore the results can be considered exploratory rather than definitive.

General perceptions about advanced cockpit systems

The qualitative analysis revealed a mixture of both positive and negative perceptions of advanced cockpit systems. Both men (21 comments) and women (3 comments) were mainly positive in their perceptions about the cockpit systems. Comments from men included "Glass Cockpits are awesome," "the glass cockpit makes me more confident in the systems I am trusting to keep me in the air," "I believe that Glass cockpits will make better pilots. There is no guessing or any confusion, you can never have enough information," and "I would prefer a glass cockpit because you get more performance figures that you can manage in-flight." Women pilots had fewer comments; however, the indication was that "they can only enhance the flight." While both groups of pilots were generally positive, some expressed reservations about the new technology. Typically, men said "I believe they are of benefit, but can cause us to be a bit reliant," "glass moving map etc is great but I am wary of me and my pilots becoming too reliant on it," while women indicated that "Glass cockpits are inherently neither good or bad" and that "if the pilots use them as they should be used." These comments indicated that perceptions were positive; however, there were some reservations about the efficacy and use of the new technology.

With fewer comments (8) on the negative side, the focus for men was that "Glass cockpits are a distraction" and that there were difficulties operating across different brands. For example, "Glass cockpit ie Garmin 1000 etc is vastly different to Advanced cockpit i.e. Autopilot, VOR, GPS" and "glass cockpits could be more intuitive and standardised across brands" and "Glass cockpits should resemble analog [sic] cockpits with as little button pushing as possible." Women pilots (2) commented "I really don't find digital displays do much for me, the analogue dials give me a really good indication of what's going on … and I don't have to worry much about electrical failure etc," "each system is very different both in display and controller requirements" and "Will be just as lethal in the hands of cashed up private pilot who has minimal ability or understanding and big ego." Among both men and women pilots, there is a cross section of perceptions about the new technology being installed in general aviation and recreational aircraft. Overall these perceptions are positive but with some doubts being raised as to their efficacy and to the standardisation of the operation and displays of various brands.

Workload

Pilot workload is an issue across all fields in the aviation domain, and the survey sought comments on how advanced cockpit systems may affect workload were examined. Workload in the aviation domain "refers to the combined mental and perceptual demands imposed by the time critical pressures of the flight environment" (Hitchcock, 1999:313). Only men respondents (6) commented briefly on workload in a positive manner. "Any device that reduces pilot workload (especially in SPIFR) makes for safer flight," "Anything that has the potential to reduce workload and provide good positive feedback to pilots is worthwhile … a glass environment reduces workload and makes the task much easier" and a warning "the increased sophistication and complexity of cockpit systems for the pilot (who now has to act as computer operator in addition to PIC [Pilot in command]."

Situational awareness

Flying an aircraft requires the pilot or pilots to maintain a high level of situational awareness. Situational awareness is "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" (Endsley, 1999:258). On the positive side, men pilots (10) gave recognition to the enhancement of situational awareness. Comments included "The benefits of improved situational awareness in advanced cockpit aircraft are beyond dispute," "just upgraded to a full glass panel to improve safety and situational awareness" and "Very expensive, but it has greatly enhanced situational awareness." Again, words of caution were evident. "Glass offers significantly enhanced geographical situational awareness … but also breeds complacency about looking out the window," "I don't think glass cockpit technology enhances PIC situational awareness," "Glass cockpits, apart from readability, if taken to far can focus attention inside the aircraft instead of outside," "I worry that in busy airspace pilots will tend to use/look/play/admire their electronic systems instead of keeping a good lookout," and "They should be looking outside, not watching TV." Similarly, women pilots (2) were reticent about the improvement in situational awareness. "In saying that the moving map I'm used to seeing is used purely for situational awareness and never relied upon" and "I am concerned that there will be too much "heads inside" rather than looking outside."

Learning

In this survey, Learning refers to how advanced cockpit systems might affect the way pilots train and maintain proficiency. This category attracted the most overall comments with men (20) and women (11) raising issues about training in advanced cockpits systems. Clearly, the emphasis on training indicated that pilots were aware of the need for in-depth training to acquire the appropriate level of knowledge about the various electronic systems. Arising out of this, a major concern from both men and women pilots was the lack of a formalised training programme for advanced cockpit systems together with a subsequent licence endorsement from the Civil Aviation Safety Authority (CASA). One woman commented "A glass cockpit needs a rating like IF flying." Others commented, "CASA or the respective flying schools utilising Glass cockpit aircraft need to run ground courses and practical courses that let the student know the limitations of their instruments" and "CASA could develop an online course for providing further instruction." "CASA, operators and pilots need to work together to ensure pilots are familiar with the operations of each specific system" and "Suggest it would be difficult for CASA to do much in terms of ground study because each system has its own idiosynchrosies [sic]. The existing requirements for use of GPS/RNAV under IFR are a bit of a joke - if they were serious they'd require a ground school for each specific type of GPS system" were from men pilots.

Both men and women pilots gave indications that training in conventional cockpits should precede training on advanced systems. Comments from women included, "In the initial stages of

flying I believe traditional methods of navigation etc should always be the foundation of knowledge with more technologically advanced methods maybe being introduced to complement that later down the track," "I believe new pilots should be trained using old 'steam gauges' and only after a period of learning should glass cockpit instruments be introduced" and "I think that the PPL licence should include training in the use of GPS." Men said "all pilots need to learn normal analog [sic] cockpits first," "Ground familiarisation (aka the Garmin simulator) is invaluable," "I think that it is beneficial for pilots to be trained on basic instrumented aircraft before they fly with moving map displays etc" and "Learning glass cockpit operations after being trained on the older analogue instruments is part of the on-going learning experience of aviation."

Retention

Retention is about retaining knowledge and skills related to advanced cockpits. Here again, both men (15) and women (2) pilots had mixed views on the impact of advanced cockpit systems on the retention of knowledge and flying skills. Women pilots said "It is the skill level of the operator which determines how effective it is. I love 'glass' but am concerned that little use of functions may be easily forgotten and hard to call upon when urgently needed" and " having all the electronics in the world will not stop a pilot from ignoring the systems (alarms); it may encourage some to become slack with their flying skills." Men pilots indicated that "Like everything else, there will be enormous variation between individual pilot aptitudes in adapting to the capabilities of advanced cockpits," "I try to maintain basic skills, but when busy sometimes you do just rely on the equipment" and "any of these type of technology are an aid to the pilot but should not replace proper piloting skills/training or proper airmanship."

Other male pilots were more direct, "Yes, we see basic pilot skills getting worse from people who have only learnt in a glass aircraft – particularly nav. yes, their situational awareness is often better from good use of glass… until it goes blank," "Currency is important when using the systems, particularly where IFR flight is concerned. The current trend towards providing low time students with advanced avionics should be considered as it could definately [sic] result in pilots with reduced piloting skills" and "However i [sic] see limited hour pilots place too much reliance on the automated systems and they do not learn airmanship or handling capabilities in an emergency situation. Map reading skills also disappear rapidly after licence qualification."

Error

Error refers to how advanced cockpit systems will affect pilot error. This area attracted the least number of comments and only by four men. Comments included "Poor pilot decision making/choices will still be the reason for most accidents … but unfortunately people will find ways to make new errors and dumb choices," "The problem with planes with glass cockpits is that different brands of glass cockpits can have subtle differences in the way they operate. This can cause confusion when flying different planes," and "Some pilots, regardless of what is occurring in and out of the cockpit will end up crashing because they fail to manage themselves wisely."

Safety

Safety is a high priority in aviation. The survey sought to examine pilots' belief about how advanced cockpit systems would impact safety. Thirteen men and no women pilots addressed the issue of safety in their comments. Again, their comments reflected mixed perceptions concerning the safety aspects of the glass cockpit. Positive comments included "Technology should help to decrease accidents," "Technology provided by the advanced cockpit is of great benefit for safe piloting," "I fly high performance single with GPS moving map advanced autopilot and weather at command instrumnt [sic] and have just upgraed [sic] it top a full glass panel to improve safety" and "can only see it as good and positive move to

safer flying." Others appear more reticent, saying "I believe the systems to be much safer, however i [sic] see limited hour pilots place too much reliance on the automated systems," "makes for safer flight in IMC but there will always be mavericks and mncho [sic] men doing it the hard way" and "The attitude and professionalism of the pilot has more to do with safety of flying either system."

Others saw the use of advanced cockpits the potential for a decrease in safety. "Without having duplicated 'glass' systems I am not yet convinced that the same level of safety is obtained," "Most mid air collisions in Australia are at GAAP reporting points and traffic alerts will not reduce them," "VFR is see and avoid, not to be 'told' that there is something there and then avoid it" and glass cockpits have "the potential for distraction."

Preference for in-flight use

This examined pilots' preferences for when to use advanced cockpit systems during flight. Pilots had little to say in when they actually used the systems. Comments such as "The auto pilot allows for vertical navigation and go around," "I recently fitted the Dynon auto pilot which makes cross country so relaxing," "I have Storm Scope, which is seldom used, but essential when it is" and "While I have a GPS I only use it as a back up, not as my main navigational aid." These comments came only from the men pilots with no comments from women.

Discussion

The main focus of the present study was to explore the possible differences between men and women based on Casner's (2008) measures of pilot attitudes towards advanced cockpit systems. Although the primary objective was to confirm Casner's proposed factors, the few numbers of pilot responses prohibited this analysis. Therefore, differences between males and females were undertaken on items rather than Casner's proposed factors.

While elements of the advanced technology are available ranging from a GPS system to a full glass cockpit, men and women pilots have both similar and differing perceptions of the application of, and benefits associated with, its use. The use of such technology is predicated upon a level of computer literacy. Both men (82%) and women (77.3%) rated themselves above average or excellent in computer literacy. No one rated themselves as poor. Therefore, respondents could be assumed to have a familiarity and experience in the use of these artefacts.

By adopting Mathieson's (1991) definition of attitude to technology-in-use, that is, the perceived ease of use and its usefulness, men found it more useful in terms of lowering their workload (item 1), increasing their situational awareness (item 4), an aiding during missed approach procedure (item 12) and flying en route (item 21). However, these comments relate to usefulness rather than perceived ease of use. In General Perceptions, qualitative analyses of men's comments revealed that although men found these advanced systems more useful, they were also concerned about becoming too reliant on them. Qualitative analysis also revealed that there were difficulties in moving from one brand to another, which may impact the relative ease of use. This also raises the question whether a larger sample of men would indicate that there were more opportunities in the use and purchase of other systems, relative to the smaller sample and possible opportunities for women. Thus, future studies may need to include a different number of trialled systems and whether this may have an influence on perceptions of ease of use.

Quantitative analyses also revealed that women were more concerned than men in relation to losing some important pilot skills, both in general (e.g. items 2, 3, 43) and in their own flying (item 26). Past studies have indicated that male perceptions of female pilots' ability led to them being more "accepted" by males. Davey and Davidson (2000) found that "By demonstrating a high level

of skill, the first female pilots were able to establish reputations for themselves as good pilots" (p. 207). Additionally, Moore (1999) found that women in a masculine occupation (police in her study) developed a greater sense of occupational identity when participating in professional courses. Thus, pilots' attitude towards technology-in-use (Mathieson, 1991) may be more complex than initially proposed, that is, it may well need to consider aspects of perceptions of "value" within a person's occupational identity as indicated for female pilots.

In line with the above, women pilots were concerned with both Learning and Retention. Items 2 and 8 in Learning and items 3 and 26 in Retention were statistically different. Women displayed concern for both themselves and other pilots in asserting that there should be more training and possible certification for advanced cockpit systems. The concern for learning was matched by the recognised need for retaining the operational information required to maintain currency on their licence and the use of the artefacts when flying. In terms of technology-in-practice, many women pilots lacked the same level of experience as that of the men (see Table 1). While generally positive over a range of items, women recognise the need for improved and follow up training to assist in the retention of skill and knowledge. This view is supported by the National Transportation Safety Board (NTSB) in the United States of America (NTSB, 2010). Familiarity with the artefacts, developed through training and practice, assists in developing confidence in the pilot's ability to recognise and deal with the various situations they may face.

Safety within aviation is of primary concern to all sectors of the domain. For item 34, the men's score was significantly different from the women's, indicating that they felt safer in an aircraft with advanced cockpit systems. There was a general belief that the introduction of advanced cockpit systems would result in the reduction of mid-air collisions, weather-related and accidents in general. There was also concern that some pilots would stretch the boundaries of safety using the new cockpits. Words of warning were made in respect of too much reliance on the systems and the attitude of pilots. However, the lack of any female responses for error and safety aspects in the qualitative findings can indicate either that men were more concerned about these aspects or that the women had already indicated their attitude about this through other means. For example, women agreed more than men did on item 48, "Advanced cockpit systems can get you into trouble just as easily as they can get you out of trouble." On face value, this item may reflect a safety or error perception, but this item was part of the General Attitude factor. Thus, the need to confirm the factors proposed by Casner (2008) becomes necessary.

While both men and women felt that advanced cockpit systems would decrease accidents, recent preliminary research by the NTSB has indicated that single engine light aircraft "had no better overall safety record than airplanes with conventional instrumentation" (NTSB, 2010). Their study covers the accident rates of over 8,000 light aircraft between 2002 and 2006. In this study, it was found that there was a higher fatality rate in aircraft with advanced cockpit systems than that of similar airplanes with conventional or round dial instruments. The enquiry recommends additional training and endorsement of licences, a position strongly supported by women pilots in the survey. However, the situation may be more of one where pilots become too complacent or prone to risk-taking when using these new devises, an aspect that was suggested by both males and females in the qualitative analysis. This situation was most apparent in the research undertaken by Casner. He stated:

> In a previous study, pilots who used GPS and moving map displays estimated their navigational awareness to be greater than that of pilots who navigated using a sectional chart and pilotage in a conventional cockpit (Casner, 2005). Believing their awareness to be superior in the presence of a GPS and moving map, these pilots appeared to assume a less active role in the navigation process. When put to a practical test of navigational awareness, these pilots in fact performed worse than pilots who used pilotage to navigate, and quickly lowered their awareness estimates. Pilots who

navigated using a sectional chart and pilotage performed better than they expected, and subsequently raised their estimations of their own awareness (Casner, 2005). These results suggest that pilots' beliefs and attitudes about advanced cockpit systems can sometimes be powerful determinants of pilot behavior and performance in the cockpit (Casner, 2008: 88-89).

Casner (2008) further adds that pilots in their research acknowledged some of the pitfalls of the advanced cockpit systems and that an important part of training should be to help pilots to "more accurately assess their own vulnerabilities" (p. 110).

While these results give an indication of differences in perceptions, there is a limitation in the data due to the small numbers of women pilots who responded and the discrepancy in numbers between men and women in the ration of 5:1. Given that females represent less than 6% of the total number of licensed pilots in Australia, research in this domain will continue to have these small numbers. Another limitation seems to be the concept of previous experience using an advanced cockpit system. One may question what kinds of advanced systems have been used and for how long, as well as experience with different brands. On average, women have less experience in a glass cockpit and flying with at least a panel-mounted GPS (as seen in Table 1). Unfortunately, there is little information to indicate whether this is because they are not interested (thus affecting behavioural intention) and prefer to use the conventional cockpit. Other aspects may relate to whether they may or may not have the funds to purchase the equipment or whether they have only used one brand of equipment. Although gender may have an impact on the possible adoption of new technology and, therefore, short-term use, Venkatesh et al. (2000, 2004) indicate that both biological and psychological gender did not have an effect on long-term use. However, short-term use was the only factor that influenced long-term use of new technology.

Conclusion

The present study provided an opportunity to compare the perceptions of men and women pilots in respect of the new technology being incorporated in general aviation aircraft. Generally referred to as advanced cockpit systems or glass cockpits, there is an expanding range of artefacts that are available or that pilots are using in their flights. For men and women pilots, technology-in-practice is routinely enacted in every flight. Pilots may choose, or not choose, to use an artefact, but if they do so then they are deliberately choosing how they will interact with that artefact (Orlikowski, 2000). This is evident in the quantitative and qualitative responses to the survey.

While generally positive towards the use of artefacts, both men and women were selective in when and how to use the technology - particularly the autopilot. Comparison of the qualitative and the quantitative data indicates that both men and women pilots, as a community of users, tend to have a general positive perception of the new advanced cockpit systems.

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Controlling Practical Drift in High Reliability Organizations

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Abstract

Practical Drift describes an incremental movement away from defined procedures. It develops over time where operators adjust procedures and workflows to suit their needs, most of the times with the intent to enhance operations. Where loosely coupled players have to interact, practical drift can cause severe accidents and adverse consequences leading to major challenges for high reliability organizations. It can be seen as a general vulnerability of organizations and a threat to their overall safety. Countermeasures to directly address practical drift are difficult because drift is considered as one symptom of deeper problems within a system (Snook, 2000). In concordance with approaches like ICAO Doc 9859 (ICAO, 2009), we suggest that practical drift can be addressed directly by reactive, preventive, and predictive strategies.

Thus, a guideline for organizations is proposed and discussed focusing on systematic monitoring and controlling processes as well as changes in the system. The purpose of the guideline and the whole paper is to create awareness of unanticipated deviances and to use sharp-end-operators' knowledge when designing and redesigning rules and procedures. A demonstration based on the linear accident causation model (Reason, 1990) is then employed to further illustrate the relevance of the guideline.

Controlling Practical Drift in High Reliability Organizations

Although rules and standards aim at reducing the variance of doing things, they never will reduce the variation completely. There will always be at least a minimal deviation when rules are applied (Ortmann, 2010). This deviation at rare occasions can lead to innovation and learning (Feldman & Pentland, 2003), but mostly it is assessed negatively and potentially dangerous. Starbuck and Milliken (1988), for example, described the fine-tuning of the odds until the o-rings of the Challenger Shuttle broke, which in the end led to the Challenger disaster. They called the process gradual acclimatization to a more and more unsafe situation. In the same Challenger context, Diane Vaughan (1999, p. 273) defines "an event, activity, or circumstance occurring in and/or produced by a formal organization that deviates from both formal design goals and normative standards or expectations, either in the fact of its occurrence or in its consequences, and produces a suboptimal outcome as organizational deviance." She saw the normalization of deviance as one among several processes that contributed to the Challenger disaster.

Not only technical standards, but also societal standards, are subject to variation. Sáenz-Arroyo, Robert, Torre, Carino-Olvera, & Enríquez-Andrade (2005), Ainsworth, Pitcher, & Rotinsulu (2008), and Turvey et al. (2009) reported shifting

baselines with regard to environmental problems and the loss of biodiversity. Young fishers in comparison to old fishers did not perceive the steep decline of fish populations (Sáenz-Arroyo et al., 2005). The shifted baseline in young people, according to Sáenz-Arroyo et al., can help explain why society is tolerant of the creeping deviation of (in this case environmental) standards in general and the loss of biodiversity in particular.

If the deviation from a standard is (a) not intended, (b) slow, subtle, and, therefore, difficult to notice, (c) long-lasting, and (d) has a certain direction, then Ortmann (2010) calls it "drift." The term practical drift was coined by Snook (2000) and describes an incremental drift away from best practice procedures. This paper focuses on practical drift with the ultimate purpose of controlling it in high reliability organizations. For this purpose, the phenomenon of practical drift and its relevance is described and explained based on relevant literature and observations. Snook's (2000) model will be further developed to include feedback loops. Some guidance is suggested to increase awareness of the problem and potential controls. Finally, a demonstration based on the linear accident causation model is presented to further illustrate the relevance of the guidance.

Where multiple loosely coupled players have to interact, practical drift may result in adverse consequences. As usually, only few players know about the adjustments of procedures, a situation may be created where different entities in the same field of operations use different workflows to complete their tasks where they all should use the same procedure. Combined with time restraints, the resulting conflicts may lead to a situation that represents a threat to the overall safety of an operation or task.

This is best shown in a study of an accidental shoot down of two U.S. Black Hawk helicopters over northern Iraq by two friendly U.S. F-15 fighters (Snook, 2000) where over years daily practice has led to an unnoticed drift away from written procedures. Multiple factors were identified that contributed to the fatal accident leading to a situation that could not have been expected by the F-15 pilots: both entities did not know of each other's presence, could not communicate with each other, and controlling facilities were not able to act in time to avoid the shoot down. The underlying factor that among others enabled this accident to happen has been termed practical drift.

However, the phenomenon of practical drift is not found exclusively in the military. It can be found in every environment where high reliability organizations develop plans and directives designed to be followed by loosely coupled interacting operators. Practical drift therefore represents a latent threat for the overall safety of organizations and can be regarded as an area of general vulnerability.

The model of practical drift (Figure 1) explains how practical drift can develop over time in any high reliability organization and reveals focus areas for a possible solution. It displays four quadrants showing how each of them is linked to situational coupling and logics of action on a path from design to failure.

