THE PERFORMANCE OF WORK AS VIEWED BY TEAM LEADERS

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ABSTRACT

Accident reports often find that workers did not follow the procedures and all-too-frequently conclude that had the worker followed the procedure, the accident would not have occurred. There is a belief that following the procedures assures safety. However, in the workplace workers safely and successfully accomplish work by following procedures while judging them and adapting them according to the context of the work. This differing perspective advocates that adaptation is normal and necessary given the local context of work. This thesis explored the question: Do team leaders mainly blame not following procedures on features of the work and its environment or on the features of the worker?

The results demonstrate that team leaders understand that a variety of factors contribute to how aircraft maintenance work is accomplished. Team leaders perceive the tension between management and workers that results from the gap between procedure and practice in different ways. They employ different strategies to manage the gap depending on features of the situation. Professionalism, explained as knowledge and experience with respect to aircraft maintenance work, is extremely important for creating safety in this domain. The creation of safety in a pursuit like aircraft maintenance depends on both standardization and maintaining a certain degree of flexibility and capacity to adapt to the work context. From the team leaders' perspective, people close and bridge the gap. The findings from this study provide a starting point for future research and practical projects to focus on improving the context of work and further equipping AMEs and team leaders to manage the gap when it is present.

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INTRODUCTION

On June 10, 1990, a BAC 1-11, Flight 528 was enroute to Spain from Birmingham International Airport. The accident happened when the aircraft was climbing through 17,300 feet on departure from Birmingham. The left windscreen, which had been replaced prior to the flight, was blown out under effects of the cabin pressure when it overcame the retention of the securing bolts, 84 of which, out of a total of 90, were of smaller than specified diameter. The commander was sucked halfway out of the windscreen aperture and was restrained by cabin crew while the co-pilot flew the aircraft to a safe landing at Southampton Airport.

The Aircraft Accident Investigation Branch found the following factors contributed to the loss of the windscreen (AAIB, 1992):

1. A safety critical task, not identified as a 'Vital Point', was undertaken by one individual who also carried total responsibility for the quality achieved and the installation was not tested until the aircraft was airborne on a passenger carrying flight.
2. The Shift Maintenance Manager's potential to achieve quality in the windscreen fitting process was eroded by his inadequate care, poor trade practices, failure to adhere to company standards and use of unsuitable equipment, which were judged symptomatic of a longer term failure by him to observe the promulgated procedures.
3. The British Airways local management, Product Samples and Quality Audits had not detected the existence of inadequate standards employed by the Shift Maintenance Manager because they did not monitor directly the working practices of Shift Maintenance Managers.

In a book, published shortly after the final accident report was released, Maurino, Reason, Johnston & Lee (1995), offered a different analysis of the underlying factors that contributed to this accident. They explained "one of the paradoxical features of this accident was that many of the contributing factors were rooted in what, under other circumstances, would be regarded as valuable strengths" (Maurino, et al., 1990, p. 87). Their explanation includes a Shift Maintenance Manager, who being concientious, replaced the bolts because the old bolts looked too old, a close-knit establishment of maintenance engineers with high morale and lots of pride who routinely competed between shifts to achieve the most work, and an excellent relationship between the flight crew and the maintenance engineers that saw the maintenance engineers responding flexibly to the rapidliy changing demands on their skills.

The Gap between Procedures and Work

Work is a complex undertaking that workers manage everyday. For over a century managers and regulators have specified procedures to minimize performance variability and maximize output (Wright & McCarthy, 2003). Work is designed and planned to coordinate performance on tasks that require people to interact (Degani & Wiener, 1990). In safety-critical systems, procedures also provide a documented and approved description of work, auditable by the operator and the regulator (McDonald, 2006). However, recent research with complex, dynamic safety-critical systems (e.g. transportation systems, healthcare, process industries) has shown that strictly following procedures does not guarantee safety (e.g. Dekker, 2005; Hollnagel, 2003; Rasmussen, 1997; Snook, 2000; Wright & McCarthy, 2003). (Procedure herein is used operationally and generally to include regulations, standards, processes, and other documented work descriptions. Procedure is defined as normative work; how work is prescribed to be done).

A procedure, by design, does not completely document all the details associated with its use in an operational environment. Procedures are frequently under-specified. Procedures often under-specify human action because they are developed without worker input and without consideration of the local context of work (McDonald, Daly, Corrigan, & Cromie, 1997; Rasmussen, 1997). Formal documentation cannot always be relied on, nor is it normally available in a way that supports a close relationship to the task (McDonald et al., 1997; Rasmussen, 1997; Wright & McCarthy, 2003). In many cases, procedures are designed to be contextually independent to fulfill regulatory and certification requirements. Procedures then, have to be interpreted and applied within the context in which they are used (Suchman, 1987).

Procedures can also be over-specified. Degani & Wiener (1990), while strongly advocating that procedures must be followed, explain that management must recognize the danger of over-specification because it fails to exploit one of the most valuable assets in the system, the intelligent worker who is 'on the scene'. There cannot be a procedure for everything, and the time will come in which the workers will face a novel situation for which there is no written procedure (Vicente, 1999). Pre-specified guidance is especially inadequate in the face of novelty and uncertainty (Carley, 1999; Woods & Shattuck, 2000).

Procedures are often written for the certifying authority, the auditor, the novice and the expert; a diverse set of users. This can make procedures insufficient to all who use them (Vicente, 1999, Wright & McCarthy, 2003). Procedures, whether executed by humans or machines, have their place, but so too, does human cognition (Dekker, 2005). There are many examples of workers adapting to situations for which there were no adequate procedures (e.g. Clapham Junction rail collision in England December 12, 1988, American Airlines Flight 232 which lost all hydraulics just outside of Sioux City, Iowa in 1989, and Apollo 13 in 1970).

Hence, the literature has shown that despite the attempts to cope with human variability in complex domains by increasing standardization of work, procedures are not a guarantee of safety. Procedures neither completely specify the details of a certain task nor are they sufficient to achieve the task. Procedures can also be under or over specified. In this sense, a gap between how the work is decomposed into procedures and steps and how it is really done creates opportunities for human adaptation when reconciling multiple goals (e.g. safety, production, compliance). However, the traditional view that safety is guaranteed by following the procedure in order to reduce human variability and system complexity creates a myth about how work is done.

The Myth about How Work is Done

Given strong evidence that a gap exists between procedures and work, research also suggests a discrepancy exists between work as it is done and work as managers believe it is done (Dekker, 2005; Hollnagel, Woods, & Leveson, 2006; Snook, 2000; Vaughan, 1996; Vicente, 1999). Research has shown that management thinks work is accomplished safely and successfully by workers following the procedures (Degani & Wiener, 1990; Dekker, 2003; Rasmussen, 1997; Snook, 2000). Yet, workers safely and successfully accomplish work by judging, applying and adapting procedures according to the local context of the work (Cook & Nemeth, 2006; Daly, Corrigan & McDonald, 1997; Snook, 2000; vander Lely, 2009; Wright & McCarthy, 2003). Management believes the work is successfully accomplished by adhering to the procedures while in practice this is not always how work is performed.

Some aviation safety enthusiasts and specialists see individuals not following procedures as the result of complacency or a lack of motivation. However as explained by Dekker and Hollnagel (2004), these studies violate a scientific principle as cases are selected on the dependent variable (failed performance) which generates an unverifiable conclusion. Research conducted this way is not accepted by other applied and pure disciplines in the way that it is accepted in the study of failed human performance.

Complacency has been defined as a feeling of quiet pleasure or security, often while unaware of some potential danger, defect, or the like, however it is a construct often taken for granted and used to explain the lack of action in many cases. The proliferation of complacency as a cause factor might have resulted from the accident investigation method employed (Hollnagel, 2003; McDonald, Corrigan, & Ward, 2002.). Complacency is an individual factor listed in many accident classification taxonomies, (e.g. Wiegman & Shappell, 2003), most of which are based on sequential accident models. However, much human factors research has demonstrated that the tools, tasks and environment of the work shape human behaviour much more than the individual's internal motivation (e.g. Dekker, 2005; Hawkins, 1993; Rasmussen, 1997; Reason, 1990). Complacency is often an incomplete or unhelpful cause factor, as it does not help us mitigate the problem because it is an unspecific label.

Research has also shown that some managers and management specialists see people who do not follow procedures as choosing of their own free will to perform outside of the prescribed method (Wright & McCarthy, 2003). This explanation also does not account for the context specific aspects of the work that shape human behaviour. Managers and management specialists view the gap as routine non-conformity on the part of individual workers (Wright & McCarthy, 2003). Some traditional organizational sociologists see not following procedures as a political lever applied on management by the workers, overriding, out smarting, hierarchically controlling and compensating for higher level organizational deficiencies (Wright & McCarthy, 2003).

Traditional human factors practitioners and work designers coming from a Scientific Management background assume order and stability in operational systems. Research has shown that these specialists believe work achieved rationally and mechanistically. Control of work is implemented vertically using formal task analysis methods (Vicente, 1999, Wickens & Hollands, 2000; Wright & McCarthy, 2003) founded in simple linear systems (Heylighen, Cilliers, & Gershenson, 2007).

It seems the real world is a little more complicated than this research would suggest. In fact, how management perceives work is done seems unimportant until something tragic happens. Research has demonstrated that work is not always done the way managers believe it is done (e.g. Flight Safety Foundation, 1999; Hidden, 1989; Vicente, 1999). Sequential accident models often point to procedural deviations as having caused the accident. However, due to the accident model and investigation protocol, these accident investigations rarely delve into understanding why the procedures were not followed and they counterfactually reason that had people followed the rules, the accident would have been prevented (Hollnagel, 2003). The investigation stops at 'they didn't follow the procedures'. Investigators and organizations sacrifice learning for an efficient investigation that points to a simple countermeasure, which is, follow the procedure (Dekker, 2005).

Despite research and experience that demonstrates there exists a gap between procedure and practice resulting largely from contextual factors of work (e.g. procedure under or over specification, time constraints, scarce resources), a tendency to blame the individual characteristics of the worker for not following procedures exists. The human failed to perform the task according to the procedure therefore the human is to blame. It remains difficult for some to see that the features of the work affect the ability to comply with procedures.

New View of Work in Complex Systems: Aircraft Maintenance Domain

The distance between formal procedures and actual work is bridged with the help of experts; those who have learned how to get the job done and who are proud to share their professional experience with others (van der Lely, 2009). In situations of over-specification, workers adapt to manage conflicting goals (Daly et al., 1997). In situations of under-specification, workers adapt creatively to get the job done (Daly, et al., 1997). Recent research into the adaptive capabilities of humans at work has shown that workers adapt to the local context. Cook and Nemeth (2006) observed workers who adapted their work practices to match the resources available (e.g. individual experience levels) and to manage multiple goal conflicts (e.g. production and protection goals), to complete work successfully.

The professional culture in aircraft maintenance includes a strong sense of responsibility for the overall safety of the system, going beyond performing a technical task to a set standard (Daly et al., 1997; Maurino et al., 1995). In the aircraft maintenance domain, the demand to meet technical requirements conflicts routinely with constraints such as time, resources and the functional work environment (Daly et al., 199; McDonald, 2006). Maintenance is a cost from all perspectives including downtime, personnel, parts and tools, and facilities.

Part of the role of the aircraft maintenance engineer (AME) is to use his/her professional judgement based on experience, knowledge and skill in carrying out the work, rather than blindly following a set of procedures (McDonald, Corrigan, & Ward, 2002). Behaviour is compliant with the emerging local norms to accommodate multiple goals (maximizing capacity utilization but doing so safely, meeting technical requirements and deadlines) (Dekker, 2005). AMEs have to reconcile technical requirements with production demands. Sometimes this requires compromise, and it is up to the AME and front line supervisors to compensate for the deficiencies in the physical and organizational system in delivering what is necessary to do the job well and safely.