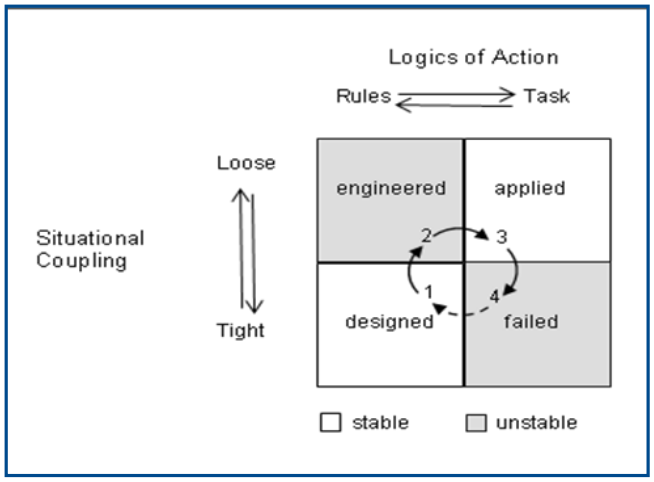


Figure 1. Model of practical drift, according to Snook (2000)

The system starts in a state termed "designed" where procedures follow their original designs. After that, the system continues to the "engineered" state in which the original designs are fitted into the work environment. In both states, the logics of action are guided by rules no matter how tight the situational coupling is. However, as operators try to apply the procedures as designed and engineered they may experience unforeseeable problems and

challenges. Therefore, the next state is termed "applied." Operators conduct small adjustments for local optimization and change a procedure by finding workarounds for daily practice. By further adapting the engineered procedures to practical demands operators stabilize an otherwise instable system. Work as applied is now guided mainly by the task and different from how it was designed and engineered. Very often these adjustments prove to be successful to the operators in the field and do not lead to adverse consequences for a long period of time thus creating a false sensation of safety. This false sensation is created partly because of a lack of knowledge about the implications in regard to other interacting operators who do not know about the applied techniques and who have a different mental model about how work is being done. In the absence of failure, it is further fuelled by an unawareness of how close to safety boundaries the adopted path is. Thus continued success is often regarded as proof of safety leading to and explaining a stable "applied" state. Additionally, further contributing to the illusion of a stable "applied" state, techniques employed by operators are often not known to higher management and the ones who planned the "designed" state. On the one hand, this can be a result of the loose situational coupling in the "applied" state where the drift will usually remain unnoticed as long as adverse consequences do not result from these adjustments. On the other hand, operator information about prevailing problems and their applied solutions may be available but is filtered or rationalized away and not passed up in the organization for various reasons. Operator's practices may even be known by management but are accepted as long as they prove to be successful in the absence of incidents and accidents. Only when the system enters the fourth state, "failed", do the problems become visible and the need for a redesign will cope for the process.

From the model of practical drift, three focus areas for downsizing the problem emerge. The first one is dealing with the design phase and engineering part of procedures as they generate the need for adjustments in the "applied" state. The second focus is on the one-way road towards failure from the "designed" state via the "engineered" and "applied" states to the "failed" state, which can be often found in reality where accidents and incidents that occurred in organizations are investigated. The false creation of safety fuelled by unawareness represents a third focus area. For a better understanding of the problem of unawareness and how this relates to multiple interacting players, the authors will later provide a different view on practical drift.

There is only little recognition of practical drift in procedures so far. ICAO Doc 9859 (ICAO, 2009), for example, suggests three ways to tackle practical drift and to integrate them in the Safety Managements System (SMS). ICAO sees a considerable learning potential about successful safety adaptations and for the control of safety risks and also considers transferring these into system redesign. The three ways to control practical drift according to ICAO are:

- Reactive: reactive to serious trigger events, followed by investigations (accidents/incidents)
- Proactive: identifying safety risks before the system fails to take mitigating actions (through reporting systems, audits and safety surveys)
- Predictive: analyzing real time operational data to actively find trouble (flight data analysis/ops monitoring)

In combination, ICAO assumes that the reactive, proactive and predictive way leads to the most complete intelligence (ISMS) within a mature safety management. However, more detail cannot be found in ICAO Doc 9859. In our work, we do not follow the reactive way. The guideline presented at the end of the paper mainly represents the proactive and the predictive strategy. Even though the reactive part can be of vital use for any organization we only mention it briefly.

A Different View on Practical Drift

An adjusted model of practical drift (Figure 2) allows an outside view to the problem. In addition to Figure 1 this model shows initial design levels

of procedures as well as how practical drift develops over time. The time cross section will be used additionally to change the perspective allowing us to adopt an operator's view to the problem of unawareness and false safety impression in order to understand why practical drift leads to adverse consequences (Figures 3a and 3b).

often be surprised as to how this could have happened despite the evidence at hand in hindsight.

When changing the perspective from the outside view of the time cross section to an operator's inside view we can become aware of the way operators see their task, why they do not recognize

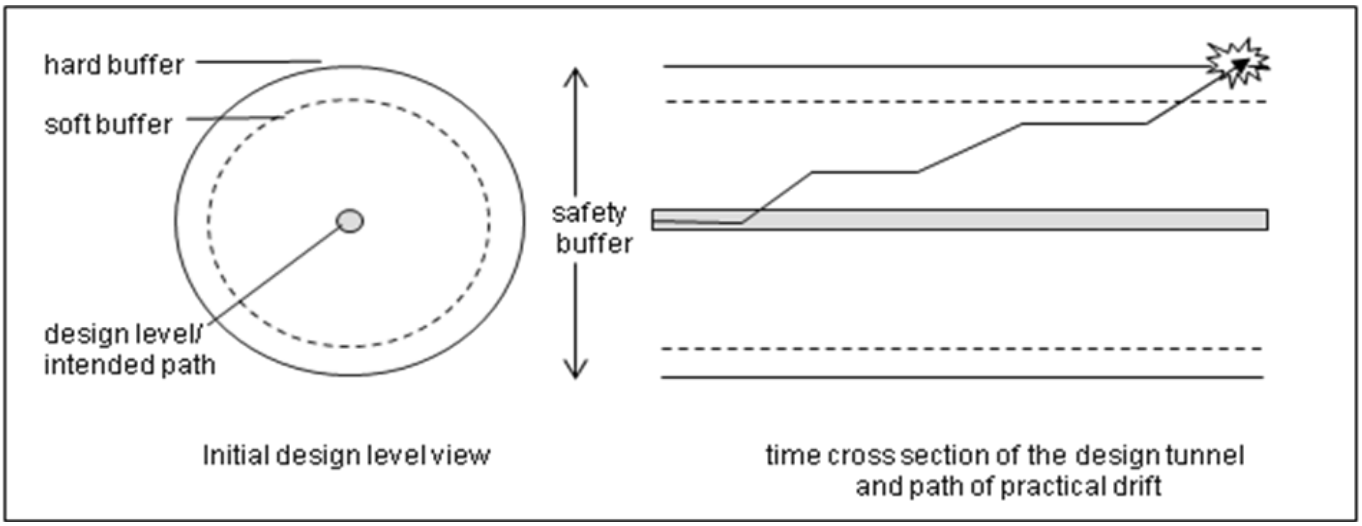


Figure 2. Outside view of practical drift: initial design level view and time cross section of practical drift.

The initial design level provides the rules and procedures for a certain task. The design level or intended path is positioned at the centre of what may be described as a tunnel (see left hand circular view in Figure 2). Usually designs incorporate contingencies or buffer zones to cope for uncertainties or possible adverse events. These are indicated by the soft and hard buffer zones.

As long as operations continue within the soft buffer zone everything will work as expected from an outside view, even though practical drift has occurred. Only the operators know about their altered daily practice. However, as a main problem, operators usually do not know how close to the buffer zones they actually are as this is very hard to assess in the absence of adverse events. But once operators work towards the hard buffer zone the organization runs the risk of experiencing incidents or accidents as shown by the time cross section on the right hand side of Figure 2. When adverse consequences occur as shown by the breach in the hard buffer zone, the majority of people will

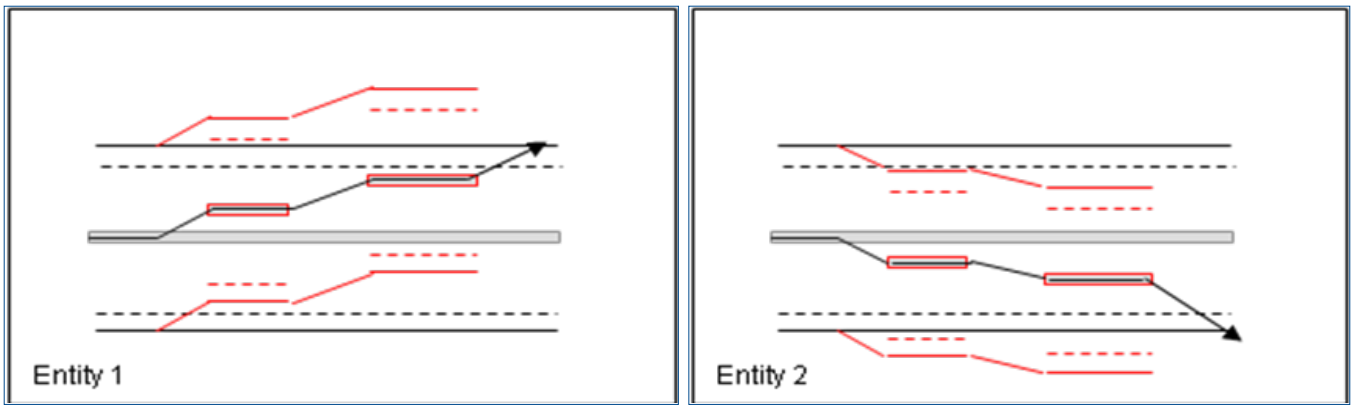
how close to safety boundaries they are and what actually happens to them as they continue on the time cross section [1].

In complex environments it is often very difficult for people at the sharp end to adhere to complex procedures of otherwise complex tasks that have been created and published by management, created at ground speed zero and often far away from the operation to be carried out and isolated from physical stressors. Working on their tasks operators may face problems that have not been fore-

1 Dekker (2006) suggests the view from the inside of the tunnel as an important means to understand human error. By providing an inside view about practical drift from the status of initial design as well as it builds up over time it may become clear how an initial plan looks like from a designers point of view and how operators do not notice they are drifting away from the design level towards failure from their point of view (see Figures 3a and 3b, an operator`s perceived design level shift with increasing practical drift for two entities).

seen or considered by the designers but that have to be dealt with in an ongoing operation. Often highly motivated or due to convenience, operators locally adjust given procedures and guidelines in small increments to meet operational requirements and to optimize their work flow in order to reach the desired objective in good faith, slowly drifting away from the design [2]. This incremental drift away from the design is considered an important fact (Dekker, 2006) because minor adjustments to the design are usually not concerning operators to a great extent, especially in the absence of adverse consequences.

ceived as being the norm. At the same time an operator's perceived buffer zone will gradually shift as well providing a false sensation of safety further contributing to an operator's unawareness of the drift. Thus to an operator this shift towards the hard buffer zone of the initial design may not be visible. Furthermore, when breaching the originally designed buffer zones after drifting constantly away from the design level an operator may still perceive he is inside.



Figures 3a and 3b. Perceived design level (hatched bars) shift with increasing practical drift for two different entities

When adjustments prove to be successful operators continue on the adjusted, and from their point of view effective, path. The success of the adjustment will give an operator the impression that there is still a safety zone around his perceived design level of the operation where errors[3] still can be recovered from, unaware of how close to a buffer zone and adverse outcomes he actually is. After a while, this adjusted path will be per-

Operators' (well) intended actions (achieving a common goal by applying daily practice) may now lead to unintended outcomes as they are not aware of the possible consequences from their inside view. With each small incremental adjustment operators drift further away from the design level until they arrive at the buffer zone as illustrated in Figures 3a and 3b, considerably increasing the gap between original design level and daily practice over time.

Additionally, making the problem of practical drift even more complex, operators usually are not aware of possible long term consequences or conflicts that may arise because of their decision to optimize or adjust procedures when working together with other entities or loosely coupled systems. The situation will aggravate where other entities are drifting towards different directions while working in the same environment. Where

2 Dekker (2006) explains that practical drift can be seen as a compliant behavior reasonable to those on the inside of the situation. These departures are departures from routine and can become the routine as a result of a much more complex picture. The departures can be fueled by rules that are overdesigned, by emphasis on efficiency or cost effectiveness or by past success that is taken as guarantee of future safety (Dekker, 2005 and 2006).

3 Error forms and error types according to the definition of Reason (1990).

both entities are unaware that they operate outside each other's buffer zone adverse effects may be experienced already at an early stage, even if both players are still within their original designed buffers (see Figures 3a and 3b).

The drift will remain invisible unless someone challenges the operator(s) on the difference to the original design (e.g. a new operator who joins from a different party) or when incidents or accidents are being investigated with the result of practical drift as an underlying cause.

Classification of Practical Drift

A classification of practical drift serves as a means towards the generation of possible improvements as will be shown later. We see practical drift as an intentional action (e.g. optimizations or adjustments to meet operational requirements by operators with best intent) with an unintentional adverse outcome considering the worst-case scenario (e.g. the accidental shoot down of two helicopters). According to the definition of errors and violations by Reason (1990), an intentional action with an unintended result is being classified as a mistake. Thus, practical drift as described above should not be seen as a violation, which is defined as intended or deliberate action with an intended outcome. We could furthermore classify practical drift as a mistake or a series of mistakes of an entity [4], leading to a latent condition as a function of human behaviour. This classification will enable us to show the effects of the proposed solution to an organization with the intent to uncover latent conditions that result from human behaviour. However, to rule out a violation where adverse consequences occur because of an adjustment of procedures, an investigation needs to be conducted for clarification whether practical drift or deliberate behaviour against procedures are underlying factors as only a very thin line between the two exists. According to Reason's error classification (1990) and the description of practical drift above we will consider practical drift as a mistake.

4 Practical drift can be classified as a mistake according to the definition of Reason (1990 and 1997). Reason describes three basic error types (slips, lapses and mistakes) and defines a mistake as an intended action with an unintended outcome whereas the mistake is rule and knowledge based. By using the term entity different group sizes are designed to this error type (individuals, parts of organizations or an organization as a whole). In Snook`s case study we can identify parts of organizations with different mistakes leading to different levels of practical drift all believing they do the right thing (e.g. AWACS, UH-60 and F-15 squadron as well as a bigger part of the organization running the operation under the condition of practical drift).

Preventing Adverse Consequences by Controlling Practical Drift

In the following, we will try to provide a possible theoretical way to prevent adverse consequences by controlling practical drift as a means of

- monitoring the gap between procedures and practice through a built-in feedback process from operators towards management
- establishing a good learning and error culture as well as
- executing good leadership

for the continuous learning of organizations as they move along. We want to enable an organization to gain knowledge about daily practices that may as well uncover problematic designs and decisions or incomplete guidelines of management as underlying factors and to react accordingly before the occurrence of adverse consequences.

Note that we are not suggesting the prevention of practical drift as it is thought of as both impossible and counterproductive. Prevention will prove to be impossible because of the complexity of today's operations and it will be counterproductive as working by the rule strikes often show. Additionally lessons learned by operators would no longer be available. Differences between the design of a procedure and its application in praxis can be a source of innovation and learning (Feldman & Pentland, 2003). Thus, we will focus on the control of practical drift with the intent to prevent possible adverse consequences by making use of

the operator's knowledge regarding all of the three focus areas [5]. Moreover, the investigation of accidents and incidents will contribute to the reactive part when all prior identified defences have failed. Prior to those events the bowtie analysis to identify defences (Hudson & Lee, 2007) can be used proactively as it not only looks at how to prevent hazards from leading to a top event but also how defences may mitigate or even prevent the consequences of that event.

Therefore, the built-in feedback process serves two needs. First of all, it is designed to allow decision makers and human-factors-experts access to raw data from the sharp end, information that is not filtered by desirability, politics, or other criteria. It is designed as a function for monitoring the gap between plans and daily practices thus enabling an organization to assess through risk management and risk assessment tools how close to a safety boundary it is operating. Consequently, the feedback loop serves as a means to either redesign plans by gaining knowledge about their effectiveness or redirect daily practices when deemed necessary thus enabling organizations to remain flexible in an ever changing and challenging environment. It will depend on an organization's learning and error culture, and will challenge leadership in that regard and requires an understanding of all organizational players involved including interacting and loosely coupled systems and, in parts, cultural changes.

Including a feedback process into an organization's operation will result in an operation driven out of a more stable "engineered" state of the model of practical drift due to a change in either the design of the plan or in daily practice following feedback (Figure 4). The applied tasks now mainly reflect the engineered rules or reengineered rules as a result of feedback and adaptation, and improve the predictability of operator's use of procedures. This is especially important when looking at operations of loosely coupled systems where everyone is expected to work according to plans and directives in order to be able to work together.

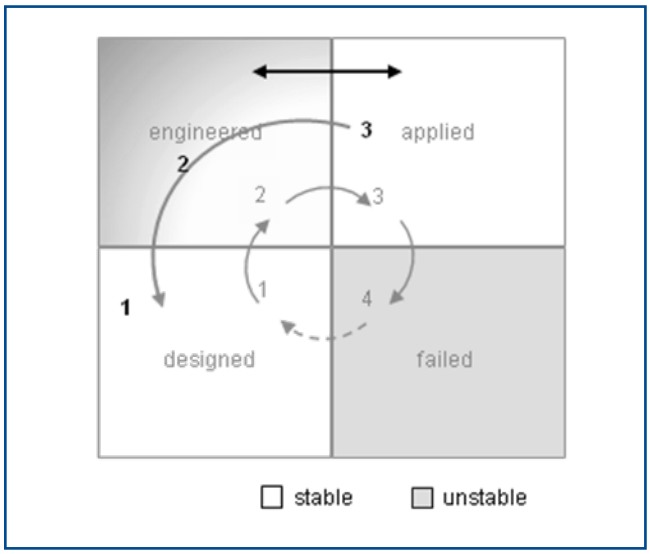


Figure 4. Providing a more stable quadrant 2 by constant exchange of data through feedback

As the situation develops different states of applied actions over time when deviating from the design level (illustrated by stages (a), (b) and (c) in Figure 5) the feedback loop is designed to discover individual adjustments that may lead to practical drift, to analyze the reasons behind it and to enable an organization to return to its original design path as shown in Figure 5 or to adopt a (redesigned) design path when the original design proves to be impracticable or even jeopardizes safety. Either path, designed or redesigned, will then support a certain safety buffer to the overall operation again. An organization's flexibility to redesign their operations will require a constant exchange between operators and management to be able to assure an operation within the boundaries as long as the operation continues.

5 The proposed way to achieve this goal is fuelled by other publications. Dekker (2003) suggests that organizations need to monitor the gap between procedures and practice and try to understand why it exists as well as helping people to develop skills to judge when and how to adapt. Additionally, Haynes, Schafer, and Carrol (2007) mention that plans need to be flexible enough for effective local improvisation where the improviser is trained and has the authority to make important local decisions with the challenge to find the "sweet spot" between reasoned, reflective planning and the need for a responder's improvisation.

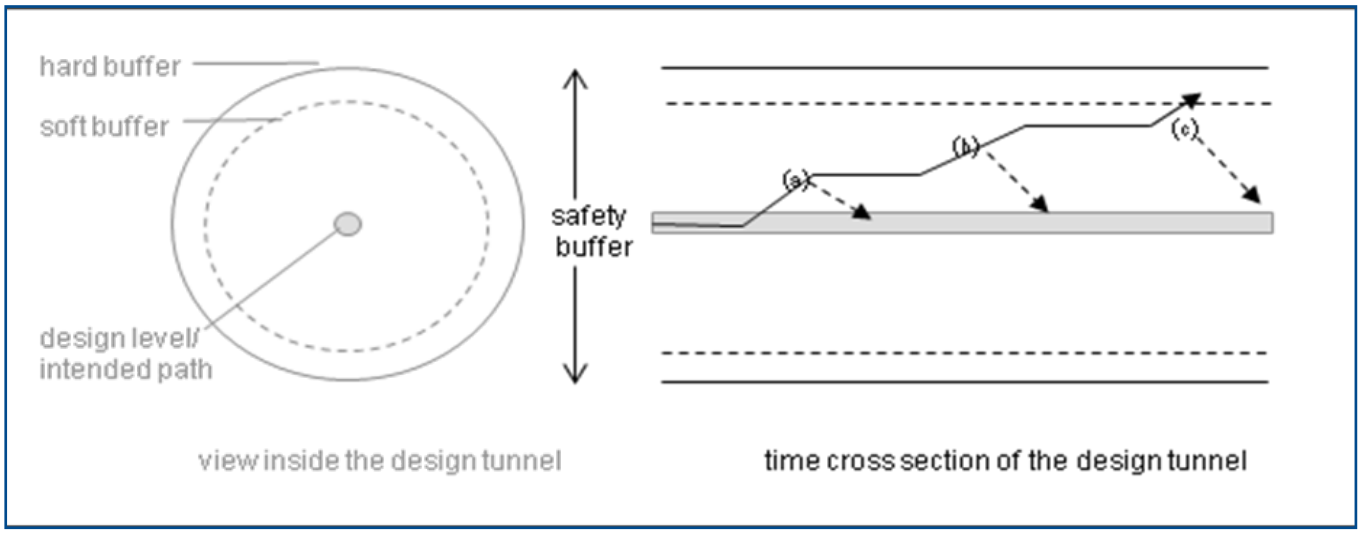


Figure 5. The aim of the feedback loop: returning to a design level by using operator`s data

Both the change in design of plans, procedures, and regulations or the readjustment of daily practice towards best practice will create a more stable "engineered" state due to the constant exchange of data or knowledge from every day practice (shown by the arrow of exchange between the "engineered" state and the "applied" state in Figure 4). This should especially prove to be beneficial where loosely coupled systems have to act together by keeping them closer to the same path.