Those who manage the compromise well are highly valued and AMEs are often rewarded for successful outcomes (McDonald, 2006). However, the nature of the compromise is never explicit or acknowledged because the compromise is not acceptable legally or socially. Management expects that workers will be professional. In some situations, professionalism means getting the job done and in other situations, it means exactly following the procedures (McDonald, et al., 2002). Often the worker is expected to do both. Outsiders (e.g. investigators or auditors) see the vast internal collection of routines, illegal documentation (e.g. books detailing personal procedural notes that elaborate or correct procedures) and short cuts as an affront to prescribed procedures (McDonald, 2006; McDonald, et al., 2002). However, workers see these practices as a necessary compromise to reconcile daily goal conflicts (McDonald, 2006).

Frontline Supervisors and the Gap between Procedure and Work

Aircraft maintenance is a complex domain for considering the gap between procedures and work, because of the legal implications associated with not following procedures (Daly, et al., 1997). Civil aviation regulations legally require aircraft maintenance engineers (AMEs) to strictly adhere to company and manufacturer procedures in all work tasks.

Daly, et al. (1997) conducted a study that explored the use of task procedures in aircraft maintenance. Two hundred and eighty-six maintenance engineers completed questionnaires after they had completed a work task. The questionnaire sought primarily to discover the normative level of deviation from task procedures, and inquire into the reasons behind this non-conformance. Daly, et al. (1997) found 34% of respondents reported not following the official procedure for the task. The most common reasons given was that there was an easier way than the official method (45%) followed by 43% saying there was a quicker way (Daly, et al., 1997).

Daly, et al.'s (1997) research provides evidence for the gap between procedure and work, but this study did not elaborate formally on management's perspective of this gap. They did discuss the relationship of the gap to performance outcome with respect to their findings. Daly, et al. (1997) reviewed accident investigations and identified a number of cases where procedural non-conformance was a causal or contributing factor. They argue that in light of their findings, approximately one third of AMEs perform the task by another method, that the results of accident investigations are hardly surprising. They state: "Causality is then usually assumed, or the existence of non-conformance used as evidence of poor control within the organization. The association of causality would seem now to be questionable and similarly the accusation of inadequate control could also be re-examined" (Daly, et al., 1997, p.48). Their findings point to the need to better understand how performance outcome is related to the attribution of behaviour around following procedures and its implication as an accident finding.

It was outlined in Daly, et al.'s (1997) research that accident reports often find that workers did not follow the procedures and all-too-frequently conclude that had the worker followed the procedure, the accident would not have occurred. This simple explanation perpetuates the belief that the system is safe when workers follow procedures. However, many safety-critical systems today, such as aircraft maintenance, are complex, dynamic and adaptive systems where small actions and reactions in one part of the operation can produce large, and in some cases, catastrophic interactions in another in an unanticipated way. The traditional view that strict procedure following guarantees safety perpetuates the myth about how work is accomplished. This view of human error is not sufficient, and, in some cases counterproductive to enhancing safety in today's complex, dynamic systems.

To make progress, safety specialists need to understand why an individual's performance made sense at the time given the condition that existed at the time. This is the principle of local rationality: humans act in ways that make sense given the conditions and circumstances present at the time (Dekker, 2006). The new view of human error explains that human error, in this specific case not following procedures, is a symptom of trouble deeper inside the system:

- Safety is not inherent in systems.
- The systems themselves are contradictions between multiple goals that people must pursue simultaneously.
- People (have to) create safety.
- Not following procedures then is systematically connected to features of people's tools, tasks and operating environment.

The new view aims to see how people interpreted the world from their position on the inside; why it made sense for them to continue certain practices given their knowledge, focus of attention and competing goals. New view accident investigations aim to study the actions and assessments of those involved in the context that brought them forth and that accompanied them. In this sense, this thesis explored if team leaders mainly blame not following procedures on features of the work and its environment or on the features of the worker? The literature regarding not following procedures and natural, intelligent adaptation of work in practice is presented as a dichotomy between workers and management.

In many aircraft maintenance organizations, AMEs perform their own quality control. They ensure their own work is done in conformance with procedures. The team leader is the frontline supervisor whose role is to oversee and ultimately ensure the safety and serviceability of the aircraft. By signing out an aircraft when maintenance work is completed, the team leader legally states the aircraft is safe and serviceable. The team leader's role requires a substantial amount of paperwork. The team leader also has regular supervisory responsibilities such as planning, coordination of AMEs and work tasks, problem-solving, sharing expertise with AMEs, and assisting whenever necessary. Team leaders typically report to middle mangers. Middle managers, in Canada known as the Chief, Aircraft Maintenance, are typically responsible for a fleet of aircraft or a specialty like avionics or mechanical workshops. Middle managers typically report to the Person Responsible for Maintenance (Canadian terminology). This person is ultimately responsible for the conduct and safety of all aircraft maintenance operations.

It was hypothesized that team leaders form a bridge between workers and management. It was expected that team leaders reconcile the tension between having to close the gap between procedure and work and understanding that gap, by regularly evaluating the situation in front of them and actively managing the tension. Performance outcome should constantly sway the tendency to close the gap and understand the gap, resulting in a highly dynamic and context-dependent supervisory job. Despite expecting a collection of factors to affect these relationships, it is expected that the following factors will be involved:

- features of the worker;
- features of the work;
- outcome of performance;
- quality and type of procedures (e.g. good procedures, under-specified procedures, over-specified procedures, and safety net procedures); and
- goal conflicts.

The thesis is organized to facilitate the exploration of the thesis question. Chapter 2 outlines the research design and method selected. Chapters 3-6 combine the results and discussion for each part of the thesis question. Lastly chapter 7 summarizes the conclusions of the study, identifies the limitations of the study and offers areas for future work in practice and in research.

METHOD

Research Design

A qualitative research method was selected for this research. Qualitative methods allow for the study of participants in their natural settings. It consists of a set of interpretive practices that make the world visible to others. A process-tracing approach, outlined by Woods (1993), was specifically used. This approach aims to externalize cognitive processes or produce external signs that support inferences about internal workings. Woods (1993) recommends the following approach:

1. define the psychological issue being studied;
2. connect the test situation to the natural context;
3. collect data;
4. document and interpret raw data into a data format that can be analysed;
5. document and interpret refined data to construct a concept-dependent description or explanation of each main theme or phenomenon;
6. analyse these concept-dependent analyses with respect to cognitive questions of interest.

Participants

Twelve team leaders volunteered to participate in the study. The participating team leaders were licensed an average of 26 years and were team leaders for an average of 12 years.

Team leaders who participated in the study were drawn from an aircraft maintenance organization that is an air operator with an approved maintenance organization. The organization performs aircraft maintenance on 71 aircraft; 39 fixed-wing and 32 rotary-wing and operates from 16 widely dispersed facilities in Canada. The organization's flight operations consist of commuter operations, air taxi operations and aerial work. The aircraft maintenance organization supports these activites and in addition, performs aircraft maintenance on a Department of National Defence aircraft fleet.

There are many similar organizations in Canada and it is therefore felt that the results and conclusions explained here are representative of other similar organizations. It is also felt that the results and conclusions are also applicable to team leaders that work in similar settings.

Protocol for Data Collection and Analysis

Aircraft maintenance work is a complex behavioural situation. The aim of this study was to explore how team leaders view the gap between procedure and practice and how they manage any tension that results from that gap.

The protocol for the interview involved: a) the review of the information letter (Appendix A); b) completion of the consent form (Appendix B); and c) background questionnaire (Appendix C). The consent form explained the purpose of the study and how the researcher planned to manage and protect research data. The consent form also noted whom to contact for any concerns with the research project. The background questionnaire captured some basic background information such as years of experience, license endorsements on types of aircraft, and general working history (e.g. years with the organization).

The organization's incident database was searched to identify prototypical aircraft maintenance incidents that had a contributing factor associated with the procedures. Eight prototypical situations were selected (Appendix D). The incident report and the documented procedures for the selected maintenance tasks were obtained and reviewed. Interviews were conducted with Quality Assurance Inspectors and AMEs to verify and accurately describe the prototypical situations as per the procedure and how the task is normally completed in practice.

Team leaders were interviewed using two prototypical situations of their choosing to explore the research question. This was done to enable the researcher to begin the interview with a contextual look at the performance of aircraft maintenance work using descriptions familiar to the team leaders. Team leaders were then asked open-ended questions about how they reconcile the tension between having to close the gap and understand the gap and what creates safety in aircraft maintenance, given the gap they had just identified in the prototypical situations. This was done to enable the researcher to transition the interview from a focus on aircraft maintenance tasks and practices to a focus on what behaviours and supervision strategies result when these gaps exist. Interviews ended following the principles of theoretical saturation (Flick, 2006). The Interview Protocol is shown in Appendix E.

The data collected and analysed included technical and contextual descriptions of prototypical situations and interview notes from the team leader interviews. Interviews were recorded by hand and handwritten notes were transcribed into individual team leader reports. The data were organized and analysed using the interview protocol and the contextual analysis frame which was drawn from the literature review:

1. What factors contribute to AMEs not following the procedure
    a. features of the worker;
    b. features of the work;
    c. outcome of performance;
    d. characteristics of procedures (e.g. good procedures, under-specified procedures, over-specified procedures, and safety net procedures); and
    e. goal conflicts.
2. How do you, personally, reconcile the tension between having to close the gap between procedure and work (given expectations from management and regulatory requirements) and understanding that gap (due to pressure from above to get the job done and pressure from below to be efficient)?
3. What for you creates safety? Following procedures, intelligently adapting or applying knowledge and experience to work using a combination of both?

The analysis of the team leader interview transcripts guided the development of a description of how team leaders understand the phenomenon of not following procedures and an explanation for how team leaders reconcile the tension between having to close the gap between procedure and work and understanding that gap. The results and discussion are included together in subsequent chapters to make as obvious as possible the researcher's interpretation of the qualitative research results. The discussion of the results with respect to the current theories and empirical data allowed for analysis across the sub-research questions. Future areas of research and limitations of the study were identified.

PROTOTYPICAL SITUATIONS

The majority of team leaders selected tasks 1, 2, 7 and 8 to describe. The practice of each task in the field is described. The researcher collated these descriptions from the transcripts of the team leader interviews. The documented procedures for each task are listed and the details are included in the appendices. The last description is an incident investigation summary that was associated with each task. These prototypical situations highlight the gap between practice and procedure.

Task 1

Task 1 was 'Defect Resolution and Installation of an Electric Trim Servo on a King Air C90'. In practice, the majority of the team leaders outlined the following steps.

1. Reconfirm the defect by trying to duplicate on the ground.
2. Based on evidence, decide maintenance action to perform.
3. Locate the procedures in the manual and review.
4. Gain access to area.
5. Obtain the tools needed.
6. Obtain the parts needed.
7. Disconnect the flight controls.
8. Change the trim servo.
9. Reconnect the flight controls.
10. Confirm defect resolved.
11. Do travel checks.
12. Do independent inspection (with flight controls, have one AME inside and one AME outside and have them communicate action and reaction. Switch places and do it again).
13. Write down the work in the Condition and Correction sheet.
14. Sign-out the aircraft.