A more stable "engineered" state will result because of two reasons: either, operators receive feedback that a certain designed rule or procedure is correct and their daily practice is moving them towards failure or the designer adopts changes to his original plan according to the suggestions of operators thereby improving the initial design. Due to the feedback process either of the above reasons will lead to an "applied" operation reflecting work as "engineered", a predictable operation known to third parties and the original designer. As designs are almost never perfect the "engineered" state will remain unstable to a certain extend. However, the feedback process enables an organization to keep this status at a minimum thus enhancing the safety of their operations.

Certainly, this method will not and cannot guarantee the prevention of incidents and accidents from occurring by simply adding a feedback loop into operations, which would be far too easy and unrealistic. First, most operations will still have to go through an unstable "engineered" state before feedback can be used to solve the situation. Second, there will always be hidden traps that are not yet uncovered leading to daily practices that are not according to the design at a certain time, indicated by the still remaining unstable part of the "engineered" state and the continued existence of the "failed" state.

The proposed method will, however, provide operations driven out of a more stable "engineered" state, thus enhancing efficiency, effectiveness, and safety of the overall operation through the control of practical drift by monitoring, using feedback, learning and adjusting or readjusting. This is why the feedback process is designed to initiate various adjustments. It shall provide a means for organizations to gain knowledge about the effectiveness of their plans, to remain flexible and to provide corrective action if necessary to keep loosely coupled systems within a certain boundary. Organizations thus can learn from and make use of the (often beneficial) contributions of operators and their daily practices at the sharp end, either by adjusting the design of plans or by adjusting daily practices of operators if they drift in the perceived wrong direction.

While in theory the added feedback loop to the model seems to be straight forward, there still is the practical problem of how to implement it and control the problem of practical drift in organizations. But as accidents such as the above mentioned shoot-down show, it is imperative to monitor the gap between the work as it is designed and engineered and how it is practiced in the daily routine. Hollnagel, Woods, & Leveson (2006) mention that a model for ensuring safety needs to be at the same time simple without the requirement of too much specialized knowledge but powerful enough to be able to look below the surface. In that regard the proposed guideline may provide useful considerations towards the control of practical drift in a simple and feasible way for implementation and application. It is as well meant to be powerful enough for an organization to gain an understanding of how and why parts of a system drift away from a design standard and how to return to a safe path making use of operators' contributions. As a variety of models for data management like critical incident reporting systems already exist, it is additional operator's feedback we are trying to implement into an organization for data management, data from the sharp end to provide a realistic picture of how an organization really functions. By using information of every day work in addition to incident reports, an organization will be able to not only work in a reactive but also in a proactive and predictive way.

Three Steps towards Approaching Practical Drift – A Proposed Guideline

The three steps to control practical drift are designed to uncover and redirect practical drift. The first step deals with the awareness of drift since the phenomenon is still not widely known in organizations even though it has already been described in several contexts and many years ago (e.g. Snook, 2000). As a consequence, raising awareness to the phenomenon, its existence, advantages and disadvantages as well as the possible outcomes is the first important step. The importance to raise this awareness is also supported by Hollnagel et al. (2006), who states that local optimization or adjustments on an individual level of performance are not exceptional but rather represent the norm.

The second step provides a consideration for designing plans and directives with the intent to minimize the need for and the risk of practical drift. It includes the constant enrichment of the design cycle with operators in order to use their knowledge at an early state where designs still can be changed easily.

The third step deals with the implementation of the feedback process, e.g. as part of already existing incident reporting systems to gather data that was unknown before in order to assess risks and raise awareness about them - and to be able to act before safety boundaries are reached. Analysing flight data and monitoring the operations can contribute to an early recognition of practical drift. While the first two steps can be implemented at the same time the third step should not be implemented before step 1 is finished. For each step aims, methods, prerequisites and problem areas or challenges are outlined below.

Step 1 – Raising the awareness of involved personnel

The aim of the first step is to raise the awareness of involved personnel from management levels to the sharp end. It needs to be understood that an individual or a group making changes in their daily practice interact with processes of others who don't know about the changes and this may have unwanted adverse effects to success and safety.

Workshops or training courses of about 20 participants are the preferred method where the underlying factors of practical drift and the implications for loosely and tightly coupled systems are being taught by experts. These workshops or courses can easily be included in an ongoing human factors training program of an organization. Contents should cover the model of practical drift as well as the view provided above. By including an example of practical drift and its possible consequences to the individual to parts of an organiza-

tion or the organization as a whole (e.g. the mentioned accidental shoot down or the Challenger disaster) it should be possible to foster motivation for controlling practical drift. Top level management needs to point out how they intend to deal with practical drift in regard to human behaviour, which includes their own fallibility as well, on the basis of a just and learning culture which will be a prerequisite for the success of step one.

A challenge will be to keep up the awareness over a longer period of time because attending a single course or workshop will not change behaviour for a long time. Constant reminders are necessary to keep up motivation over a lifetime until it becomes part of an organization's culture. This can be done via annual refresher courses including feedback from management on what has been encountered in regard to practical drift and how the problem was solved, by safety meetings including operators on a regular basis, by reminders on written procedures and guidelines to contact the responsible managers and experts in case of noticing problems, by internal audits that include questions designed for uncovering practical drift and the underlying causes (e.g. Line Operations Safety Audit, LOSA), by an established standard of using data or a reporting system in an organization (e.g. step 3).

Apart from what is suggested in this paper, the staff attending the workshops should be given the time to work out solutions for practical drift in the courses as well. They may generate ideas that are much more practical for their organization since they know how work is being done there. Overall, raising the awareness and staying aware is the main aim of this step. By routinely using the second step, enriching the design cycle constantly with operators, this aim will be sustained as well.

Step 2 – Constantly enriching the design cycle with operators

The aim of the second step is to constantly enrich the design cycle with operators contributing to the final design by sharing their experience with the design team. Operators from the sharp end should be included into the design phase of operations, plans and directives or changes that affect their daily business. Even though practical drift is not necessarily only a problem of design, the design phase can contribute either in a positive or in a negative way to practical drift. Design teams as well as top and line managers, even though very experienced, are often too far away from the daily business at the sharp end, and design their plans to the best of their knowledge expecting that operators are able to follow their thoughts. This may foster the need of adjustments at the working level due to incompatibility or incompleteness. Thus, a design distant from operators may facilitate practical drift. On the other hand, implementing vital knowledge from the working level can reduce the need for otherwise practicable workarounds. An operator from the sharp end is able to give advice as to what will cause problems and what might work well. Using this "operator data base" throughout the design cycle can enhance the planning cycle and smooth the operations, thus contributing to the control of practical drift.

A prerequisite for this step is the availability of operators from the sharp end and the commitment of management to let operators attend in design phases. This is not only a prerequisite; it represents a challenge for management as well since productivity will suffer from an operator not being available for the front line. Thus, they may decide to have the operator just attend at certain stages of the design cycle. However, only involving operators in the early phase will not bring later design changes to their attention thus leading again to daily practice around design intentions. Involving the operator just during later stages may lead to a point where the organization has committed and invested into certain designs or technologies and is reluctant to a change due to costs or delays. Thus, by involving operators throughout the planning phase, delays or odd events can be avoided or at least reduced when implementing the design into an organization's operation. The number of operators participating in the design phase should depend on the entities involved after implementation.

Depending on the field of operation, a trial phase should be run. In case of changes to manuals and directives, operators should have an opportunity to evaluate them prior to implementation to see if critical items have not been covered during the design or planning phase. This will enable changes to critical items before plans are implemented.

Step 3 – Implementing a feedback loop

Implementing a feedback loop for all users is a means of receiving information from below the surface and using this data for further decisions. In order to get the necessary information an organization has to ensure that everyone involved knows where to report and what to report. The question as to "why" to report and the general motivation to report has been addressed in step 1. This is where the feedback loop should be introduced as well with its main emphasis on constant improvement by the contributions of every player involved in the light of a just and learning culture. The main aim is to identify hidden traps that would not appear in a top down only approach. In the top down only approach, gaps between work as intended and as it is actually carried out often remain hidden until an incident, a failure, or an accident occurs.

The feedback loop includes data collection, (risk) analysis of data and conclusions for suggestions for change [6]. To allow for a systematic data gathering a single point of contact (POC) should be identified to collect data within each loosely coupled entity involved. After checking that the reports contain all vital information they are forwarded to an overall POC, a safety manager, who is responsible for the suggestion of changes to the overall leader of the operation. Ideally, the overall POC should have been involved in the design of plans and directives and needs to have knowledge of the operational environment. He should as well be outside of the hierarchy of the organization and independent. Fulfilling these two prerequisites the POC is both knowledgeable and not subject to prosecution when reporting odd events. Safety sections usually have that status in organizations. Data collection can be done via intranet or internet if a reporting system is available. An existing incident reporting program only needs to be amended for the task of data gathering in respect to practical drift. The amount of data to expect depends mainly on how effective steps 1 and 2 were implemented.

By using this approach, filters are omitted in the line of reports from the sharp end to the overall POC. Remember, when including filters into a reporting cycle, important data might be filtered out of the report due to various reasons (e.g. not perceived as important by the filter or threatening his position). In designing the filter out of the feedback loop the responsibility on deciding what is important or not is tied to the overall POC who has access to raw data from the sharp end and who reports directly to the leader or manager of the operation as a part of line management.

Figure 6 shows the idea behind the implementation of a feedback loop within an organization. On the left hand side, the components of an organization are listed [7] with an assumed and often found one-way information flow. On the right hand side, a feedback loop as described above is included. For a better understanding of how the feedback loop may be established within an organization, the actual players of the components of an organization are listed. The components listed will be subject for further discussion in the next chapter as to what the proposed guideline can provide for organizations.

In order to enable an easy data management, organizations should provide a standard feedback form for data collection, which also enables an open-ended answer at the end of the form to make

6 Data is often collected and put into files but it is not always systematically analyzed and used in larger organizations. Even if analyzed there is the pitfall to draw incorrect conclusions out of the data when operating under the phenomenon of practical drift. This is one of the reasons why incredible accidents occur in large organizations which thought to be safe (e.g. the Space Shuttle Challenger loss in 1986; Vaughan, 1996).

7 Components of productive systems according to Reason (1990)

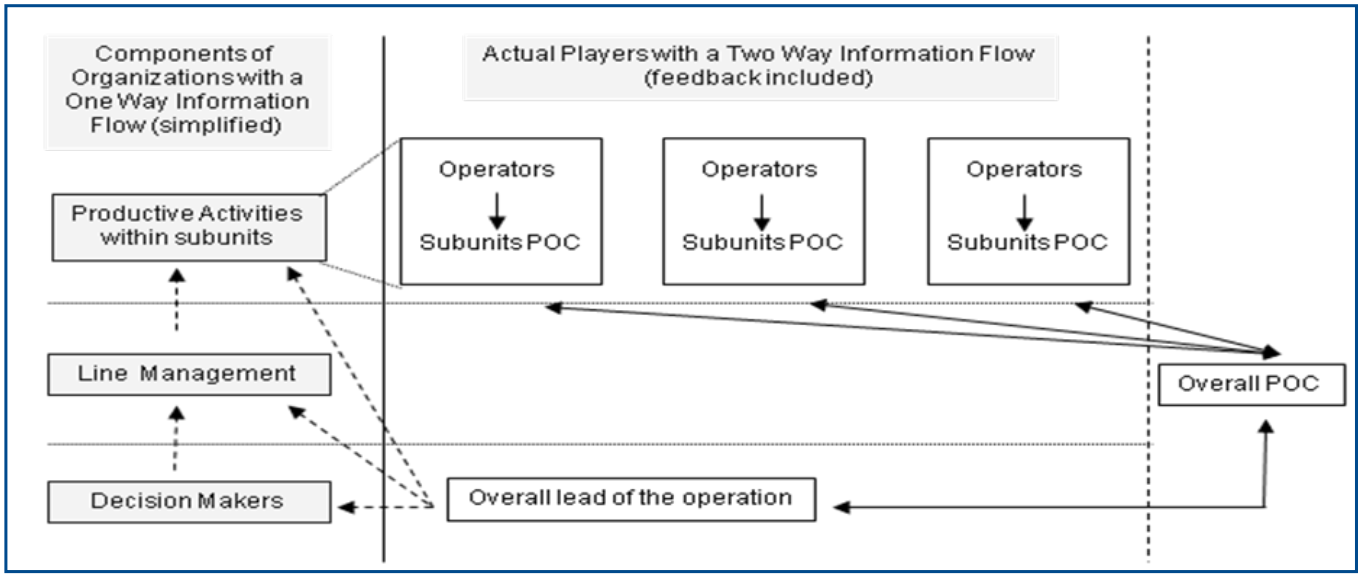


Figure 6. One-way information flow (left) vs. multi way information feedback loop in an organization (right)

sure that no relevant question was left out. The form or amended incident reporting form needs to be tailored to the needs of the organization. It should at least include questions about

- procedures that do not work as intended or cannot be carried out as intended
- reasons why procedures do not work as intended or cannot be carried out as intended
- possible solutions to the challenges faced with the procedures and experienced operators are willing to share with respect to any adjustment they have made to existing procedures.

All data have to be reviewed and assessed for risks. Most important is whether experienced operators have already changed procedures to suit their needs and how these affect the overall operation. In order to get valid information of this kind, the feedback process must be handled on a non-punitive basis, as it is standard in incident reporting programs. By collecting and reviewing the reports of all entities and continually assessing the risks thereof, the overall POC gets the big picture of how the operations work and can identify priorities for change. The continued risk assessment can furthermore provide an actual picture of an organization's current safety status in the absence of incidents or accidents thus preventing an invalid impression of safety. Depending on the complexity, changes can be suggested either within a short amount of time or, if very complex, with more time to be assessed for a redesign. There are many tools available that can be helpful when assessing the gathered data, among them non linear accident causation models like STAMP [8] and FRAM analysis [9]. Changes can then be approved by the overall leader and implemented by the overall POC accordingly. When there are good reasons not to change a given procedure it should be emphasized and explained. This should be done due to a simple reason: if one operator (or even one entity) has difficulties understanding why things need to be carried out in a certain way, others may as well, e.g. because the initial presentation of the design or procedures may not have been clear to them.

8 Systems Theoretic Accident Modelling and Processes (Leveson, 2004)

9 Functional Resonance Analysis Method (Hollnagel, 2004). An example of a reactive post accident FRAM analysis is given by the analysis on Comair flight 5191 by Hollnagel, E., Pruchnicki, S., Woltjer, R., Etcher, S.; an example of proactive FRAM analysis is given on the analysis of RNAV by Hollnagel, E. and Goteman, Ö..

Knowing why a certain procedure is designed in a specific way can already prevent practical drift to a certain extend. On the other hand, if an organization tolerates operators that do not know why certain procedures are designed in a special way it runs the risk that parts of the design will have to be interpreted resulting in practical drift including all its consequences.

The key to controlling practical drift is the identification of the gap between work as intended and work as it is actually carried out. As this is directly dependent on the operators reports, the question of how operators would actually be able to recognize their daily practice as being different from the original design may arise. Asking this question is supported by the earlier statement that operators are usually not aware that they have shifted towards the safety boundaries of a system by applying daily practice and making things work. However, recognizing the difference between daily practice and work as it is intended and at the same time not being aware of how far one actually has drifted towards the safety boundary is not necessarily contradictory in itself.

First, there are two aspects to be looked at regarding the above question. One aspect is that workers apply daily practice to make things work, using workarounds and small adjustments to get the job done or to find a way to optimize an otherwise complex procedure. The other aspect is not knowing how close one actually is to the safety boundaries. These are two very different aspects. What we are looking for is to gain information for monitoring the gap (the first aspect) – the use of workarounds either because designed procedures are incomplete or incompatible or because they are complicated and an easier way has been established over time. The second aspect, how close an operator or an organization is in relation to the safety boundary, might never be answered by an operator except in case of an incident or accident. This second aspect is not the focus of this guideline. The focus is on how to retrieve the valuable information to be able to monitor the gap and how to use it to control practical drift. We will look at two problem areas in that regard – newly implemented processes or changes and longer running processes as they present different aspects to look at.

After implementation of the proposed guideline, data gathering should not be a problem when dealing with new processes or changes to processes as everyone will notice in the very beginning what should be improved and what is impracticable (a problem that is supposed to be reduced by step 2 of the proposed guideline). This is different for longer running processes. Depending on how long processes have been run in a certain way it may not be clear to an operator that he or she is not adhering to the official procedures. However, there are several ways operators may still recognize that there is a difference between daily practice and the original design. Step 1 of the proposed guideline, raising the awareness of practical drift, is one way to make everyone involved think about his or her daily practice. In case of known design flaws there should be feedback immediately because operators usually talk (or lament) about things that are not working the way they are intended to. Another chance for operators to identify practices that are not according to the procedure is a new operator that enters his or her career or enters the organization from a different employer or unit. Even though most people may not notice that they do not adhere to the rules in detail, after a while because it has become routine, they still do know why they do things in a certain way. When a newly trained operator or new employee enters the system and is instructed to apply certain processes, which are different from the procedure because it has 'proved' to be the better way, the gap often becomes clear. An actual example shall demonstrate this 2nd way to identify data in longer running processes:

> In pilot training a technique was offered by an instructor pilot that would optimize ground operations by being more convenient. In order to check the electrically controlled engine lanes a test had to be run by the pilot. That test would identify whether the spare control lane was serviceable or not. As a first step, a test button had to be pressed to check indications on a warning panel. Then the spare lane of the engines would have to be manually se-

lected to check engine response on that relevant lane. However, in order for one caption (out of a few to check) to illuminate on the warning panel, it would require some minutes for the engines to warm up so this step had to be repeated at a later time. Because of this the instructor told the pilot that he could omit the step of pressing the test button when the checklist demanded it and to do it at the end of the ground operations when the engines definitely had warmed up thus saving time. This created a latent condition yet to be identified. The student pilot did as instructed and put a reminder to his checklist to press the test button for completion of the test at the very end just prior to taxiing to make sure the relevant indications would show on the warning panel. As expected, it was a more convenient way and the button had to be pressed only once during ground operations. A few years later this adjusted procedure almost proved to be fatal to a ground crew. After starting the engines, the pilot switched both engines manually to the second lane as usual to see whether the engines behaved normally there as well. On this particular day, however, one engine spooled up uncontrolled to maximum thrust within less than 2 seconds. Caught by surprise, the pilot switched the engine control back to the first lane without any change to the engine that was still running at maximum thrust. He immediately shut down the engine and aborted the flight. Asking other pilots whether they had an explanation as to what had happened did not bring any results. The pilot was even praised for his very quick decision to shut down the engine within less than a second after the engine had reached maximum thrust. A few days later he had an appointment with the head of flight safety department. This meeting revealed that by adjusting the procedure for the engine lane test the pilot unknowingly contributed to this incident. What he did not realize was that the test of the control lanes (by pressing the button) was designed to check the serviceability of the second lane before manually switching to it and to latch a caption on the warning panel if the second lane was unserviceable which had never been experienced by any pilot of that particular aircraft type up to that incident. If the warning was triggered upon pressing the test button an engine runaway could occur when switching manually to the second lane, as it did on that day, and the aircraft had to be aborted. This was all written in the operating manual but unfortunately not known to the pilot (and others as well as it turned out). If any of the ground personnel would have been directly in front of the engine at the moment the engine runaway occurred he or she might have been sucked in with an open end as to the consequences.

In regard to the 2nd way to identify data in longer running processes – the pilot as well as the instructor were not aware how close they were to the safety boundary but they were aware that their daily practice was not according to the designed procedure. A learning and just culture and awareness training about practical drift might have supported the prevention of this incident. Knowing, even after a long time, that procedures are adjusted does not imply knowing how close the safety boundary actually is (unless revealed by an incident).

The third way to recognize differences between daily practices and designed procedures is given by the use of audits that are designed for that very purpose. There are several possibilities to gain access to the data needed with the emphasis on the recognition of differing procedures rather than on how close a system has come to the safety boundaries. We cannot assume, however, that everyone will provide information about his practices that are not in conjunction with the designed procedures just by implementing a (new) guideline.

The organization itself holds the key to the willingness of operators to report, which is directly dependent on the status of the just and learning culture of the organization as well as on leadership commitment. This is an important, if not the most important, prerequisite of the feedback approach. It includes that the return to the design path or redesign path is not associated with blame but with learning form the operator's experience in the field using the data at hand. This prerequisite is based on

the understanding that change based on blame will lead to a reduced willingness to share experiences thus leaving organizations with a reactive option to failure only. As many organizations run non-punitive error reporting systems this fact should already be known but is worth to be considered once more. Management commitment to this pre-requisite must be very clear. The three steps are oriented towards practice. They should not be too complex, neither in implementation nor in application. Many parts of the guideline are already in place so they just need to be adjusted, amended, extended, or applied. As we address high reliability organizations, the proposed guideline should be more than worth the effort if only one incident or potential accident is prevented.

What does the Proposed Guideline provide?

Practical drift was earlier classified as a mistake, a series of decisions of an entity, which lead to the margins of safe operations, leading to a latent condition as a function of human behaviour in situational and organizational conditions. As we are dealing with organizational failure, the perspective of what the guideline can provide for an organization in regard to latent conditions can be shown with Reason's Swiss Cheese Model (Reason, 1990). In his model, Reason defines the components of any productive system as decision makers (plant and corporate management), line management (operations, maintenance, training, etc.), preconditions (reliable equipment, skilled and motivated workforce, etc.), productive activities (integration of human and mechanical elements), and defences (safeguards against foreseeable hazards). To each of these components Reason mapped various human contributions to the breakdown of complex systems and assigned either active and/or latent failures to them. These represent holes in the system. If these holes match in a certain way, the path for an accident trajectory is laid out which will finally result in adverse consequences. Even though the original model shows a rather linear path it does not necessarily imply that this is the road that leads to an incident or accident. It is rather a simplified means to show the possible effects of latent conditions and active failures. Any lateral component can contribute to adverse consequences as well, making it necessary to look at interactions. Thus, the accident causation is much more complex and lateral than Reason's model may suggest. The interacting components, however, will not be different. A system (the organization as a whole or parts of an organization) thought to be safe when operating on its own may thus become vulnerable again. For visualization a modification of Reason's Swiss Cheese Model [10] is shown in Figure 7 amended to combine interactions of other system's components as well.

We relate the proposed guideline to Reason's model to show that it addresses its components, trying to close holes in the Swiss Cheese by unveiling latent conditions within a system as well as between interacting parts and dealing with them directly.

Decision makers often must decide although data and knowledge is incomplete. Having them attend the courses (step 1) will make them more able to understand the theory behind and the causes of practical drift. By suggestions of changes and assessments of current safety states from line management (information from the overall POC who is part of the line management) in step 3, they will stay in the loop of information and are able to base their decisions on additional knowledge thus leading to less fallible decisions [11].

Line management is responsible to implement the strategies of decision makers into their areas of operation. Their decisions depend on different

10 Different versions of Reason`s model exist. In his book The Human Contribution Reason provides an overview of the evolution of his model (Reason, 2008). The model shown in figure 8 on the left hand side represents a combination of some of Reason`s versions.

11 In the face of production pressures, decision makers may borrow from safety in the absence of incidents or accidents, taking that absence as a proof of safety thus inadvertently manoeuvring towards the safety boundaries – underlying the phenomenon of practical drift themselves. The proposed guideline contributes to an early realization of where an organization is heading within the safety tunnel as well.

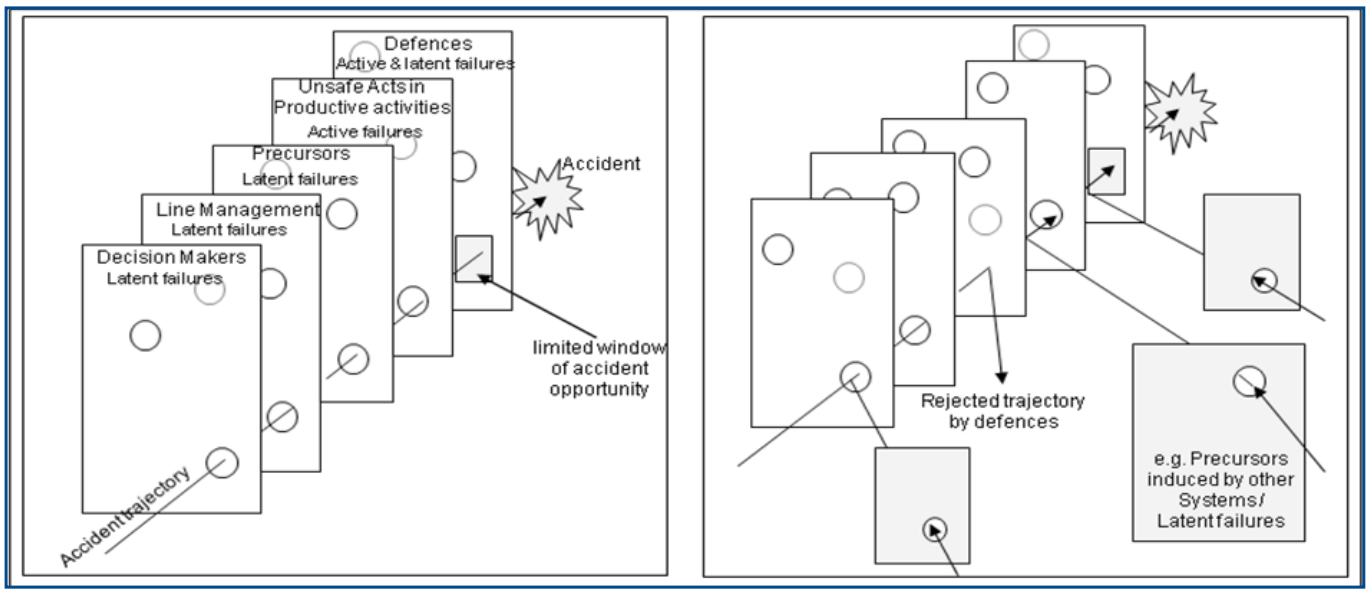


Figure 7. Swiss Cheese Model (modified) by Reason (1990), amended to include lateral inputs from other components that can either be dealt with or that an organization is unaware of

resources (e.g. budget, pressures, etc.). Line managers can either mitigate or aggravate decisions of the decision makers depending on their resources and authorization. One resource they need is knowledge to be more able to mitigate fallacies in a superior's decision. Again, the attendance of the courses, the use of operators in the design phase and information from the feedback loop allows for more knowledge to understand the phenomenon of practical drift, to enhance initial designs, to intervene against undesirable practice or design procedures and to promote changes in either direction (towards the top and towards the sharp end). Their direct contact to the overall lead of the operation will keep their knowledge alive.

The third component, preconditions, can facilitate improvement of a wide variety of undesirable conditions. One of the precursors is described as a skilled and motivated workforce. Something we actually deem as very positive. But due to its skill and motivation the workforce is likely to fall prey to practical drift. They want to make things happen (in this regard practical drift can be seen as a precursor for unsafe acts in the next component of Reason's model). The courses aim at raising the workforce's awareness and understanding of practical drift and the possible adverse and severe consequences thereof by including them in the loop. The emphasis here is on "understanding" since it can lead to a change of thinking and behaviour. The approach to daily practice may change in a positive way due to understanding and the feedback participation should be facilitated. By raising awareness of practical drift this precursor can be addressed directly which then is more likely to have an influence on the next component.

The last component is the component of defences. Even though defences are already included in the initial design plan as contingencies resulting in soft and hard buffers, practical drift is often not a part of the considerations when designing defences. The feedback loop facilitates this consideration because it is directly designed for that purpose – as a defence. Defences themselves may also need to be adapted.

The three steps towards controlling practical drift address all five components of Reason's Swiss Cheese Model (figure 7). Thus, they increase the chances to open the view to latent conditions. Applying this knowledge to larger organizations with various subunits or systems that laterally interact (figure 6) can contribute to closing critical holes to stop a trajectory (linear, lateral, or combined) that

could otherwise lead to disaster (both within systems and between interacting systems). Not only does the proposed guideline address practical drift directly by helping to identify latent conditions, it also aims at problems deeper in the system. Like other human factors in safety programs (e.g. critical incident stress management); (Vogt, Leonhardt, Köper, & Pennig, 2004; Vogt, Leonhardt, & Pennig, 2007a, b), the consideration of practical drift might initiate a positive cultural change within the organization with regard to learning and safety culture. It is clear, however, that a cultural change takes time and the proposed guideline is only a tiny part of it.

Limits of the Proposed Guideline

Practical drift cannot and should not be prevented completely by the proposed guideline. It can only be controlled to a certain extent. This is due to the simple fact that a designer will not be able to know in advance what an operator experiences when executing a previously designed plan, no matter how good and thoughtful a plan may be. The proposed guideline must not be mistaken for a zero accident model. Practical drift is just representing one single precursor among a variety of precursors in the model of Reason. Due to the identification of this precursor by Snook and other authors, we are aware of it and more able to mitigate. Other precursors and especially their interactions remain to be identified and worked on in order to create safer processes.

As figure 6 provides a view to a systems approach within an organization, there will be certain limits where different organizations operate together. A combined POC may be hard to agree on and there may be different views in regard to just or learning culture. These might become obstacles and must be overcome in order to monitor the gap and to gain an inside view. The proposed guideline therefore is more suitable for operations within one organization and of less value for operations across organizations.

Conclusion

Even though practical drift can lead to adverse consequences it is not necessarily only a negative side effect of daily practice. Interestingly, practical drift as a phenomenon can even prove to be valuable to a certain extent because it may keep a system running and foster innovation. This is due to the simple fact that rules and procedures cannot foresee every eventuality throughout their intended lifecycle. This is best illustrated by the major problems organizations can face when their operators work by the rule to the point that can bring operations to a stop. Even though practical drift can contribute to an operation by keeping a system running, the risk of coming close to the design and safety boundaries remains.

Practical drift can be seen positively, but it must be uncovered and controlled because it may eventually come too far away from original design levels and close to safety margins. Even though failure does not happen very often, it can have a devastating effect on organizations. Financial and reputational loss in the follow-up of a major failure can lead to an organization's disappearance. This is one more good reason to control practical drift rather than to react after incidents or accidents have occurred. Through data from monitoring the gap between operations as intended and daily practice an organization can learn about its effectiveness which can thus become a chance for change in design and in daily practice.

By addressing practical drift, the proposed guideline also aims at deeper problems. While the steps are directed at the prevention of adverse consequences of practical drift by controlling it, they address critical processes and the culture of an organization as well. In order to reach the desired result staff throughout the organization (top managers, line managers and operators) need to understand practical drift and possible control mechanisms. Organizations need to be willing to change their rules and their culture in a way that enables them to enhance their operations. Then a learning culture can evolve and reduce the negative effects of practical drift. There is no quick fix due to the long-term nature of cultural change but there is

a good chance to improve during the process of implementing practical drift control. As a positive side effect, organizations not only may be enabled to identify latent conditions that otherwise could lead to adverse consequences (incidents and accidents), but also they may get insights into what is running well. The proposed guideline to control practical drift has not been validated by empirical data yet, and hopefully will be subject for further discussion, development, and investigation in the future.

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A Qualitative and Quantitative Analysis of Fatigue Countermeasures Training in the Aviation Industry

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Abstract

Today's 24/7 operations have produced a number of well-documented fatigue-related consequences (e.g., on-the-job injuries, workplace accidents, morale issues). In the current effort, a unique strategy was applied to identify key attributes of an effective fatigue countermeasure-training program. Fatigue countermeasure programs were reviewed and content was analyzed to identify critical dimensions across industry programs. The results of the content analysis provide a recommended outline for fatigue countermeasure training programs. The subsequent personal and organizational benefits of fatigue countermeasure training are also discussed.

A Qualitative and Quantitative Analysis of Fatigue Countermeasures Training in the Aviation Industry

All of our aviation professionals (flight crew, cabin crew, maintenance personnel, etc.) are critical to the safety and security of air travel. All human performance is vulnerable to sleep loss and daily variations in physiological processes that are tied to our underlying body-clock mechanisms or circadian rhythm (Caldwell, 2005). Recent events documented by the Aviation Safety Reporting System (ASRS) and the National Transportation Safety Board (NTSB) provide practical evidence that sleep loss and fatigue do impact the performance of aviation professionals. Technological advances in the last 20 years have produced a 24/7 aviation industry, and as a result, aviation professionals are constantly challenged by multiple flight legs, extended duty days, limited time off, early departures, late arrivals, less-than-optimal sleeping conditions, jet lag, and non-standard work hours such as night duty and rotating schedules (Caldwell, 2005). Herein lies the problem. Despite operational requirements, the body's biological need for sleep to maintain alertness does not change. In other words, individuals are not equipped to operate on the 24/7 schedules that define today's flight operations. Consequently, a well-planned, science-based fatigue management strategy is

crucial for combating acute and cumulative sleep loss, sustained periods of wakefulness, and circadian factors that have been shown to contribute to fatigue-related flight mishaps (Caldwell, 2005; Rosekind et al., 1996). An effective fatigue risk management program must include some type of fatigue countermeasure training or educational program to equip individuals with the knowledge and resources to successfully combat fatigue on and off the job.

Fatigue Management

Fatigue management generally refers to the identification of fatigue risk and the implementation of strategic controls. In the aviation industry, the Federal Aviation Administration (FAA) has typically taken a traditional approach to manage fatigue through hours of service (HOS) regulations. The increasing number of fatigue-related ASRS reports (Holcomb, Avers, Dobbins, Banks, Blackwell, & Nesthus, 2009), however, seems to indicate that HOS regulations are insufficient for systematically managing fatigue as a stand-alone strategy. In other words, effective fatigue management requires more than just scheduled rest and duty time regulations and might benefit from a multi-level, science-based approach. Systematic fatigue management requires everyone to take responsibility – the regulator, the operators, and the aviation professional. For example, the FAA is responsible for fatigue management regulations, while the operators have a responsibility for work schedule design, workload distribution, working conditions, and training (Rosa & Colligan, 1997). Aviation professionals are responsible for optimizing their rest opportunities to get the sleep they need to be fit for work and for implementing personal fatigue countermeasures as needed to mitigate fatigue and maintain alertness. Thus, an important part of fatigue management is educating employees and managers regarding the causes and consequences of fatigue, including scientifically-based countermeasures designed to better manage their on and off-duty fatigue (Caldwell, 2005; Dawson & McCullough, 2005; Rosekind, Co, Neri, Oyung, & Mallis, 2002b; Rosekind, Gander, Connell, & Co, 2001).

Fatigue Training

Education about the dangers of fatigue, the causes of sleepiness (both in the air and on the ground), and the importance of sleep and proper sleep hygiene is one of the keys to addressing fatigue in operational aviation contexts (Caldwell, 2005; Dawson & McCullough, 2005; Rosekind et al., 2001; Rosekind et al., 2002b). Some aviation professionals have the ability to bid their schedules; to do so effectively, they must understand that sleep and circadian rhythms are important issues for consideration and that quality off-duty sleep is the best possible protection against fatigue prior to beginning a duty period. Recent studies have made it clear that as little as two hours of sleep loss can result in almost immediate performance decrements and an increased likelihood of error or accidents (Carskadon & Roth, 1991; Mitler et al. 1988). In fact, continuous wakefulness beyond 17 hours can result in performance decrements comparable to an individual considered legally drunk i.e., Blood Alcohol Content [BAC] = 0.05–0.10 (Arnedt, Wilde, Munt, & MacLean, 2001; Lamond & Dawson, 1999; Maruff, Falleti, Collie, Darby, & McStephen, 2005). Given the safety hazards associated with fatigue, it seems clear that fatigue training is a necessary component of systematic fatigue management. Thus, the purpose of this paper is to: 1) identify the essential components of a fatigue countermeasure training program and 2) examine the benefits a fatigue countermeasure training program can have for reducing fatigue and improving safety.

Review of Fatigue Countermeasures Training Programs

Fatigue training is not a new approach to fatigue management. In fact, fatigue training has been utilized across a number of industries with 24/7 operations (e.g., railroad, trucking, water transport) for more than 20 years (e.g., Nicholson & Stone,

1987). In a recent survey of flight attendants, 51% of cabin crewmembers revealed that their carrier did provide some type of training or information regarding fatigue, however, 79% indicated that the training airlines were providing did not help reduce or minimize fatigue (Avers, King, Nesthus, & Banks, 2009). Given this shortfall in the industry, an extensive review of the fatigue training literature was conducted to identify the critical components of an effective fatigue countermeasures training program. Existing fatigue training programs were collected from diverse workforces and content analyzed to develop a basic outline of critical fatigue training topics. A frequency index was computed to determine how often each topic occurred across fatigue training programs. This index was then used to identify the topics that were deemed most critical for inclusion in a fatigue countermeasures training program. When available, general information regarding the benefits and effectiveness of fatigue training programs were also collected and reviewed.

Acquisition of Training Programs

Acquiring information on fatigue countermeasure training programs began with a three-pronged approach: 1) a search of scientific literature databases, 2) a general search of public and private educational materials, and 3) a series of inquiries to prominent fatigue researchers. Initially, an extensive literature search was conducted using eight academic computer databases (Academic Search Premier, Business Source Premier, ERIC, E-Journals, Military & Government Collection, PsycARTICLES, and PsycINFO) and the Civil Aerospace Medical Institute (CAMI) Online Library. Separate searches were also run on the FAA and National Aeronautics and Space Administration (NASA) websites to identify aviation-specific technical reports. General search terms included phrases such as alertness management, fatigue countermeasures, fatigue management, fatigue education, and shiftwork training. To expand the search beyond scientifically published training programs, a general internet search was conducted to locate public and private training programs. In particular, this internet search attempted to locate programs available online and to identify companies that may have developed or implemented fatigue management training programs. Using the Google™ search engine, key phrases such as fatigue training and fatigue risk management were entered to locate fatigue training programs. The identified companies were then contacted to request a copy of their complete training program materials or an outline of the topic-areas covered in their training program. The third approach was to contact a number of prominent fatigue researchers requesting information regarding training program materials they had used or helped to develop. The companies and researchers represented fatigue institutions worldwide. Responses from the companies and researchers that were contacted were very positive (73% response rate) and ultimately resulted in the collection of 50 training programs. All of the training programs we received were written in English. Although training programs have been developed in other languages, these were not included in the scope of this study.

Inclusion criteria. After collecting the training program materials, each was reviewed and evaluated using three inclusion criteria: 1) the materials provided education on fatigue, shiftwork, or alertness management, 2) the materials were created or published after 1985, and 3) the materials included at least an outline and summary of the topic areas included in the training program. If a program did not meet all three of these requirements, it was dismissed from further content analysis. Using these criteria, two doctoral students reviewed each of the programs, with 49 programs retained for further analysis (100% agreement; see Table 1).

Characteristics of training programs. The training programs included in this study covered a broad spectrum of educational materials that were developed for various workforces, instructed or disseminated to employees using multiple methods, and designed for different purposes according to organizational or work task requirement. Specifically, six programs were developed for the general driving population; 17 programs

were developed for unspecified populations or general shiftworkers; 22 were developed for the transportation industry; and four were developed for an 'others' category. Of the 22 programs developed for the transportation industry, 13 were developed for aviation specific operations – pilots (n = 4), maintenance workers (n = 2), air traffic controllers (n = 2), and general or unspecified (n = 5). Dissemination of the educational materials to employees also utilized a number of different approaches and media venues, including: video (n = 2), web-based courses (n = 2), printed materials (n = 30), classroom instruction (n = 6), combination of the above methods (n = 7), and two with unknown approaches. Some of the educational materials were developed by businesses, considered proprietary information, marketed and sold for profit. As such, some training programs were only available for review in summary outline form (n = 10). However, full training materials were obtained for the remaining programs (n = 39).