The documented procedures for this task include the following references. Copies are located in Appendix F:

1. MCM Procedure 30 – Work Performance Procedures
2. Pitch Trim Servo – 1C469-6-456 Parts Group IX
3. Drawing No. 69D1179

In the incident scenario, the following took place. The electric trim servo was replaced to rectify a defect that stated the trim wheel was jerky in auto flight. Three AMEs were involved in replacing the trim servo. AME1 connected the control cables and safety hardware from the elevator trim servo. AME3 removed the malfunctioning elevator trim servo and installed the replacement servo. AME1 then reconnected the control cables and safe-tied the connections. AME2 inspected that the control cables were routed correctly and the safety locking was correctly installed. AME1 then operated the trim wheel mechanically by hand from inside the aircraft and AME2 verified that the up and down movements of the trim surface were responding correctly and recorded the travel range in both directions. The mechanical trim functioned correctly and normally.

The direction check of the electric trim wheel was not completed by AME2 as he was completing an Independent Check of the mechanical portion of the trim system only.
AME3 functionally checked the trim wheel for smooth operation with one hand operating the switch and the other on the trim wheel, which was the rectification for the original defect of "trim

wheel jerky". He focused on correcting the snag and not on the electric trim system for sense of direction and travel. The electric trim system was not checked for sense of direction.

AME1 did not know or expect that the trim servo could be wired backwards when received. AME2 recalled later that the trim servo could run backwards and should have been checked on installation but was focused on fixing a specific defect; trim wheel jerky. AME3 was aware that the servo could be wired incorrectly and that it should be verified for moving in the proper direction after installation. He had received training on this particular unit 25 years previously. AME3 followed the instructions in the Century Flight Systems manual but did not see the instructions for rewiring the servo to change its direction as these instructions are only found in the wiring diagram and installation drawings.

A senior pilot completed a test flight, although not required. This is partially because vacuum pressure is used in the autopilot and aerodynamic forces in flight may affect the elevator. Prior to flight, the team leader mentioned to the pilots that these trim servos have been known to work backwards.

The travel limits were recorded on paper but not entered in the technical record as part of the independent check as per MCM Procedure 30.4. The pilots who completed the test flight also failed to detect the incorrectly responding trim wheel until airborne.

Summary of the Gap
The procedures instructed the AME to confirm the configuration of the trim servo that had arrived from the manufacturer prior to its installation because, it notes, the trim servo can arrive configured (wired) for another aircraft configuration. Without the benefit of these procedures because they were located in an obscure wiring diagram necessary to be used during the first installation only, the AMEs involved installed the trim servo without verifying the configuration of the wires. In this case, knowledge about an unusual circumstance was hidden in an obscure first time installation procedure where it would not be accessed by AMEs conducting a replacement. This example demonstrates some of the ambiguity around the documentation of aircraft maintenance procedures and the many different manuals, diagrams, instructions, notes, training materials and other sources that comprise aircraft maintenance procedures.

Task 2
Task 2 was 'Heavy Maintenance Landing Gear Functional Checks (combined with Thrust Reverser Deployment Checks and Brake Bleeding on a Cessna Citation II Aircraft)'. In practice, the team leaders who have supervised or done this task outlined the following steps.
These tasks are accomplished as part of a phase 5 (heavy maintenance) inspection. At this point in the check, the aircraft is already on jacks. The landing gear functional checks need to be done with the aircraft in a simulated air condition. The thrust reverser deployment check and the brake bleed need to be done with the aircraft in an on ground condition. Normal practice is to take one task at a time and set up the aircraft for that condition.

1. Print off maintenance manual procedures and use as a check sheet.
2. Complete landing gear functional check as per procedure in simulated air condition with squat switches secured out of the way.
3. Complete thrust reverser deployment check as per procedure in on ground condition using squat switches.
4. Complete brake bleed as per procedure using squat switches.

5. Document work completed.

Note: One team leader indicated that whenever there are many tasks going on at one time that a leader must be designated to take care and coordinate AMEs and work. Anything that is disconnected needs to be flagged visually (P8).

The documented procedures for this task including the following references. Copies are located in Appendix F:

1. MCM Procedure 30 – Work Performance Procedures
2. Model 550 Maintenance Manual (Rev 28) Task 32-01-00-710
3. Model 550 Maintenance Manual (Rev 28) Task 78-31-00-710
4. Model 550 Maintenance Manual (Rev 28) Task 32-42-09-710
5. Model 550 Maintenance Manual (Rev 28) Task 32-42-00-710

In the incident scenario, the following took place. A C550 aircraft undergoing a heavy maintenance inspection required numerous landing gear functional checks and thrust reverser deployment checks. These are normally carried out at the same time once hydraulic power is available and prior to the landing gear functional checks. The aircraft was on jacks at the time these checks were carried out. AME1 and AME2 were on the complete inspection and two others joined that day from other crews, AME3 and AME4, were brought in on overtime on a Sunday to carry out the required maintenance. No team leader was present for completion of these checks and no one was officially appointed as acting team leader. AME2 was to assist AME1 with the landing gear operational checks. AME3's task was to complete an independent inspection on the flap system while AME4's task was to complete engine work and cowl the engines. AME3 and AME4 were also to assist with other tasks as necessary.

The first task was to carry out brake bleeding procedure per the maintenance manual chapter 32-42-00 (5B) with aircraft on jacks, using the squat switch to simulate an on ground condition. The second task was to carry out landing gear functional test task 32-01-00-710. At this time it was decided by AME1 to leave both squat switches in the disconnected position, in anticipation of the third task, 78-31-00-710 Thrust Reverser Operational Check. Gear functional checks where initiated and during the gear swinging process AME3 advised AME1 that the gear squat switch was disconnected and at that point AME1 stated that he believed it was not a problem.