Table 1

List of Educational Materials by Industry

	Educational Materials
	General
1	Moore-Ede, M., 2006
2	Moore-Ede, M., 2009
3	Shapiro, C., Heslegrave, R., Beyers, J., & Picard, L., 1997
4	National Highway Traffic Safety Administration, 2000
5	Reed, A.T., 1993
6	Monk, T.H. & Folkard, S., 1992
7	Clockwork Research, unknown
8	Enform, 2007
9	Department of Industrial Relations, 2005a
10	Department of Industrial Relations, 2005b
11	Scuffham, A., Pringle, D., & Gander, P., 2004
12	Kerin, A., & Aguirre, A., 2005
13	Klein, M. & Dubas, K., 1986
14	Saskatchewan Labour: Occupational Health and Safety Division, 1998
15	Rosa, R.R. & Colligan, M.J., 1997
16	WorkSafe Western Australia Commission, 2001
17	Canadian Centre for Occupational Health & Safety, unknown
	Aviation
18	McCulloch, K., Baker, A., Ferguson, S., Fletcher, A., & Dawson, D., 2007
19	Delta Air Lines, 2007
20	Civil Aerospace Medical Institute., 2003
21	European Organisation for the Safety of Air Navigation EuroControl, 2005
22	Civil Aerospace Medical Institute, 2001
23	Rosekind, M.R., Gander, P.H., Connell, L.J., & Co, E.L., 2001
24	Rosekind, M.R., Co, E.L., Neri, D.F., Oyung, R.L., & Mallis, M.M., 2002a
25	Rosekind, M.R., Co, E.L., Neri, D.F., Oyung, R.L., & Mallis, M.M., 2002b

Educational Materials

Aviation cont.

26 Rankin, B., 2009
27 Hughes, R., 2009
28 Delta Air Lines, 2006
29 Virgin Blue, 2007
30 Rhodes, W. & Gil., V., 2002

Driving

31 Royal Automobile Association, 2001
32 Rural Ambulance Victoria & Metropolitan Ambulance Service, 2001
33 Gander, P.H., Marshall, N.S., Bolger, W., & Girling, I., 2005
34 Department of Transportation, 2007
35 Hartley, L.R., 1996
36 Department for Planning and Infrastructure, 2004

Railroad

37 Leutzinger, J.A., Holland, D.W., & Richling, D.E., 1999
38 Sherry, P., 2000
39 Sherry, P., 2000

Water Transport

40 Maritime New Zealand, 2007
41 Maritime New Zealand, 2007
42 International Transport Workers' Federation, 2006

Trucking

43 National Transportation Commission of Australia, 2008
44 Dinges, D.F., Maislin, G., Krueger, G.P., Redmond, D.P., et al., 2004

Mining

45 Aliaga, A., van de Linde, A., Eksteen, A., Aspeling, C., Lusse, C., & Cather, D., 2005

Other

46 Nicholson, A.N. & Stone, B.M., 1987
47 Caldwell, J.A. & Caldwell, J.L., 2006
48 McCallum, M., Sanquist, T., Mitler, M., & Krueger, G., 2003
49 VonThaden, T., 2009

Content Analysis of Training Programs

Each program was reviewed to develop a comprehensive outline of the topic-areas that appeared to be critical to a fatigue education and countermeasures training program. Once the outline was established, the programs were content analyzed by two doctoral students to identify the presence of each topic area (Cronbach's $\alpha = .92$). Although our understanding of the circadian physiology and sleep processes has evolved over the last twenty years, there was no evidence in the training programs to suggest that the core training topic areas have changed. A topic area was only to be considered present in the training program if at least three sentences were devoted to it or one specific, prescriptive recommendation was described. The intent of this content analysis was to quantify the topics included in the training programs by creating a frequency index of how often each topic area had occurred across the various training sources. The frequency index thus provided the basis for identifying a hierarchical listing of critical topics for the fatigue countermeasures training program (see Table 2).

Table 2

Frequency of Fatigue Topics Across Training Programs

	Overall				Aviation Specific		
Topics	# T[a]	Total T[b]	% T[c]	Programs[d]	# T[a]	Total T[b]	% T[c]
Fatigue	49	49	100%	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17, 18,19,20,21,22,23,24,25,26,27,28,29,30,31, 32,33,34,35,36,37,38,39,40,41,42,43,44,45, 46,47,48,49	13	13	100%
Definition	21	49	43%	2,9,10,11,16,18,20,22,23,24,25,26,27,29,30, 42,44,45,46,47,48	10	13	77%
Symptoms	33	49	67%	1,2,3,4,5,8,9,11,15,16,18,19,20,22,23,24, 25,26,27,28,29,30,31,35,36,42,43,44,45,46, 47,48,49	12	13	92%
Causes	36	49	73%	2,5,6,7,8,9,10,11,15,16,18,19,20,21,22,23, 24,25,26,27,28,29,30,32,33,35,36,38,40,41, 42,45,46,47,48,49	13	13	100%
Consequences	45	49	92%	1,2,3,5,6,7,8,9,10,11,13,14,15,16,17,18,19, 20,21,22,23,24,25,26,27,28,29,30,31,32,33, 34,35,36,37,39,40,41,42,44,45,46,47,48,49	13	13	100%
Mental	40	45	90%	2,3,5,6,9,10,11,13,14,15,16,17,18,19,20,21, 22,23,24,25,26,27,28,29,30,33,34,35,36, 37, 39,40,41,42,44,45,46,47,48,49	13	13	100%
Physical	41	45	91%	1,2,3,5,6,9,10,11,13,14,15,16,17,18,19,20, 21,22,23,24,25,26,27,28,29,30,31,33,34,35, 36,37,39,40,41,42,44,45,47,48,49	13	13	100%

Notes:

a. Number of training programs that included information on the topic area.
b Total number of training programs included in the percentage calculations based on category breakdowns.
c. Percentage of training programs that included information on the topic area.
d. Training programs that included information on the topic area (see Appendix A for the list of training programs)

	Overall				Aviation Specific		
Topics	# T[a]	Total T[b]	% T[c]	Programs[d]	# T[a]	Total T[b]	% T[c]
Health/ Well-being	34	45	76%	1,2,3,5,6,9,10,11,13,14,15,16,17,18,20,21, 22,23,24,25,26,27,28,29,30,36,37,40,42,44, 45,47,48,49	12	13	92%
Digestive	16	34	47%	1,3,6,9,10,11,14,15,17,18,22,27,30,42,45,48	4	12	33%
Cardiovascular	16	34	47%	1,3,6,9,10,11,14,15,17,18,22,27,30,42,45,48	4	12	33%
Mood	24	34	71%	2,3,6,9,10,11,13,16,20,21,22,23,24,25,26,27, 28,29,30,36,42,45,48,49	11	12	92%
Circadian Rhythm	40	49	82%	1,3,4,5,6,7,9,11,13,14,15,16,17,18,19,20, 21,22,23,24,25,26,27,28,29,30,31,32,33,35, 36,38,39,43,44,45,46,47,48,49	13	13	100%
Sleep	44	49	90%	1,3,4,5,6,7,9,10,11,12,13,14,15,17,18,19,20, 21,22,23,24,25,26,27,28,29,30,31,32,33,35, 36,37,38,39,40,41,43,44,45,46,47,48,49	13	13	100%
Cycle	22	44	50%	1,3,5,6,9,18,19,22,23,24,25,26,27,29,30,35, 37,39,44,46,48,49	10	13	77%
Debt	26	44	59%	1,4,9,11,18,19,20,21,22,23,24,25,26,28,29, 30,32,33,35,36,38,40,44,47,48,49	12	13	92%
Quantity	39	44	89%	1,3,4,5,6,9,10,11,13,14,15,17,18,19,20,21, 22,23,24,25,26,27,28,29,30,32,33,35,36,37, 39,40,41,44,45,46,47,48,49	13	13	100%
Quality	35	44	80%	1,3,4,9,12,13,14,15,17,18,19,20,21,22,23, 24,25,26,27,28,29,30,35,36,37,39,40,41,43, 44,45,46,47,48,49	13	13	100%
Napping	30	49	61%	1,3,6,11,12,13,15,18,19,21,22,23,24,25, 26,27,28,29,30,31,32,33,35,36,43,44,45,47, 48, 49	12	13	92%
Work Hours	35	49	71%	1,3,4,5,6,9,11,13,14,15,17,18,20,21,22,23, 24,25,26,27,30,33,35,36,37,39,40,41,42,44, 45,46,47,48,49	10	13	77%
Shiftwork	28	34	82%	1,3,4,5,6,9,11,13,14,15,17,18,20,21,22,23, 24,25,26,27,33,35,37,44,45,46,48,49	9	10	90%
Overtime/ Extended Hours	19	34	56%	9,11,13,14,15,18,23,24,25,26,35,36,40,41, 42,45,46,48,49	5	10	50%
Shift Scheduling	25	34	74%	3,6,9,11,13,14,15,17,18,21,22,23,24,25,26, 27,35,36,37,44,45,46,47,48,49	8	10	80%

Notes:

a. Number of training programs that included information on the topic area.
b Total number of training programs included in the percentage calculations based on category breakdowns.
c. Percentage of training programs that included information on the topic area.
d. Training programs that included information on the topic area (see Appendix A for the list of training programs)

	Overall				Aviation Specific		
Topics	# T[a]	Total T[b]	% T[c]	Programs[d]	# T[a]	Total T[b]	% T[c]
Nutrition	34	49	69%	1,3,5,6,7,9,10,12,13,14,15,17,18,19,21,22, 23,24,25,26,27,29,30,32,35,36,37,39,43,44, 45,47,48,49	11	13	85%
Hydration	15	49	31%	1,17,18,23,24,25,26,27,29,36,40,41,43,47,49	7	13	54%
Exercise	30	49	61%	1,3,4,5,7,9,13,14,15,17,18,19,21,22,23,24, 25,26,27,29,30,35,36,37,39,43,44,45,48,49	11	13	85%
Substances	35	49	71%	1,3,4,5,6,7,9,10,11,13,14,15,18,19,21,22,2 3, 24,25,26,27,28,29,30,31,32,35,36,43,44, 45,46,47,48,49	12	13	92%
Alcohol	30	34	88%	1,3,4,5,6,9,10,11,13,14,15,18,19,21,22,23, 24 ,25,26,27,28,29,30,31,35,36,45,47,48,49	12	12	100%
Caffeine	33	34	97%	1,3,4,5,6,9,10,11,13,14,15,18,19,21,22,23,2 4,25,26,27,28,29,30,31,32,35,36,43,44,45, 47,48,49	12	12	100%
Nicotine	14	34	41%	1,3,5,13,14,18,19,21,26,27,30,36,47,48	6	12	50%
Other Drugs	26	34	76%	1,3,4,5,6,7,9,13,14,15,18,21,23,24,25,27,29, 30,32,35,36,43,45,46,48,49	8	12	67%
Sleeping Disorders	26	49	53%	1,4,9,13,14,18,19,21,23,24,25,27,28,29,30, 3 2,33,35,36,40,41,44,45,46,48,49	10	13	77%
Workload	8	49	16%	11,15,16,24,25,29,40,46	3	13	23%
Family & Social Life	26	49	53%	1,3,4,5,6,7,11,12,13,14,15,16,17,18,20,21,22 ,27,31,35,36,39,43,45,47,48	5	13	38%
Work Environment	22	49	45%	1,3,5,9,13,14,15,16,17,20,22,23,24,25,29,33, 35,40,41,45,47, 48	6	13	46%
Commuting	17	49	35%	1,3,4,6,9,10,11,13,18,21,22,27,30,39,40,41, 48	5	13	38%
Jet Lag (if applicable)	10	10	100%	18,19,20,23,24,25,28,29,46,49	8	8	100%
General Countermeasures	40	49	82%	1,3,4,5,6,7,8,9,10,11,12,13,15,16,17,19,22, 23,24,25,26,27,29,30,31,32,33,34,35,36,37, 38,39,40,43,44,45,47,48,49	10	13	**77%**

Notes:

a. Number of training programs that included information on the topic area.

b Total number of training programs included in the percentage calculations based on category breakdowns.

c. Percentage of training programs that included information on the topic area.

d. Training programs that included information on the topic area (see Appendix A for the list of training programs)

Identified topics areas. The content analysis revealed that each of the topic areas included in the initial outline should be included in the recommended fatigue countermeasures training program. In general, the fatigue experts consistently agreed on the most important topic areas that are necessary for an effective fatigue countermeasures training program. Topics were consistent across the overall training programs reviewed and even more consistent amongst the aviation-specific training programs. Any variations noted were mostly a function of the degree of detailed information provided and the specific focus of the training program (e.g., on-duty countermeasures vs. off-duty countermeasures). As expected, fatigue was a focal topic in all of the training programs (100%). However, not all fatigue-related factors were included with the same degree of frequency across programs. To break this down, topic areas such as sleep, circadian rhythms, nutrition, work hours, and substance use (e.g., caffeine, alcohol) were cited more frequently, while commuting, workload, and hydration topics were cited less frequently. That said, all topic areas were cited in at least eight of the 49 training programs reviewed and could arguably be included in a comprehensive fatigue training program.

Organization of training topics. To organize the training topic areas for this report, two doctoral students reviewed the educational materials and used a q-sort procedure that identified three broad content areas: introductory fatigue information, off-duty rest and activities, and on-duty or operationally specific issues. Within each of the three content areas, topics were broken into multiple sub-levels to insure that all relevant information would be included. For instance, under the off-duty rest and activities section there are two secondary headings: sleep fundamentals and lifestyle. Each secondary topic was further delineated to provide in-depth guidelines regarding content development.

Review of Fatigue Training Effectiveness

Although a number of focused and detailed fatigue training programs exist, relatively few organizations have evaluated and reported the effectiveness or recurrency recommendations of their fatigue training programs. The following studies provide the only current, published, and open-source documentation of fatigue countermeasure training benefits. The preliminary evidence, however, does suggest that training provides a number of physiological and psychological benefits to the individual, as well as the organization, and should be considered as one aspect of a company's overall fatigue mitigation strategy.

Individual Benefits

In 2005, Gander and colleagues adapted a NASA Ames Fatigue Countermeasures Program and administered it to both heavy- and light-vehicle drivers. Heavy-vehicle drivers were tested on key concepts using a pre-post test administered before and after each training session and also by a follow-up survey sent out within 26 months of the initial training. The survey inquired about the usefulness of the training course and about knowledge retention and use of fatigue countermeasures. The results indicated a significant change between the pre- and post-measures of knowledge. The median ratio of correct responses for the pre-measure was 9/16 items and 14/16 items for the post-measure. The follow-up survey revealed a median ratio of 13/14 items correct with 82% answering at least 12/14 correctly. Seventy-five percent of drivers thought that the fatigue training was at least "moderately useful," with 47% changing the fatigue management strategies that they used at home and 49% changing the strategies they used at work. Sixty-one percent of drivers indicated that they would benefit from recurrent fatigue management training to refresh and update their knowledge on countermeasure strategies.

For light-vehicle drivers, a more informal follow-up questionnaire assessing the usefulness of training was administered within 2 years of the

initial training. Results of these assessments indicated that 70% answered at least 11/13 questions correctly and 91% found the training at least "moderately useful." A total of 50% reported having changed their fatigue management strategies at home while 43% had changed their strategies at work. A handful of drivers in this study also reported that they thought that management had made positive changes including improved roster designs and increasingly open communication with drivers regarding fatigue.

Using a similar pre- and post-test design, Kerin and Aguirre (2005) administered a training program to mining company employees and their domestic partners in a single, four-hour group session that included 10-50 people. It has been suggested that training may have the greatest impact when partners are included because shiftworking schedules affect the entire family. The training course itself was meant to "provide factual information on solutions to the special challenges of shiftwork" (Kerin and Aguirre, 2005, p. 202). Before completing the training course, workers filled out sleep/wake logs for a 28-day shift cycle including a questionnaire regarding their sleep habits, lifestyle, family/home life, fatigue, alertness, health and safety to provide a baseline measure of behavior. Six weeks after attending the training session, workers completed the sleep/wake log and the questionnaire again. The differences between the pre- and post-measures were used to assess the impact of training. Results from the study indicated that six weeks following the training, there was a reduction in the number of workers reporting that it was difficult to fulfill their domestic responsibilities (41% vs. 23%), find time for entertainment and recreational activities (46% vs. 23%), or believing that their health would improve with a different schedule (77% vs. 50%). The miner's average scores on the gastrointestinal index declined considerably (17.9 to 13.6), as did their excessive use of caffeine (32% vs. 8%). The amount of sleep obtained during daytime hours increased by nearly an entire hour (from 4.8 to 5.8 hr) and more workers reported getting at least 5 hours of sleep each night (45% vs. 67%). Additionally, over half of the workers that completed the training with their domestic partners reported making changes in their physical environment to make it more conducive to sleep. Overall, the feedback from managers and workers alike was very positive and indicated that fatigue training was beneficial.

The general evidence suggests that fatigue countermeasure training does influence behavioral change both at work and at home. Across studies, the results indicate that individuals who participated in training experienced a number of individual benefits, including improved knowledge, quality of life, health, and safety.

Organizational Benefits

Additional research suggests that organizations benefit from fatigue-related training. Large scale surveys of shiftwork facilities have linked fatigue and shiftwork training to reduced turnover, reduced absenteeism, fewer fatigue problems, and fewer morale issues for organizations (Kerin & Aguirre, 2005). Fatigue training has also been predictive of worker perceptions of safety (Arboleda, Morrow, Crum, & Shelley, 2003) and fewer accidents and injuries (Moore-Ede, Heitman, Dawson & Guttkuhn, 2005). A follow-up survey for one training program indicated that over half of the respondents surveyed reported that the educational materials were the basis for positive change as they related to fatigue in their organizations (Rosekind et al., 2001). Even seasoned long-haul truck drivers had very positive responses to fatigue training with as high as 96% reporting that they have applied the course lessons presented during training and intend to continue using them (Dinges, Maislin, Brewster, Krueger & Carroll, 2005). Clearly, the evidence suggests that fatigue-related training programs can be beneficial to both the individual and the organization.

Conclusion

Mitigating fatigue in complex aviation operations is a challenging proposition. Results of this report, nonetheless, suggest that fatigue can be managed to some extent with a well-developed fa-

tigue countermeasure training program. The content analysis conducted with the fatigue training programs reviewed for this report revealed the topic areas that should be included in an effective fatigue training program (See Appendix A for the final proposed training outline). Despite the scarcity of research regarding fatigue training effectiveness, the available evidence suggested that training provides a number of benefits to both the individual and the organization. These benefits can only be realized, however, when individuals take personal responsibility and are committed to change. Taken together, the training content analysis and review of fatigue countermeasure training benefits indicate that a fatigue countermeasure training program is a viable and potentially beneficial method for managing and mitigating the effects of fatigue.

Future Research

The preliminary evidence does indicate that fatigue countermeasure training is beneficial, however a number of unanswered questions exist. The current data only examined the benefits of training delivered via face-to-face interactions over a relatively short period of time. Some follow-on questions for future research might include: Would computer based training be equivalently useful? How long do the benefits of training last? Is recurrent training necessary? If recurrent training is necessary, what needs to be included in it?

The metrics used to evaluate training effectiveness have stand-alone merit, but alternative measurement strategies may provide improved assessment. For example, future research might utilize biometric tools (like the actigraph) to measure changes in physical activity trends following training. Alternatively, accident/incident investigators could investigate associations between incidents/accidents and the use or absence of fatigue countermeasure training.

Limitations

Despite the contributions of the current study for training developers and fatigue researchers, two noteworthy limitations do exist. First, some of the training programs included in the content analysis were developed by overlapping authors. An alternative approach might be to only examine programs that were developed from the ground up and independently of other programs. This would limit the breadth of training programs that were included in this study, but provide a more accurate assessment of the prioritization by each training developer. Second, the current study reports on the benefits of fatigue countermeasure training found in other studies rather than presenting results associated with the proposed training outline. A study examining the short-term and long-term effects of the proposed training outline would provide additional evidence to support the prioritization of topics revealed by the content analysis.

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* Indicates training programs included in final analysis.