Following numerous gear swings the right hand gear squat switch contacted the gear actuator causing damage to the actuator and breaking the switch. The disconnecting of the squat switches for brake bleeding constitutes a non-routine maintenance procedure that was in violation of the Maintenance Control Manual Section 9.13, which states in part… "when components or aircraft systems are disconnected during a non-routine maintenance procedure (i.e. the Instructions for Continued Airworthiness do not direct that the component or aircraft system be disconnected), technical record entry shall record the condition of the aircraft and a warning tag or highly visible flag shall be attached to the component or system that was disconnected. The warning tag or flag must be visible from outside the aircraft, ensuring that if it were forgotten, it would be visible during an aircraft walk around…" The organization uses an alternate method of activating the squat switches; instead of using a floor jack, the squat switches are disconnected and physically positioned to simulate aircraft on ground condition.

Summary of the Gap
The procedures indicate the tasks are done separately in the correct condition (on ground or off ground). However, the procedures also allow an alternate way of doing the task provided all of the details are documented in the Condition and Correction Sheet. Administrative safety nets like flags and tags must always be used to clearly identify removed or disconnected parts. In headquarters during heavy maintenance checks these tasks are sometimes done concurrently. At regional aircraft maintenance bases, these tasks are normally done separately. In this particular case, the heavy maintenance inspection was behind schedule. The AMEs were working overtime on a weekend. In the interests of efficiency they sequenced the tasks together using an alternate way of doing the task but did not secure a disconnected part resulting in damage. By sequencing these tasks together the AMEs gained efficiency but introduced new, unanticipated risks.

Task 7
Task 7 was 'Defect Resolution and Reassembly Error on a Fuel Check Valve'. There were two different practices identified.

Practice #1: the team leaders outlined the following steps.

1. Diagnose the defect by trying to duplicate on the ground.
2. Trouble shoot based on most recent maintenance performed, evidence and experience.
3. If unsuccessful, trouble shoot based on procedures in the manual
4. Decide maintenance action(s) to perform.
5. Obtain the tools needed.
6. Obtain the parts needed.
7. Perform maintenance action.
8. Confirm defect resolved.
9. Do independent inspection or critical task inspection if necessary.
10. Write down the work in the Condition and Correction sheet.
11. Sign-out the aircraft.

Practice #2: some of the team leaders stated that it would be replaced, and not disassembled, inspected and reassembled. However, some of the team leaders stated that they would have disassembled and reassembled it, but in a proper workspace, with the diagram open, and the work documented.

There are no documented procedures for this task, only the illustration of the parts and parts numbers. This part is to be replaced, not repaired.

1. Illustrated Parts Catalogue 250-C20 Series 73-20-00 Fig 01

In the incident scenario, the following took place. The helicopter was loaded, fuelled and on the heli-pad for departure. As the pilot attempted to lift off from the helicopter platform, he noticed that he had a large torque split between the two engines. He reduced the power, attempted another application of power and found that the #1 engine would only produce 60% torque and 90.5% N1 thrust setting. Both engines were shut down and a visual inspection of the N2 thrust linkage on #1 engine which revealed no abnormalities. The flight was cancelled and the helicopter moved back into the hangar for further troubleshooting where it was discovered, days later, that the fuel check valve had been incorrectly assembled and was restricting the fuel flow to the fuel nozzle. The troubleshooting took longer than expected as the information regarding the fuel check valve was not recorded in the technical record, was not passed on verbally and the individual who carried out the work was away from base. Analysis concluded that fatigue was a factor.

Summary of the Gap
The organization's procedures indicate this component (the fuel check valve on an MBB BO 105 helicopter) is a component that is replaced and not repaired. There is a diagram of the component in the maintenance manual but no procedures to disassemble it and reassemble it. The team leaders had different views on whether the correct action was to disassemble and reassemble the unit or to replace the component. This example demonstrates some of the ambiguity around the different experience and knowledge brought to bear on aircraft maintenance work given the diverse backgrounds of the AMEs.

Task 8
Task 8 was 'Routine Maintenance Oil and Filter Change'. The majority of the team leaders outlined the following steps.

2. Get CAMP card.
3. Drain the oil reservoir to facilitate the inspection and cleaning of the filters.
4. Inspect and clean filters.
5. Replenish oil reservoir.
6. Sign-off the CAMP card.
7. Make entry in journey logbook.
8. Release aircraft.

The documented procedures for this task including the following references. Copies are located in Appendix F:

1. MCM Procedure 30 – Work Performance Procedures
2. Sikorsky Aircraft S-61N Maintenance Manual – Filters – Maintenance Practices

In the incident scenario, the following took place. During the pre-flight inspection, the pilot noted that the main landing gear reservoir was empty. Earlier during the day the aircraft was undergoing routine maintenance, (inspection & cleaning of the main landing gear filters). The AME who drained the oil reservoir to facilitate the inspection and cleaning of the filters, forgot to replenish the reservoir. During the completion of the task, the AME was distracted (minor disruption) and upon return to the aircraft, the AME forgot to replenish the reservoir. The aircraft was released for flight operations with an empty oil reservoir.

Summary of the Gap
The AME skipped a step by reentering the task sequence a step further than he was when he returned following an interruption. The procedure was accurate and available, however, this is a routine maintenance task that is done very often. AMEs do not consult maintenance procedures for these kinds of tasks because they know the procedure and they know the task. The gap here is that in this case the AME suffered a skipped step following a distraction. This case demonstrates the fallibility of human attention and how this well-known human limitation interacts with skill-based action sequences of routine tasks.

Features Associated with Not Following Procedures

Using the prototypical situations as a starting point for discussion, all twelve team leaders explained there are differences between practice and procedure. However, there was no overwhelming bias to the features of the worker or the features of the work. Results from the interview data analysis suggest that team leaders attribute not following procedures to a variety of factors.

Features of the Worker

A number of aspects related to the features of the worker contribute to how AMEs use procedures. "It's [interesting] to study why people don't follow the manual. Frankly I don't know why they don't. They should" (P2). (Please note P2 refers to interview data associated with participant 2. The same format applies for all twelve participants and will be used throughout the Results and Discussion chapters).