Appendix A

Recommended Training Course Topics

I. Category: INTRODUCTORY FATIGUE INFORMATION

1. Goals of training

A. Education about the causes and consequences of fatigue

B. Provide strategies for fatigue management on and off the job

2. Topic Areas

A. Fatigue basics

i. Definition

ii. Signs & symptoms

iii. Misconceptions

B. Causes of fatigue

i. Circadian rhythm

ii. Homeostatic sleep process

a. Sleep quality

b. Sleep quantity

c. Total amount of continuous wakefulness

iii. Shiftwork

iv. Workload

v. Previous hours and days worked

vi. Time zone changes

vii. Illness / Stress

viii. Off-duty activities & responsibilities

ix. Nutrition, hydration, substance use

C. Introduction to the FAA regulations & NTSB recommendations on fatigue management

i. Code of Federal Regulations

ii. NTSB recommendations

D. Consequences of fatigue

i. Fatigue research

1. Prevalence of fatigue

2. Implications

a. Mental

b. Physical

c. Health / Well-being

i. Digestive

ii. Cardiovascular

iii. Mood

iv. Cancer risk

d. Accidents & job performance

e. Post-duty

i. Dead-heading

ii. Driving concerns

ii. Evidence of fatigue management training effectiveness

II. Category: OFF-DUTY FATIGUE ISSUES; PREVENTATIVE STRATEGIES

1. Topic Areas

A. Sleep fundamentals

i. Stages of sleep

ii. Sleep quality & quality

iii. Sleep debt

B. Alertness and the circadian rhythm

C. Common sleep disorders

D. Physiological v. subjective assessments

i. Countermeasures

1. Napping

2. Sleep environment

3. Good sleep habits

4. Scheduling sleep

E. Lifestyle

F. Nutrition
    i. Hydration
G. Exercise
H. Substance use
    i. Caffeine
    ii. Alcohol
    iii. Nicotine
    iv. Sleep aids
I. Domestic situation / Family / Social life
    i. Women-specific issues
    ii. Partners, children, elder family care
J. Commuting
    i. Recovery and preparatory rest strategies
K. Countermeasures
    i. General health strategies
    ii. Appropriate substance use
    iii. Scheduling and management of non-work life

III. Category: ON-DUTY FATIGUE ISSUES; OPERATIONAL STRATEGIES

1. Topic Areas
    A. Work environment
        i. High ambient temperature
        ii. Noise
        iii. Cabin pressure
    B. Dehydrating effects of aircraft
    C. Workload
        i. Physical
        ii. Mental/emotional
    D. Scheduling
        i. Extended duty time
        ii. Rest periods
            1. Continuous wakefulness
        iii. Multiple flights
        iv. Night flying
        v. Reserve duty
    E. Transmeridian / Time zone changes
        i. Eastbound v westbound
        ii. Recovery time
        iii. Seasonal effects
    F. Ultra long range, long-haul, and short-haul flights
    G. International v domestic
    H. Countermeasures
        i. Strategic naps
            1. Sleep inertia
        ii. Breaks
        iii. Strategic nutrition (sensitive to circadian digestive issues)
            1. Nutritious food and snacks
            2. Strategic caffeine use
        iv. Social interaction
        v. Physical activitys

An Assessment of General Aviation Advanced Composite Aircraft Repair Methodologies

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Abstract

Composite aircraft structures are increasingly being adapted in Air Transport to General Aviation (GA) aircraft designs. Maintenance repair technology varies for each Original Equipment Manufacturer (OEM) and aircraft type. Whereas previous aircraft structural repairs used similar construction, aluminum and rivets, composite aircraft manufacturers certify each aircraft with a mixture of different fiber reinforcements and resin matrix systems. Without standardization in the build or repair of composite aircraft, aviation maintenance inspectors and technicians are tasked to interpret the airworthiness of each aircraft with approved repair procedures on increasingly complex composite aircraft. This study is an examination of composite repair methods used with the top three GA composite aircraft manufactures; Diamond Aircraft Industry's DA40, Cessna Aircraft Company's 400TT, and Cirrus Design Corporation's SR22. The focus of this study is a review on how each OEM's Aircraft Maintenance Manual or Structural Repair Manual differs in the repair of similar damage in composite sandwich core wing damage.

An Assessment of General Aviation Advanced Composite Aircraft Repair Methodologies

Composites have been in use on aircraft in one form or another for decades now. Wood laminated props, dope and fabric surfaces are some of the earlier forms found aboard aircraft. The standards for repair on sheet metal aircraft are well known and documented with published substitutions and variances. Typically, repair technicians have a supply of rivets, fasteners and various sheets of metal on hand to mend most damaged metal aircraft.

Today's aircraft manufactures have moved from building aircraft with aluminum to building aircraft using advanced composite materials to reduce weight and improve performance. For example Boeing Aircraft Company is building the 787 with over 50 percent composites (Hale, 2006). Business Aircraft, Hawker Beechcraft 4000 is in production as a three-part all-composite carbon fiber fuselage. Bombardier Aerospace's Learjet 85 is in design to be the first all-composite aircraft structure for certification under Title 14 Code of Federal Regulations (CFR) Federal Aviation Administration's (FAA) Federal Aviation Regulations (FAR) Part 25. The Very Light Jet (VLJ) market is designing and engineering to build economical jet flight transportation. The Honda Jet, Diamond's D-Jet, and Cirrus's Vision SF50 are just a few of the

early VLJs under development utilizing advanced composite materials. General Aviation Manufactures Association reported in 2007 over 51 percent of all general aviation aircraft sold was composite aircraft (Black, 2008). Light Sport Aircraft (LSA) is favoring composites for the improved strength to weight ratios. The LSA category is relatively new to the industry and is developing innovative designs using composite structures.

With the increase of composite aircraft, there is a requirement for standard and effective repair procedures. Through rigorous test and analyses each aircraft manufacturer has established unique repair procedures specifically for each type design. Aircraft Maintenance Technicians (AMT) and inspectors are adapting their technology and training requirements to cope with these composite aircraft. The repair techniques used in the old fiberglass shops on non-structural components are not suited for the advanced composites used today. Composite repair training centers are being established to provide suitable courses. This short review examines and compares the repair requirements for the three leading general aviation composite aircraft manufactures, Diamond Aircraft's Star DA40, Cessna Aircraft Company's Corvalis 400TT and the Cirrus Design's (G3) SR22.

Methods

Manufacturing

Diamond Aircraft Industries (DAI) has certified several aircraft designs DA20, DA40, and the DA42 under Title 14 CFR, FAA, FAR Part 23 regulations to normal-certifications standards. DAI builds its line of composite aircraft using open mold, hand, wet layup techniques. The majority of the aircraft fuselage is manufactured with a 2x2-twill weave E-glass rolled through a wet-out resin basin and joined with plastic sheeting for handling as it is worked into place in open molds. The E-glass is laid out with carbon fiber reinforcements in the fuselage, door, and canopy frames. The core material used in the DA40 is Divinycell H series, a Poly Vinyl Chloride closed cell, rigid foam. Divinycell H series core material has a high strength to density ratio enabling it to absorb energy with less damage. The wing skins and cowling are constructed of carbon fiber with similar weave 2x2 twill fiber with interwoven aluminum fibers for conductivity for added lighting dissipation. All cloth types comply with LN 9169 of German Aviation Standards (Black, 2008). The molds are vacuumed bagged over night in a warming room elevated above room temperatures to 100 °F (38 °C). Once de-molded and trimmed, major structures are bonded with subassemblies and co-cured at 176 ˚F (80 °C) post cure for up to18 hours before moving on to paint (Diamond, 2007).

Cessna Aircraft Company's (CAC) Corvalis 400TT is similar in fabrication using open mold, manual, hand layups. CAC uses several types of epoxy pre-impregnated (prepreg) unidirectional and woven carbon fiber and E-glass fabrics. The prepreg is computer cut and kitted for each part. The core material is manufactured by Advanced Honeycomb Technologies Incorporated and is a unique cell design of 3lb density resin-impregnated aramid paper honeycomb core (Black, 2008). The molds are vacuumed bagged and cured in gas fired commercial ovens ramping up at stepped rates over 300 ˚F (149 °C) for 18 hrs to flow and crosslink the thermoset epoxy prepreg systems. The two halves of the fuselage and the tops and bottoms of the wing are bonded with secondary structures prior to close out of each major structure. The major structures are once again cured for the structural bonding prior to paint.

Cirrus Design Corporation's (CDC) G3 SR22 also uses manual, hand layups in open molds. Using a majority of E-glass epoxy prepreg, CDC also incorporates S-2 glass epoxy prepreg and strategically adds carbon epoxy prepreg for stiffness and strength. The core material used is Divinycell HT series and is interpenetrating polymer network core foam designed to be used with the epoxy prepreg materials temperatures (Black, 2008). The molds are vacuum bagged and step cured in commercial ovens. A comparable process of secondary bonding during the closeout of the major structures is used. While bonding composite parts, a tent type of containment area "heat in place" process using

hot air and electrical heat tape is used to help focus heat to cure bond seams (Cirrus, 2007).

These overly simplified manufacturing descriptions emphasize that even though all three are fixed gear, four-place, single engine aircraft, they are manufactured using similar open mold methods with dissimilar materials. Each uses manufacture specific FAA certified processes, materials, and suppliers. All manufactured structures are without the use of autoclaves. The only expectation to the use of autoclaves is with Cirrus' (G3) carbon spar and E-glass gear legs explained by Tim Wright of Cirrus Designs Advanced Composite Training Center (personal communication, May 29, 2009). DAI and CDC meet or exceed certification requirements under Title 14 CFR FAA FAR Part 23 Normal-certification with CAC meeting the higher Utility-certification. Materials and repair methods used after manufacturing most often differ from OEM processes. Following certification any damage repairs need to meet strict guidelines found in each individual aircraft OEM's Aircraft Maintenance Manuals (AMM) and, if applicable, the Structure Repair Manuals (SRM).

Damage Assessment

The first step of any composite repair is to determine the extent of any suspected damage. A crack in the paint may only be a crack in the paint. All three general aviation aircraft manufactures recommend using visual inspection of both sides of the composite surface whenever accessible. Visual inspections should be followed by coin tap inspection of any suspected damage areas. Coin tap inspections are specific for each aircraft OEM. Any suspected damage found during coin tap inspections is referenced to AMM for placement of subassemblies structures and core termination edges. Damage assessment is one of the few times a technician can make improvements as long as the inspections are visual in nature. The techniques used include the use of high-intensity lighting, endoscopes, eye looms, lighted magnifying glasses, borescope, and mirrors. Visual inspections should not be limited by eyesight, but accompanied with a hand surface inspection. By running hands over the surface of suspected damaged area, the technician can often detect imperfections and anomalies (Cessna, 2008; Cirrus, 2007; Diamond, 2007). If no cracks are found then DAI's AMM instructs the technician to "Push the middle of the area to be tested with his thumb. If he can feel the skin of the aircraft hitting the core of a sandwich (or other layer/component), the skin is considered disbonded and must be repaired" (Diamond, 2007, 51-10 p3). Other non-destructive inspections (NDI) methods as ultrasonic, thermography, radiography, and laser holography inspection may only be accomplished in direct coordination with the individual aircraft OEM under repair.

The examination of repair methodologies among the three aircraft manufactures will be restricted in scope to approved structural repairs published in AMMs and SRMs. For this reason, damage assessment will be limited to structural laminated surfaces with sandwiched core damage. All other repairs not published in AMMs or SRM need to be dispositioned by aircraft OEM's engineering and approved by the FAA or Designated Engineering Representatives.

Classification of Repairs

All three manufactures use varying terms in the classification of repairs. CDC's self-descriptive titles define the extent of repairs and follow the FAA's definitions. The remainder of repair discussions will reference abbreviated definitions to classify repairs.

1. Cosmetic – designed to repair localized surface defects to the original profile and to prevent moisture ingress. Have no significant effect on the structural strength to sustain stress loading.
2. Minor – 14 CFR, Part 1 § 1.1 describes a minor repair as a repair other than a major repair.
3. Major – 14 CFR, Part 1 § 1.1 describes a major repair as a repair, that if improperly done, might appreciably effect weight, balance, structural strength, performance,

powerplant operation, flight characteristics, or other qualities affecting airworthiness; or a repair that is not done according to accepted practices or cannot be done by elementary operations (Cirrus, 2007, 51-10 p7). Additionally, the repair is field allowable if the repair is specifically covered in the AMM or SRM.

4. Restricted – repairs not covered in the AMM or SRM and require disposition from aircraft OEM (Cirrus, 2007).

Repair Qualifications

CAC specifically states, "The repair facility must be a FAA Certified Repair Station rated for composite aircraft structure work, in accordance with FAA approved CAC repair methods, or other methods approved by the FAA" (Cessna, 2008, p19).

CAC Field SRM further states, "Abaris Training will perform the CAC specified composite training using CAC approved course curriculum, the CAC Field SRM in coordination with the FAA Flight Standards District Office, and applicable FAA Regulations. The classes will meet both the initial and recurrent training required in CFR Tile 14 Part 145.163 for repair stations with Airframe Class 1 Rating (composite construction of small aircraft)" (Cessna, 2008, p. 19). In addition CAC requires that each repair technician annually perform 100 hours of composite repair or annually attend the phase III composite repair training course to maintain their certification. Repair of composites of any certified aircraft may be applied toward this requirement (2008).

CDC Authorized Service Centers (ASC) is not required to acquire CFR Title 14 Part 145 Repair Station Certification. Nevertheless, they do require the ASCs to obtain OEM level of composite repair certification. They may acquire this by attending Cirrus Advanced Composite Training Course in which they are required to pass both a practical and written examination (T. Wright personal communication, May 29, 2009).

DAI's ASC or independently operated centers or repair certified technicians must successfully complete Diamond's Composite Repair course for each individual DAI model for certification (Diamond, 2007).

The repair qualifications listed for each aircraft is specific in exactly how the AMT is trained and who may perform the training. The only non-factory training authorized is Abaris training for Cessna Aircraft. All other composite training is not accepted as qualifications for repairs and could render any repaired aircraft with unacceptable trained AMT as out of type design.

Sandwiched Core Damage Repairs

This discussion compares similar laminated sandwiched core damages on the upper wing skin at Wing Station 80. The assumed damage is a single dent with the maximum depth of 0.05 in (0.127 cm). The outer face sheet and core are delaminated with crushed core material. Since each aircraft OEM's wing is constructed and attached differently to the fuselage, the wing station location will be related to the centerline of the wing; clear of any spars and ribs. The inner laminate sheet suffered no damage or disbonding from the core.

All three OEMs consider this repair to be major structural damage and all have published repair procedures for upper wing skin sandwiched core damage. Before performing a structural repair per Field SRM, CAC requires any structural damage to be documented on a structural repair map and reported to CAC to be kept with the aircraft's build record (2008). The intended purpose of the repair map is to document and track all repairs to structures. As a structure is repaired each time the structure as a whole may become weakened and require additional attention and disposition for repair not authorized in the SRM. DAI and CDC aircraft require no notification of approved damage repairs. Refer to Table 1 for wing laminated sandwiched core repair comparisons.

Table 1

Wing Laminated Sandwiched Core Repairs

	Diamond Aircraft Industries DA40	Cessna Aircraft Company 400TT	Cirrus Design Corporation SR22
Original ply count	3	3	2
Replacement plies	3	3	4
Repair fabric material	1 ply carbon/aluminum 2 ply carbon	E-glass 7781	E-glass 7781
Scarf distance per ply	0.8 in (20 mm)	0.5 in (13 mm)	0.5 in (13 mm)
Structural resin	MGS L285	MGS L418	MGS L418
Cloth to mixed resin ratio	Carbon 100 : 85 grams E-glass 100 : 70 grams	100 : 42 grams (+/-) 4	No published ratio
Core replacement	Remove and replace damaged foam core.	Remove damaged core and fill with bonding paste.	Remove damaged core and fill with bonding paste or filler.

Note. Diamond aircraft repair information is from DA40 series Aircraft Maintenance Manual (2007); the Cessna aircraft repair information is from Cessna RX512100B Field Structural Repair Manual (2008); with the Cirrus' aircraft repair information from Cirrus Design SR22 Maintenance Manual (2007).

Laminate Repairs

After removing damaged material and establishing proper ply count and orientation all three aircraft OEM's published repairs are wet layup. Following any core replacement or fills per AMM or SRM the fiber placement laminate is replaced. The Laminating Transfer Method is acceptable with all three OEM's repairs, especially in difficult repair positions. The Laminating Transfer Method is comparable to laminating in place except the repair plies are laid-up on release film first, cut to size, wet-out and stacked in reverse order for placement of plies. Once prepared the stack is lift up off the repair table and placed face down on the damaged area. This method simplifies multiple ply repairs while maintaining orientation and replacement schedule.

The ply orientation in the repair described by each OEM is different with the order, size, and replacement schedule. CAC removes the damaged three surface plies and removes crushed core. The core is replaced with bonding past and the original damaged plies with three plies arranged in a "wedding cake" fashion, first ply the largest, final ply the smallest as illustrated in Figure 1. Each replacement ply is staggered at 0.5 in (12 mm) for E-glass and 1 in (24 mm) for carbon. The replacement ply schedule for the damaged area as outlined in the SRM is 45 °, 0 °, and 45 °.

Diamond Aircraft uses a similar method of replacing repair plies with the largest ply first with smallest last with an overlap over of .80 in (20 mm) refer to Figure 2. The damaged core is removed and replaced with new core material. The replacement ply schedule is 0/90°, +/- 45°, and +/- 45°. (2007).

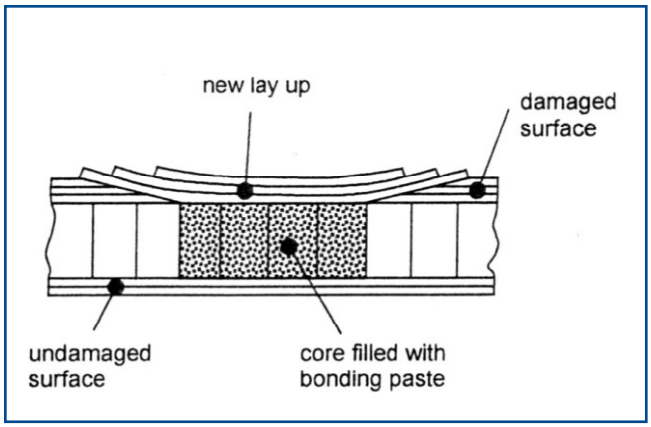

Figure 1. Cessna's Damage Core Cell Shown with Replacement Ply Order. *Cessna Structural Repair Manual Rev B, p.24 Copyright 2008 by Cessna Aircraft Company. Reprinted with permission.*

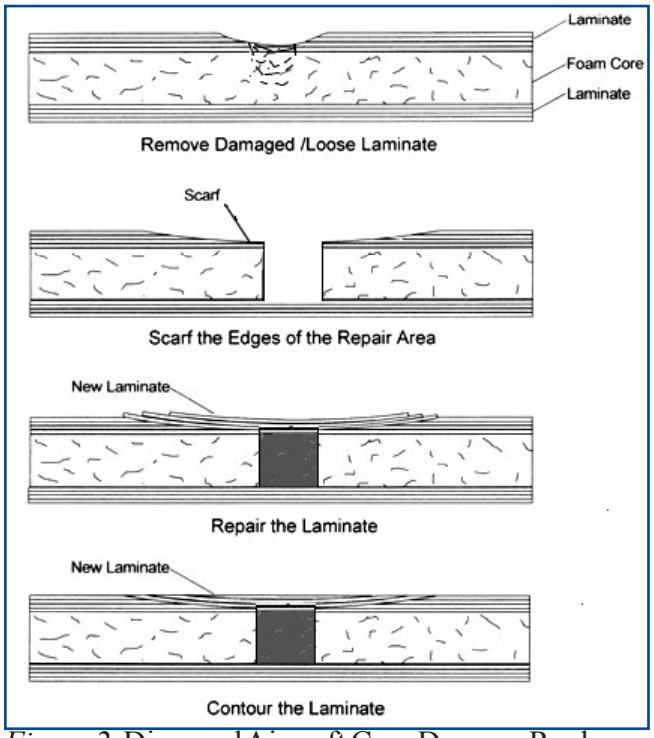

Figure 2. Diamond Aircraft Core Damage Replacement and Laminates. *Diamond Aircraft Industries Maintenance Manual Rev 5, Copyright 2007 by Diamond Aircraft. Reprinted with permission.*

However, Cirrus' AMM replaces the plies in reverse order compared to CAC and DAI. The ply placement is illustrated in Figure 3 with the first ply smallest and each consecutive ply larger overlapping the preceding ply with the final ply being the largest. The ply orientation schedule with CDC is +45°, -45°, +45°, and -45°. CDC replaces two plies for every one ply damaged to ensure original structure strength is achieved. Plies must be applied in the same opposing orientation as the original plies to prevent the repair from warping (2007).

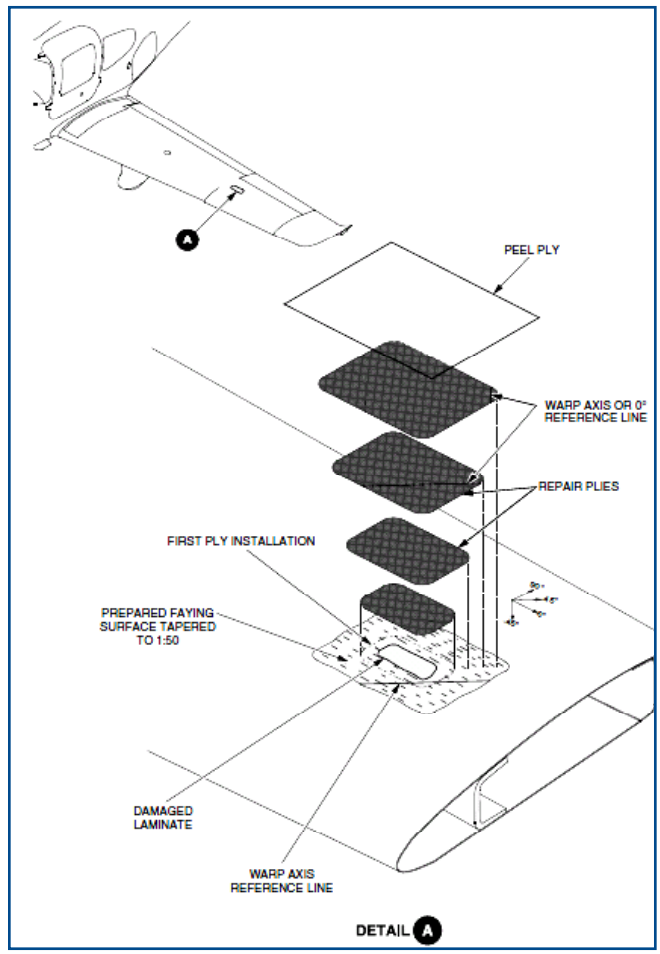

Figure 3. Cirrus Design's 2:1 Ply Replacement with Largest Ply Placement Last. *Cirrus Design Maintenance Manual Rev A-3, 51-20 p.30 Copyright 1999 by Cirrus Design. Reprinted with permission.*

Curing Repairs

All three aircraft OEMs use MGS laminating resin products manufactured by Kunstharzprodukte GmbH, Stuttgart, Germany. The liquid synthetic thermoset resin is an epoxy-based system requiring heat to reach maximum cross-linking strength. Each OEM certified designs and

Table 2

Resin Cure Comparisons

	Diamond Aircraft Industries DA40	Cessna Aircraft Company 400TT	Cirrus Design Corporation SR22
Resin	MGS L285	MGS L418	MGS L418
Pre-cure	24 hr at 68 °F - 77 °F 20 °C - 25 °C)	<100 °F (37 °C) until resin feels solid and does not deform to the touch	None published
1st cure	6 hr at 149 °F (65 °C)	Optional Handling Cures 8 hrs at 100°F (37 °C) or 6 hrs at 120°F (49 °C) or 4 hrs at 140°F (60 °C) or 2 hrs at 160°F (71 °C)	Initial 3 hr at 150 °F - 210 °F (65 °C - 99 °C) or 5 hr at 125 °F - 210 °F (52 °C - 99 °C)
2nd cure	14 hr at 176 °F (80 °C)	(Option 2) Post-Cure 1. Ramp from ambient to 220 °F (104 °C) over a period of 240 min 2. Hold at 220 °F for a minimum of 90 min 3. Cool down at a rate not to exceed 10 °F (5 °C) min to 170 °F (77 °C)	Post-Cure 1. Ramp from ambient at a rate of 1.0°-5.0°F per min 2. Hold 175°-210°F for 3 hr or 3. 125°- 210°F for 5 hr 4. Ramp down at 1 °F - 15 °F (0.5 °C - 8°C) per min
Verification Testing	Not required	Glass transition temperature (Tg)	Not required

Note. Diamond aircraft resin cure information is from DA40 series Aircraft Maintenance Manual (2007); Cessna aircraft resin cure information is from Cessna RX512100B Field Structural Repair Manual (2008); Cirrus aircraft resin cure information is from Cirrus Design SR22 Maintenance Manual (2007).

repairs using varying time and temperature cures as listed in Table 2. The use of MGS resin systems is not the exclusive resin systems used by the aircraft OEMs, it is the predominate resin matrix system used in wet layup repairs. DAI uses a lower temperature resin MGS 285 as a result from the wet layup production compared to the prepreg production of CAD and CAC. CAD has approved the use of MSG 418L or MSG 285L in structural wet layups. CAC has only MGS 418L approved for structural repairs. CAC's SRM has an additional requirement for structural wet layup testing. Each repair requires a small sample be taken from cured resin mixture for Glass Transition Temperature (Tg) testing via differential scanning calorimeter testing or dynamic mechanical analyses. It is required that the cured resin sample be sent to CAC for verification. The purpose for the Tg testing is to ensure the resin matrix in the repair is at the required strength. Factors that can affect the strength of the resin system are improper mix ratios, low temperature cure, and short soak times at desired temperatures. Process verification sam-

ples are taken from the same batch of resin and hardener used for repairs prior to the addition of filler materials. The sample should be exposed to all handling and post cures during repair to experience the same temperature conditions. Sample size and additional requirements are listed in CAC's Field SRM (2008). After completing the cure cycle, the repaired area requires coin-tap test for possible delamination of the repair plies.

Aerodynamic Restoration

Following successful repair, the composite structure surface finish must be restored to certified standards. Because of the relatively low conductivity of composite compared to aluminum additional repair measures prior to painting may be required to restore the ability to dissipate high energy levels produced by lightning strikes. All paints used on composite aircraft including those used for repair must contain ultraviolet protection.

Diamond Aircraft's DA40 uses a carbon fabric with woven aluminum fibers as outer surface ply for the cowlings and wings. Carbon fiber fabric is used on flaps and ailerons without the interwoven aluminum fibers. All other flight control surfaces are constructed of E-glass fabric. The DA40 also use anti-static spray filler beneath the aircraft's painted surface. Therefore, any paint damage during composite repairs must include anti-static filler. Before applying paint, the painted area around the repair site must be scarfed back one inch, allowing continuity of the anti-static filler. Once two coats of anti-static filler is applied, dried, and lightly sanded the aircraft is ready for paint. The DA40 has a paint coating system approved for use with three different paint manufactures identified with specific aircraft serial number blocks (2007). As new paint systems became available for use though testing and certification, they were introduced in to production by serial numbers first and last applicable serial numbers. The serial number effectively is not listed in the AMM; however, DAI Customer Support can supply that information.

Cessna's 400TT uses extensive amounts of carbon fabric in its fabrication process. All flight controls, ailerons, evaluators, rudder, and flaps are built of carbon fabric. In addition to the flight controls, the cowling, doors, and horizontals stabilizers are made of carbon fabric. Any carbon surface identified as a high probability lighting strike zone has an additional surface layer of expanded copper metal mesh to help dissipate energy. All other exterior surfaces, excluding cowling and wheel pants are covered with an expanded aluminum metal mesh. During repairs or after completing a repair the area, depending on size and zone, may require expanded metal foil repairs. Mesh repairs typically overlap one inch and are tested with electrical resistance checked for continuity. CAC has three topcoat systems approved for use listed in Table 3 (2008).

Cirrus' SR22 has no exterior carbon fabric material. All major structures, wings, fuselage, and horizontal stabilizers use E-glass fabric as outlined in the AMM. Expanded aluminum metal mesh is laid in varying striped patterns in areas with a high probability of lighting strike. Only after completing and inspecting a composite repair can the metal mesh be re-applied. Minimum overlapping mesh joint is 0.20 in (0.50 mm), with some areas requiring butt joints. All flight control surfaces, ailerons, evaluators, rudder, and flaps are constructed out of aluminum and require no mesh. Cirrus has three exterior paint system approved for use listed in Table 3 (2007).

Each paint system used on composite aircraft is tested for durability and damage size. The use of non-approved paint systems will take the aircraft out of type design and if not corrected could cause major structural damage if struck with lighting.

Conclusion

The analysis of the repair methods used on composite GA aircraft reveals that despite the similarities in aircraft classifications, fiber reinforcement and matrix systems vary from each composite manufacturer. Diamond, Cessna, and Cirrus are unique in designs and repairs. It's apparent

Table 3

Approved Exterior Paint Systems

	Diamond Aircraft Industries DA40	Cessna Aircraft Company 400TT	Cirrus Design Corporation SR22
Paint Systems	Single Stage Polyurethane	1.Single Stage Polyurethane 2.Two Stage Polyurethane 3.Three Stage Polyurethane	1.Single Stage Polyurethane 2.Single Stage Acrylic 3.Two Stage Polyurethane
Manufacture	ICI Paints BASF Imron	PPG Industries	PPG Industries
Paint line	ICI Zynatec BASF UNO Imron 5000	Global	Delfleet

Note. Diamond aircraft paint information is from DA40 series Airplane Maintenance Manual (2007); Cessna aircraft paint information is from Cessna model LC41-550FG Maintenance Repair Manual (2008); Cirrus aircraft paint information is from Cirrus Design SR22 Maintenance Manual (2007).

that a one-time general composite training course will not meet the requirements of today's advanced composite aircraft. All three aircraft OEMs require the attendance of specific aircraft type composite training with Cessna's having additional requirements of only Certified Repair Stations rated for composite aircraft structure being authorized to perform composite repairs. The additional requirement is that each repair technician must annually perform 100 hours of composite repairs or attend advanced training courses. This is a requirement that the GA industry should review as a standard to help ensure technicians stay current in technique and methodology.

The damage scenario to a wing discussed in this review has revealed that the multi-stage complex structure repairs have no real process in common between the three manufacturers considered. Damaged ply restoration can change from fabric type and ply count. Even the ply order and replacement schedule can be reversed from one manufacturer to another. Cure cycle times for similar resin system are certified and approved at varying times and temperatures. The added lighting protection systems are dissimilar in repair and design. The exterior paint systems are certified per aircraft type design with no common paint line between the three OEMs.

Without specialization in aircraft type repairs or recurring training, composite repair technicians could unknowingly confuse one repair with a completely different aircraft repair method. Aluminum aircraft repairs can be inspected for proper installation after the completion of a repair. After repairs composite aircraft ply orientation, resin mix ratios and even core repairs are undistinguishable. Cessna's required Tg testing for structural repairs is an admirable attempt to ensure structural integrity. However, Tg testing does not assure that the ply orientation and fabric type are correct. Thus from damage classification to paint repair areas the structural integrity of the aircraft is at risk each time a composite repair is performed.

Today's GA composite aircraft are certified per type design. This author believes how a simple check sheet requiring technicians to record materials, processes, and steps to be taken during repairs might help focus the technicians on which aircraft methodology is used. Once the steps for repair have been outlined, inspectors could insert in-progress inspection points to verify critical repair steps prior to completion. These exercises of completing a repair process list not only assist technicians in keeping processes straight but by the addition of in-progress inspections by inspectors during repairs could help ensure structural integrity is maintained.

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Teaching Maintenance and Inspection Aspects of the Rotax 900 Series Aircraft Engine at a Traditional Part 147 Airframe and Powerplant Technician School

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Abstract

The Rotax 912 series Aircraft Engine is a 4-cylinder, 4-stroke, high RPM, liquid cooled, lightweight power unit used in a host of recreational, experimental, and special light sport aircraft. The non-certified 912 ULS 100 horsepower visual flight rules (VFR) only version is the most common. Since the Rotax is substantially different from typical light aircraft reciprocating engines in several respects, additional training above what is offered in a typical Airframe and Powerplant (A & P) curriculum is recommended and in some case required to perform various levels of maintenance on the engine. Rotax approved maintenance courses at several levels are available through a number of factory approved providers. Due to the popularity of these power plants and the recent emergence of the experimental light sport aircraft (E-LSA) and special light sport aircraft (S-LSA) markets, familiarization with these engines and/or addition of factory approved maintenance courses may be viable additions to traditional Part 147 A & P programs. This paper examines some of the engine's characteristics and provides some suggestions for development and inclusion of Rotax engine familiarization material in such a program.

Teaching Maintenance & Inspection of Rotax 900 Series Aircraft Engine at a Traditional Part 147 Airframe and Powerplant Technician School[1]

Background

Rotax 912 series engines are manufactured by BRP Powertrain GmbH, an Austrian company which was acquired by Bombardier in 1970. Originally designed for Sea- doo® Watercraft and BMW motorcycles and all terrain vehicles (ATVs), the engines may more closely resemble motorcycle rather than aircraft types in some respects. While the first Rotax designed for aircraft use was certified in 1975, development of the 912 series began in 1984 with the 912F type certified 10 years later and the increasingly popular 912 ULS light 4-stroke light sport aircraft engine more recently (Rotax, 2009). During the course of its evolution to the modern light sport aircraft power plant

[1] Author Note: The material presented in this manuscript is not intended as a guide to practical application of any maintenance or inspection procedure or a substitute for any material contained in the various manuals published by the engine or airframe manufacturer. Further, the information contained herein is not endorsed by Bombardier, BRP Powertrain GmbH & Co, Rotax or any of its subsidiaries.

marketed today, the Rotax endured some growing pains (Cox, 2008), however, the present day series exhibit few problems when properly maintained (Hamilton, 2007). The Rotax 912 ULS currently is in use in a large number of experimental and special light sport aircraft (E-SLAs and S-LSAs), the latter including the popular Remos and Tecnam lines.

Characteristics of the Rotax 912 include 4-cycle operation, liquid cylinder head cooling, use of balance tube connected twin Bing carburetors with embedded starting carburetors (perhaps inaccurately called chokes), a dry sump oil lubrication system, a propeller speed reduction gear box and a magneto type generator for accessory operation and ship's battery charging. While some of these characteristics mirror what is common in motorcycle engines, similarities to typical aircraft engines include battery independent redundant solid state magneto driven ignitions, dual spark plug cylinders, and automatic fuel mixture metering for efficient operation at altitude. The engines operate to a service ceiling of around 12,000 feet and at a considerably higher RPM than conventional reciprocating aircraft engines.

The FAA, Rotax, and LSA manufacturers collectively have developed guidelines on engine servicing and inspections. In addition to the conditional requirements that the Federal Aviation Administration (FAA) and primarily Rotax may impose for individuals to service and inspect its engines, the light sport aircraft manufacturer may also have specific guidelines as to qualifications for performance of maintenance and inspections on it's products. These are generally specified in the manufacturers' maintenance manuals for a particular engine/aircraft and must be adhered to. Certain items may be approved for inspection by the aircraft owner, and other generally more complex or airworthiness related ones, by a certificated airframe and/or powerplant technician or a light sport aircraft repairman with the proper training and/or experience. Any modifications to the airframe or its components must be approved and specified by the manufacturer as to what can be performed and how the procedure is to be accomplished. Unlike conventional aircraft in which major alterations or modifications require an approved FAA form 337 Major Repair and Alteration (Airframe, Powerplant, Propeller, or Appliance) form, both major and in some cases minor alterations require the manufacturer's, but not necessarily the FAA's, approval. Certain repairs may also require manufacturer's approval and documentation as specified in the aircraft maintenance manual or via direct communication with the manufacturer. In any case, a thorough understanding of the applicable aircraft and engine maintenance manuals is paramount to performing required maintenance and inspections properly (FAA, 2006). The intention of this paper is to assist interested FAA Part 147 Airframe and Powerplant Maintenance Schools in the development and addition of Rotax engine maintenance and inspection familiarization procedures to their programs. As additional aircraft maintenance schools include these procedures in their training curricula, future evaluations as to their impact on the improvement of aviation maintenance technicians' knowledge and skills can gauge the success of their programs.

What Part 147 A & P Schools Can Do

Part 147 airframe and powerplant mechanic schools are a primary source of entry level aircraft maintainers in the U.S. (GAO, 2003). While these schools are governed in the topics they must include in their curriculum by the FAA, there is some latitude for adding instruction beyond specified topics included in the regulations. The topics are arranged in Appendices B - D to Part 147.2 and include material that must be taught in the general, airframe and powerplant curricula respectively. Although certain topics are specified, the regulations do not limit the inclusion of ancillary material where time permits (FAA, 2009). It is in this realm and under these guidelines that material relating to unconventional aircraft power plants such as the Rotax 900 series may be introduced. This being said, it should be noted that a revision of the Part 147 curriculum requirements is presently under review by the Aviation Rules Advisory Committee in conjunction with the FAA and

revision of the topics and contact instructional time allotted to each of the three categories is subject to change. Specifically, the contact hours of instruction required for the FAA power plant mechanic certification may be reduced from the present 750 to 650 although a total of 1900 hours for the sum of all three categories of instruction is expected to remain (Thompson, 2010).

In the power plant curriculum at Southern Illinois University Department of Aviation Technologies, five courses deal directly with power plant maintenance, repair and inspections. These are the Reciprocating Power Plant; Carburetion, Lubrication and Fuel; Power Plant Testing; and Powerplant Inspection classes. Additionally, the Ignition Systems, Electrical Systems, and Propellers classes offered provide additional venues wherein Rotax related material may be covered. The five primary and three secondary power plant courses occupy 21 and 13 credit hours and make up over 600 and 300 semester contact hours respectively.

What to Add and Where to Put It

Using a typical A & P curriculum as an example, a discussion of the appropriate areas of instruction to place the additional material follows.

Most of our students begin their power plant courses in the second year of the program. The first of the engine related classes in which the students participate is a Reciprocating Powerplant course. This class teaches construction, operation and timing mechanisms as well as cleaning and inspection of typical aircraft engines. Basic concepts as well as adherence to manufacturer's guidelines are stressed. It is in this course that the characteristics of the Rotax engine could be introduced. Approximately two hours of instructor led discussion and demonstration may be adequate for a basic overview. Included in the instruction could be a discussion of the close tolerances of manufacture including the engine's liquid cooled, high compression, high RPM and twin carburetor distinctiveness permitting the development of 100 horsepower in a 130 lb package. Use of a large graphic of the engine and a typical installation as depicted below in Figures 1 and 2 would afford the instructor the opportunity of teaching the highlights of its construction and operation while giving the students a proper visual overview.

Figure 1. Rotax 912 ULS

Figure 2. Typical Rotax 912 Installation

With permission from the producer, the inclusion of a one-hour video entitled Rotax 912 Engine Introduction produced by Paul Hamilton and featuring Phil Lockwood and Dean Vogel of Lockwood Aviation describing aspects of Rotax 912 operation and maintenance would be appropriate in this course (Hamilton, 2007). Once initial introduction to the engine is accomplished in

the Reciprocating Powerplant course, details of its line maintenance can be covered in the various component courses such as carburetors, ignitions, propellers, etc. and inspections covered in the Powerplant Inspection course.

The details of the twin top mounted carburetors can be examined in a carburetors class. These units consist of two Bing-64 constant depression float type carburetors connected by a balance tube at the intake manifolds. They are mounted to the intake manifold body of the engine with a flange secured with clamps that facilitate easy removal. Most installations do not employ filter screens in the carburetor bodies making installation of a gascolator on the airframe firewall and a course particulate filter at the fuel tank-fuel line connection advisable. Installations can be made with or without an airbox; however, for the benefit of a carburetor heat control its inclusion in the installation is recommended (Rotax-Bombardier, 2009). In the Rotax, the cold starting sequence consists of operating a "choke" rather than priming the engine or pressurizing the fuel system as in injector type systems. The "choke" is actually a starting carburetor, which injects additional fuel when activated to enrich the fuel-air mixture for cold starts. The throttle must be in the full idle position and the choke at full activation for the system to operate properly. As the choke lever also increases engine starting RPM, Rotax recommends that the choke lever be backed off and the throttle increased to 2200 RPM for warm-up after the engine starts (Rotax-Bombardier, 1998). Part of the installation and inspection process consists of balancing and checking the two carburetors such that the two throttle valves open equally and an equal vacuum level throughout the throttle travel path is achieved on both carburetors. This is a multi-step process, which consists of an initial mechanical setting of the cables and linkages followed by a pneumatic balancing wherein fine adjustments are made ultimately achieving a smooth idle and run condition. The process is delineated in the Rotax Line Maintenance Manual (Rotax-Bombardier 2009) and several other sources including the article Looking After Your Rotax 912 Series Engine (Beale, 2009) and Reaching Smooth Idle, Parts 1 & 2 (Lockwood, 2005). As the Rotax actually functions as two 2-cylinder engines connected to a common crankshaft, it is imperative this aspect of engine installation and maintenance be carried out (Lockwood, 2005). Additionally, according to the Rotax 912 Line Maintenance Manual, carburetor balance must be inspected, checked, and corrected if necessary at each annual/100 hour inspection and at the initial 25 and 50 hour engine inspections (Rotax-Bombardier, 2009) reinforcing the importance of performing this operation.