The most cited reason that AMEs do not follow procedures is that they do not need to use the documented procedure when they know the procedure. Many maintenance tasks are done repetitively and routinely and AMEs have much experience and knowledge of these tasks (e.g. "I've done it a thousand times, I don't need the manual" (P6)). They know the task, they know what to do and they know how to do it and therefore referring to the documented procedure to complete a task they have memorized is inefficient. One team leader labeled this laziness, but he qualified it by saying only success (i.e. saving time accomplishing the task to the benefit of the organization) is intended by not following the steps in the manual or not using the manual while doing the work (P1). He also explained as an AME he had a desire to look like a hero, to demonstrate how good he was at his job by not needing the manual (P1). AMEs also assume these procedures have not changed therefore they do not need to refer to the manual (P2). There is often a modified way or a more efficient way. Sometimes AMEs are thinking ahead, coordinating work in a more efficient way (P11). In these cases they are actually deviating from the procedure whether the procedure is referred to or not.

One team leader explained AMEs take things apart to trouble shoot problems or defects, they fix it, and then they put it back together. AMEs try to understand how things work. If they understand how it works they do not have to use a procedure (P1). Knowledge and experience mean they know what to do and how to do it and therefore no longer need a procedure to step them through the task. It was also explained that AMEs use photos and diagrams more than written procedures because AMEs and aircraft maintenance work tend to be more visual and spatial (P6, P7, P12). One manufacturer understands these abilities and has put much more emphasis and information on its diagrams to support this use of its procedures. Other manufacturers, especially manufacturers of older aircraft and associated manuals are much more focused on the written procedures so if an AME uses a diagram as his procedure he can miss information (P5). That said, in one of the prototypical situations, there was critical information written as a note on a supplemental diagram and not in the written procedures, which were consulted and followed (P1, P10).

One aspect that was described by many of the team leaders was the development of individual and team habits. The team leaders explained that an AME's initial training, apprenticeship, and first few years as a licensed AME shape how he uses procedures for the duration of his career. AMEs who learn from those who respect the procedures tend to practice with respect for the procedures (P2, P5, P7). AMEs who learn from those who work around procedures, take shortcuts, and work as individuals and not in a team tend to perform maintenance work without procedures (P2, P5, P7). Furthermore, AMEs who spent the start of their careers working solo, in the bush without a base, without the manuals, with no one but themselves to answer to, with one primary job - ensure that aircraft can fly – never used the manuals (therefore the procedures) and have always been successful (P5, P10). Two team leaders explained some AMEs never transition from working independently without adequate resources to working in teams with adequate resources (P5, P10).

The team leaders explained different bases use procedures differently. Some bases have a strong commitment to using manuals and following procedures whereas other bases do not. Local norms are established. This is the case at a number of bases where it is normal to use the manuals (P1, P2 P8). At some bases the use of administrative safety nets is normal and has become practice (P1, P2, P8). At other bases where the team has not adopted such practices, some individuals have learned to use the administrative safety nets because they have experienced errors. Experience has demonstrated to these individuals that using administrative safety nets will save you from errors (e.g. flagging, tagging, returning from an interruption and starting 3 steps before where you think you left off, documenting work which are all documented in MCM Procedure 30 – Work Performance Procedures) (P7).

Some team leaders explained the issue of not following procedures was directly related to attitude (P7), and disrespect for supervisors and managers (P7). Some AMEs are fed up, demoralized and just do not care anymore (P7, P8, P10). This suggests that when moral is low and relationships between AMEs and management breakdown, that one outcome can be procedural non-conformance. A number of team leaders also explained individual human performance factors such as distractions, attention, fatigue, stress, and a lack of competence can contribute to an AME not following the procedure (P1, P5, P7, P9, P12).

One interesting feature identified that was not described in the literature was that team leaders who have experienced the aftermath of accidents first hand have a greater respect for procedures and their use (P1, P5, P7). These team leaders explained that their direct experience witnessing and working in the clean-up and investigation efforts following aircraft crashes lowered their risk tolerance and increased their respect for all aspects of accident prevention, including prescriptive procedures.

Features of the Work

The criticality of the component or system being worked on contributes to AMEs following procedures or not. For example, procedures are referred to and attentively followed more for tasks relating to flight controls or infrequent, heavy and complex tasks like rotor changes, than for routine tasks like changing a tire or daily inspections (P3, P5, P6). All team leaders explained that any work done on critical components or systems like flight control rigging is done by strictly following the documented procedure.

Another factor that contributes to variability in following procedures is having proper tools and facilities (P1, P2, P6, P8). Operational settings are often different than manufacturing settings where limits and other specific details were decided and written into the maintenance manual procedures. "AMEs need to know what it takes to make this aircraft fly in its natural habitat" (P6). Location and context are important factors. The presence or absence of maintenance manual procedures, the environment whether in a hangar or in the bush away from base, the support you have (e.g. quality assurance inspectors, supervisor, avionics, structures or other specialties) all affect how the procedures are applied. AMEs need to be able to think and apply procedures. AMEs need to be able to decide if it makes sense (P8).

An improvement or change to a part that occurs without update to the manuals causes AMEs to deviate sometimes because there is no guidance on how to install this new or modified part (e.g. the procedure required the removal of a part so that another part could be installed near it. The manufacturer improved the part so that the adjacent part did not need removal but the procedure was not updated) (P5, P10).

Annoyances such as limited access to materials, equipment, manuals, technical library, parts, workshops, Internet for reference and other normal maintenance resources on off hours and on weekends can create workarounds (P11). Barriers like these slow everything and people come to say why bother. Frustration with barriers to doing the work creates distraction and stress (P11). "One of the hardest parts of our job is finding technical research" (P11). In addition, the lack of system defenses to counteract or reduce the incidence of fatigue, distractions, interruptions, and other normal human limits can also contribute to AMEs not following procedures (P1, P2, P3, P6, P8).