It should be mentioned that the Rotax 900 series runs very well on automobile gasoline, 91 octane or above, as well as 100 low lead (LL) avgas, however, there are some caveats that apply to each fuel type usage. As the Rotax is partially liquid cooled, the engines normally do not run as hot as a typical Lycoming or Continental aircraft power plant. When using 100 LL, lead deposits accumulate on the cylinder heads, valves, connecting rods, etc. as well as spark plugs, and a pasty lead residual will accumulate in the sludge and particulate catching area at the bottom of oil reservoir. Rotax recommends that use of 100 LL more than 30% of the time requires a shorter interval between spark plug and oil changes (Rotax-Bombardier, 1998). The shorter intervals are generally at one-half the normal plug change interval and every 50 hours for an oil and oil filter change. While Rotax does not comment on the use of lead scavenger additives such as TCP, some of the other literature suggests that its use may decrease problems associated with the use of leaded fuels (Aircraft Spruce, 2009). Rotax does conclude that field experience has shown that no detriment to the engine occurs with their use (Rotax, 2009). Use of unleaded automobile fuels with gasohol added may create some problems if the percentage of ethanol in the fuel is high enough. Since ethanol has a tendency to absorb water, condensation in fuel tanks may tie up some of the ethanol, which while good to eliminate water from the fuel can lower its octane rating below the minimum of 91 required for proper operation of the engine (Hamilton, 2007). This can also lead to a condition called phase separation of the fuel, which could cause further degradation of fuel system components. One of this paper's au-

thors noted through an unfortunate personal experience with high (93) octane unleaded automotive fuel not containing ethanol, degradation of some composite fuel tank slosh coatings and adhesives on the inside surfaces of the fuel tanks. It appeared possible that this damage may have been caused by the effects of unknown additives in the fuel. Providentially the degradation was noticed early and repairs affected before serious damage threatening the integrity of the fuel tanks occurred. While the octane rating and presence or absence of ethanol in automotive fuels is easily determined, the presence of other additives, which may damage particular systems, may not be evident until damage is done. As the federal Environmental Protection Agency and others push for replacement of leaded aircraft fuel with an acceptable standardized unleaded, non-ethanol containing substitute (Douglas, 2010), caution is appropriate in the usage of automotive fuels as they may cause damage to the fuel system.

Additional information for instruction regarding lubricants relates to crankcase oil. As indicated previously, the Rotax 900 series engine resembles a motorcycle engine in many aspects. One aspect is the use of a gearbox similar to what constitutes a motorcycle engine transmission to reduce the high engine RPM to a rate appropriate to drive a propeller. Because of both the tight mechanical tolerances utilized in manufacture of the engine and the use of a lubrication system common to both the crankcase and gearbox, regular aviation engine oil is not recommended for use in the Rotax power plant. Instead a non-synthetic petroleum oil, high quality multi-grade motorcycle oil (10W 40 or 10W 50) or specially formulated semi-synthetic (Hamilton, 2007) such as Aeroshell Sport Plus 4 is recommended (Aircraft Spruce, 2010).

Oil level check and change procedures in the Rotax require a different approach than in conventional aircraft engines. The Rotax uses a dry-sump type system wherein the oil is contained in a separate reservoir rather than the engine crankcase. The system does, however, use an oil cooler, a mechanical engine driven oil pump and a fiber filter with a pressure bypass as is the case in typical aircraft engines. Rotax recommends the oil reservoir be mounted on the firewall and the oil cooler mounted in the air stream with the intake and output ports facing upward. The Hamilton Rotax Introduction video also recommends exclusive use of Rotax brand oil filters due to their bypass pressure characteristics and manufacturer's assurance of quality (Hamilton, 2007).

Prior to checking the oil level in the reservoir, the engine needs to be hand cranked in the counterclockwise direction of normal rotation (when facing the power take off or propeller side of the engine) with the oil reservoir filler cap removed until a gurgling sound is heard. This procedure assures any engine oil remaining in the crankcase is returned to the reservoir and to prevent the introduction of air into the oil lubrication system. The process may take up to 10 or more rotations. When performing an oil change or servicing the system, care should be taken not to permit engine rotation in the direction opposite of normal rotation. Should the lubrication system require service necessitating disconnection of the oil lines at areas other than the top of the reservoir tank, removal or replacement of oil lines, changing of the oil cooler, or total draining of the oil system, the system must be purged as oil is added, again to prevent introduction of air which may become trapped into the system. Procedures for accomplishing these tasks are outlined in the Rotax engine Line Maintenance Manual (Rotax-Bombardier, 2009), and the purging procedure is also demonstrated by a video posted on the Rotaxowners.com web site. Additional procedural Rotax "E-learning" and instructional videos relating to oil and filter changes as well as other maintenance and inspection procedures are also available there (Rotax-Bombardier, 2010).

Although not actually part of the fuel and lubrications topic, a magnetic plug inspection should be performed at specific intervals as described in the line maintenance manual and instruction videos. The Rotax engine has a single magnetic plug, which is located on the left side of the engine above the oil filter flange. As is the case in any engine, an excessive amount of metal filings (greater than a 3 mm [0.125 in] clump in the case of the Rotax) adhering to the magnetic plug is an

indication of possible internal engine damage or malfunction and should be promptly investigated. As with conventional aircraft engines, the oil filter should be cut open and the element examined for metal filings or other particulates at the change cycle (Rotax-Bombardier, 2009).

The Rotax uses a liquid cooling system for the cylinder heads while conventional air-cooling is used for the balance of engine temperature regulation. As is the case in automobiles and liquid cooled motorcycle engines, a radiator, expansion and overflow bottle are employed and all need periodic checks and maintenance. The liquid coolant may be a typical 50/50 (50 percent distilled water and 50 percent antifreeze) antifreeze solution or a waterless coolant such as Evans® may be employed. The coolant type used is designated by the manufacturer. The Rotax cylinder head gauge temperatures generally range between around 160° to 300° F (150° C maximum) and the oil temperature between 120° and 285° F (50° – 140° C). In the event a change is the coolant type is made, the system must be thoroughly flushed and treated in accordance with the manufacturers' directions. Waterless coolants and 50/50 coolants are generally not compatible. Engines will typically run somewhat hotter when waterless coolant is used (Hamilton, 2007).

An ignitions class would be a good venue to discuss the redundant dual magneto solid state ignition while an electrical systems class may be more appropriate to discuss the DC power system. In the ignition system, there are no mechanical contact points to wear out. However, a study of the mechanism is important as an adjunct in proper maintenance and inspection of the system. The energy for the ignition spark is generated in a magneto coil, which is co-mounted in the ignition housing at aft end of the engine along with a "light coil" circuit. The 8 light coils generate an alternating current that is rectified and filtered to provide the 12 – 14 volts direct current (DC) to run the aircraft radios, instruments and accessories as well as keep the ship's battery charged. Rotating magnets on the flywheel induce voltages in both the light and ignition coils. There is also a take off to power an electronic tachometer. The AC power from the redundant ignition coils is sent to the electronic ignition module for spark energy processing and that from the light coils to a rectifier-regulator-filter unit to achieve the 12 volt, 250-watt DC energy for battery charging and accessory power. Figures 3, 4 and 5 below reveal the external components of the electrical and ignition systems (Lockwood, 2005).

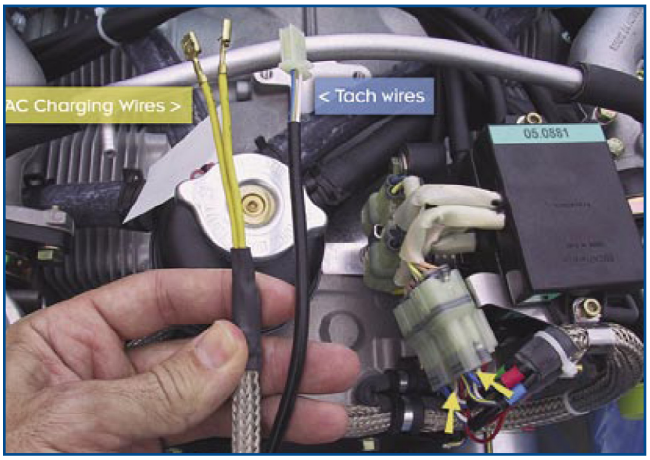


Figure 3. External Electrical Modules (Lockwood, 2005)

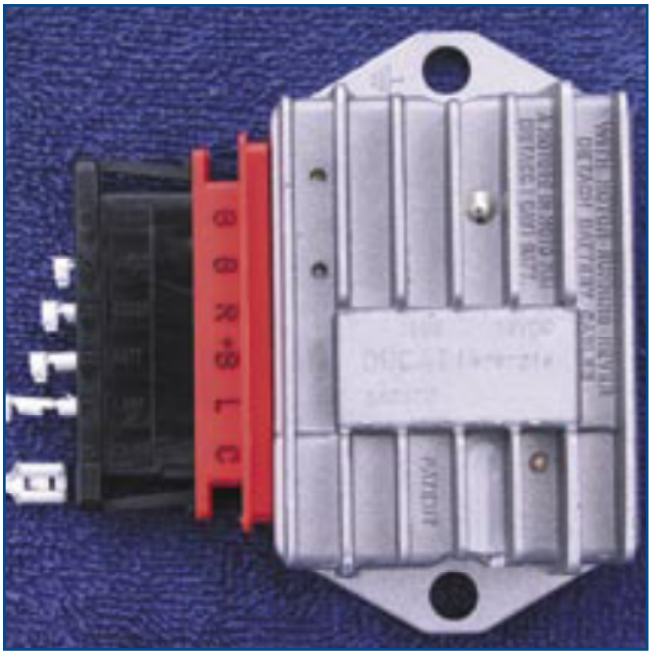


Figure 4. Rectified-Regulator-Filter Module (Lockwood, 2005)

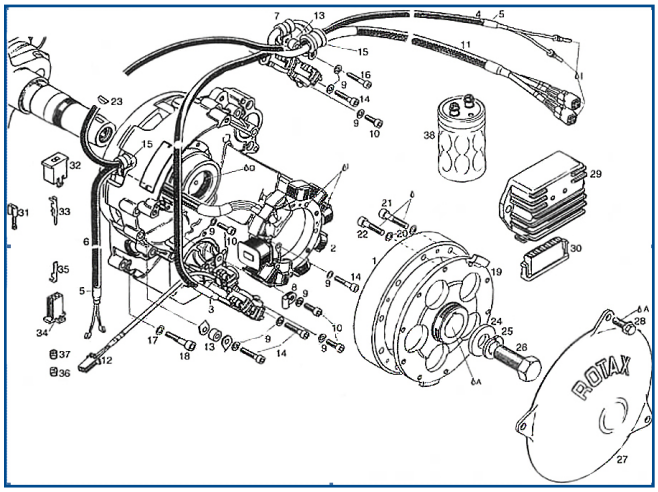


Figure 5. Rotax Magneto-Generator and Associated Parts (Rotax-Bombardier, 2009)

As is the case in a typical reciprocating aircraft engine, the Rotax uses redundant spark plugs, two per cylinder. Plug electrode gaps should be checked and set during replacement or cleaning and at inspection intervals (Beale, 2009). The spark plug heat rating is important, and the plugs should be changed with a direct replacement type typically every 100 hours or every 50 hours if 100 LL fuel is used (Rotax-Bombardier, 2009). Spark plugs for the Rotax are sold at a cost comparable to automotive plugs so frequent changes are an inexpensive portion of maintenance costs. Rotax recommends a heat conductive silicon based paste be applied to the plug threads taking care not to permit the paste to contact the bottom 3 threads or electrode area. Disabling of the ignition system subsequently shutting down the engine is accomplished by grounding appropriate pins on the 6-pin connectors to the ignition modules. Typically this is controlled through a set of toggle switches or a conventional OFF- MAGNETO 1 ON-MAGNETO 2 ON-BOTH ON-START ignition switch. If it becomes necessary to test the ignition system, removal of a plug to check for spark at the electrode while cranking over the engine is not advisable. According to the Hamilton Rotax video, the engine must rotate at about 250 RPM to produce a usable spark of sufficient magnitude to be visible. Hand cranking of the engine by turning the propeller, even with the effect of the gearbox, does not provide sufficient rotation speed to accomplish this. Further, if a plug is not adequately grounded, damage to the ignition coils may occur, as the energy generated has to be dissipated somewhere. If this energy does not have a suitable path, it can cause an overload, burning out the excitation coil necessitating an expensive repair. If ignition testing becomes necessary, use of a timing light or other appropriate testing device is recommended (Hamilton, 2007).

A number of types of propellers are suitable for the Rotax engine although usage of different types and manufacturers call for a particular RPM idle setting (Lockwood, 2005). A benefit some three blade composite prop types is a single blade can be changed out in the event of chips or damage rather than replacement of the entire propeller assembly (Warp Drive, 2010). In most cases the airframe and or propeller manufacturer defines how the process is to be performed and it should be followed precisely. Because of the Rotax' high RPM characteristic, a gearbox with a reduction rate of 2.43:1 is required to ensure the propeller tip speed is not excessive. Maintaining the engine idle RPM between 1800 and 2200 is recommended in any case although extremely light weight propellers may permit speeds as low as 1400 RPM. An idle speed lower than 1400 will damage the torsion damper system in the gearbox and would probably result in a rough idling engine in any case (Rotax-Bombardier, 1998). The gearbox shares its lubrication oil with the rest of the engine, necessitating the use of somewhat specialized oils as described above. The gearboxes in newer engine models are equipped with an overload clutch to mitigate damage in the event of a prop strike; however, should one occur appropriate inspections of the crankshaft and other engine components are necessary prior to return to service. Checking the amount of torque required to engage the overload clutch is part of the maintenance and inspection procedure (Rotax-Bombardier, 2009).

Putting it all together

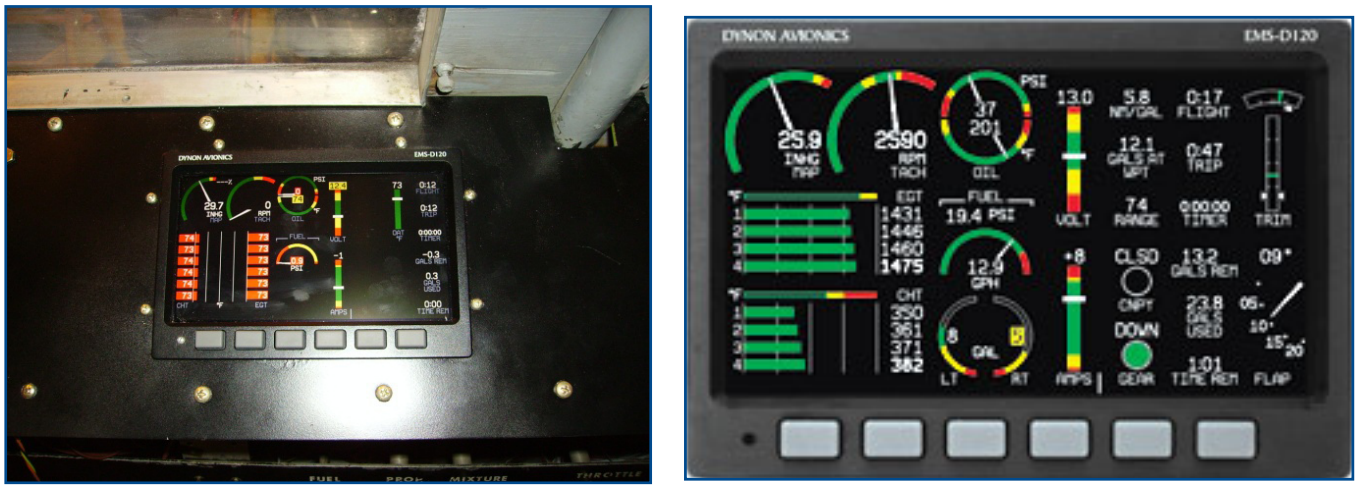
The final areas to combine and review the Rotax maintenance and inspection material together

are Powerplant Testing and Powerplant Inspection classes. It is here that students use the knowledge and experience they have gained in the 2.5 to 3 year airframe and powerplant technician program to complete their training.

A powerplant testing class can provide the students with knowledge of the correct procedures and precautions to be observed during engine installation, ground operation and fuel and oil servicing in addition to culmination of the material they have learned in previous training. Troubleshooting and interpretation of instrument readings is also taught in this class. Particularly applicable to the Rotax, the manufacturer recommends a number of installed monitoring instruments to assure the health and well being of its engines during normal operation. In addition to the typical fuel quantity, oil pressure, temperature and hour-meter gauges, two cylinder head temperature gauges and an oil temperature gauge is advised as well as fuel pressure, exhaust gas temperature, and electrical system DC voltage output indicators. Provisions are made in the new glass cockpit engine monitoring systems designed for light aircraft such as the Dynon EMS-D120 (Figures 6 & 7) in installations where electronic monitor system has replaced the older analog steam gauge type instruments (Dynon, 2008). Whichever method is used, continued familiarization with the Rotax Engine operators' and installation manuals as well as the line maintenance manual can be stressed here.

In a powerplant inspections class, students can demonstrate their knowledge of Federal Aviation Regulations relating to engines, applications of Federal Aviation Administration Airworthiness Directives, Service Bulletins and proper use of inspection equipment. Generally, Rotax engine installations fall under the FAA Special Light Sport or Experimental Light Sport rules which would include demonstration of adherence to both the engine and airframe manufacturers' guidelines, service directives and maintenance procedures as well as any directives imposed by the FAA. Figure 8 is an example of an engine inspection checklist portion developed by one of the authors for a Rotax 912 engine.

As is generally the case under light sport rules, the manufacturer is at liberty to determine maintenance tasks and who should perform them. In this case, some of the inspection items may be



Figures 6 and 7. Dynon EMS-D120 display with engine off and engine running (Harrison and Hannon, 2009)

Inspection Description	Hours			
Task	50 hr	100 hr	other	Performed by
1. Clean engine	X	X	200	owner
2. Visual engine check	X	X	200	owner
3. Engine leak check	X	X	200	owner
4. Check engine mounts	X	X	200	owner
5. Check engine external parts	X	X	200	A & P
6. Reduction gear check	X	X	200	A & P
7. Check oil level	X	X	200	Owner
8. Change oil and filter	X	X	200	A & P
10. Check cooling system	X	X	200	A & P
11. Change coolant (every two years or)			200	A & P
12. Replace coolant reservoir pressure cap			200	A & P
13. Check and regulation of carburetors	X	X	200	A & P
14. Check control cables	X	X	200	Owner
15. Change spark plugs			200	A & P
16. Check compression			200	A & P
17. Check engine electrical parts	X	X	200	A & P
18. Change rubber parts			200	A & P
19. Check overvoltage relay			200	A & P
20. Overhaul engine (15 years)			1500	A & P

Figure 8. Typical engine inspection checklist in an LSA Airplane

performed by the owner and others by a qualified airframe and powerplant technician (A&P). The inspection lists and maintenance items generally have one or more caveats advising that FAA or appropriate regulatory agency and/ or engine manufacturer's regulations and guidelines be followed with respect to individuals considered qualified to perform the maintenance and inspection tasks (Figure 9). It is recommended that a separate engine logbook be kept (Beale, 2009), and Rotax actually supplies one with its engines. The Rotax Line Maintenance manual contains a section

IMPORTANT :

As far as ROTAX 912 engine installation, inspections and maintenance are concerned, carefully follow the instructions of the engine manual supplied with the engine.

For maintenance and inspections of parts with finished materials or supplied by other manufacturers, such as: propeller, hubs, wheels, brakes, pumps, filters, pulleys, cables, pipes, bolts, rivets, extrusions, fusions, etc., follow the suggestions of the manufacturer, if supplied.

Figure 9. Manufacturer's Caveat Concerning Installations and Maintenance (Rotax-Bombardier, 2009)

on performance of inspections and an inspection checklist (Rotax-Bombardier, 2009)

Per Special Light Sport Rules, the aircraft manufacturer is the last word in aircraft maintenance and repair. It is reiterated that the FAA 337 Major Alteration form is not required in performing special light sport aircraft repairs and maintenance, however, manufactures approval along with a method of compliance is.

Summary

Addition of Rotax engine training material would be an enhancement to any A & P school curriculum. There is a wealth of information available on the Rotax web site and also through a variety of other sources. Depending on the needs and desires of the institution, a greater or lesser degree of material can be introduced. Several organizations offer the factory approved courses in the form of 2 day service and maintenance courses as well as a Rotax technical instructions course (Rotax-Owners, 2010). These courses may be of value for Part 147 Airframe & Powerplant instructors in preparing instructional materials.

In the case of institutions certificated by the Federal Aviation Administration under Part 147, integration of Rotax engine familiarization material into systems courses where engine repair and maintenance is covered where desired, may become easier as a result of suggested revisions to Part 147 by the Maintenance Technician Schools Curriculum and Operating Requirements Working Group of the Aviation Rules Advisory Committee (ATEC, 2009a, 2009b). In such cases, FAA guidance as well as curriculum committee or other approval depending on local practice should be undertaken prior to implementation of any course revisions. As these materials are taught, the end result will be better informed and educated airframe and powerplant technicians available to service a popular aircraft engine in the emerging light sport category. Future evaluation and research involving technician qualifications and performance can verify program success in providing a more comprehensive training regimen for aviation maintenance professionals.

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