The age of the aircraft is a feature of the work. The aircraft used by this organization are between 20-40 years old, parts are becoming difficult to obtain, and the aircraft are very modified due to the work of the organization and the specific operational and safety requirements that support the operation. This is a common feature of aircraft operators who fly commuter, air taxi, and aerial work operations and less common of aircraft operators with scheduled airline service. The complexity of the modifications makes it very difficult to identify and access all the procedures associated with these modifications. The procedures and paperwork (e.g. manuals, service bulletins, technical bulletins, drawings) are, for the most part, managed manually by the AME on the floor who is in the position of least access to records and under time pressures (P6, P7, P8, P10, P11, P12). This can make it difficult to identify the correct procedures to follow and to access all of them in a timely manner when performing aircraft maintenance work.

Characteristics of the Procedures

All twelve team leaders explained AMEs deviate from procedures when the procedure as documented cannot be followed, is incorrect, or is located in many different documents requiring much time for finding the references. Sometimes there are no procedures. As aircraft get older, sometimes defects are very difficult to trace and resolve (P11). In some cases, procedures do not outline how to do the task, rather just what to do. "As we gain experience and knowledge we can apply [this knowledge] but we often don't share it so it can look like an individual is deviating when it is the whole system" (P12).

Maintenance manuals can be confusing and complex. Maintenance manuals contain legal language, references to other manuals and documentation, and multiple documents to consult (Maintenance Control Manual, Manufacturer Maintenance Manuals, Illustrated Parts Catalogues, service bulletins, Service Difficulty Rerports, etc). Some documents are in paper format, some documents are on the Internet, some documents are on CD, some documents are on the Intranet with passwords, some documents are on network drives (P5, P6, P8, P11). Different manufacturers write their manuals differently. Some manuals tell you every detail (e.g. Bombardier Challenger) and some state only the high-level task to do (e.g. de Havilland Twin Otter).

Manuals routinely contain mistakes, inaccurate data, and broken references (P5, P11, P3, P11). In one case, a team leader explained a situation where two AMEs worked through the procedure with the maintenance manual only to get to a place in the task where the procedure could not be performed as written. The sequencing was wrong. They consulted an out of date version of the manual, and discovered that a number of procedural steps were removed in the revision. It was obvious that the old way of doing the task would have worked with this particular aircraft but they would have been deviating from procedures. The manuals themselves, their design, location, structure, focus on text versus images, etc., contribute to following the procedures. Some manufacturers have adapted their manuals to support the AMEs preference for diagrams and one manufacturer has taken advantage of the visual and spatial abilities and tendencies of AMEs and improved the diagrams in their manuals to allow visual and spatial procedure following (P3, P8, P10, P11).

One interesting note that was raised by half of the team leaders is that AMEs sometimes add administrative safety nets such as undocumented procedures, that are good ideas but sometimes these get them into difficulty (P1, P2, P5, P6, P7, P11). A good example of this is when the Shift Maintenance Manager replaced the old bolts before Flight 528 departed Birmingham for Spain (Introduction Chapter). Another example is an AME who changed a part because it looked worn, but was not at its limits yet, closed the compartment where he replaced the part incorrectly which resulted in an in-flight engine shutdown and an emergency landing.

Goal Conflicts

In some cases it takes more time to find the procedure in the manual than to do the actual maintenance task from start to finish (e.g. filling an oil reservoir). In some cases, it takes much longer to complete the maintenance task using the procedure than with out the procedures (e.g. one team leader explained a daily inspection of a particular helicopter takes 4 hours with the procedure, 1.5 hours without the procedure, largely due to the sign-offs and the sequence of the tasks) (P6). Using manuals can consume time and result in less time to fix the aircraft. "We don't have time to know everything, just do it. Is it good enough to work?" (P2). It was also explained that AMEs are 'can do' people. "Often we have experience where the machine must fly; and we make it fly" (P10).

There is also a client focus to the work of aircraft maintenance.

> We try to keep the customer happy. Sometimes we circumvent the manual to save the time to come down, open the book, look, walk back across the floor, back up. Lots of opportunity for distraction. If we are going to delay it must be a valid delay. To the two new guys we hired 'you might have heard we do things fully by the book. There is only one way to do maintenance and that's the right way. I also know you will bring your common sense and experience to work'. It's normal to practice with common sense and experience but I can't sanction not using the manual (P6).

That said, in other parts of this organization, in some cases, it is more accepted to tell the pilots that they have to wait for an aircraft. This is not the case in all operations or situations (P1, P2).

Time pressure when it is present can lead to short cuts, but most of the time short cuts are not problematic. The shortcut is an effort to be efficient (P1). AMEs deviate from procedures when goal conflicts occur and they follow more procedures when the work tempo is more appropriate (all 12 participants). The manual protects AMEs (from themselves). It is easier to do it right once than fix it afterwards (P2). It was, however, explained that aircraft maintenance is not black and white (P11). In some cases, in private industry, AMEs were rewarded for not using the manual and for time savings that was achieved (P1).

New Factors

Aircraft design, maintenance procedures, practices and manuals differ by aircraft type. Helicopters are complex machines that have many moving and vibrating parts. Procedural details go with the complexity of the aircraft, within wing type. The team leaders explained fixed-wing manuals are more specific and better written generally than rotary-wing manuals (P1, P2, P5, P10). Rotary-wing AMEs typically spend the start of their careers working solo, in the bush, with one job; to ensure 'their' helicopter can fly. Fixed-wing AMEs typically spend the start of their careers working in a small team, their time located near bases, and working with other AMEs (P2). The team leaders explained there are some differences in the procedures themselves and the practices of AMEs with respect to procedures that are associated with aircraft type (fixed-wing or rotary-wing).

Another new factor, the transition to electronic procedures, was also identified as contributing to AMEs not following procedures. In recent years there has been a transition to the publishing of traditional maintenance manuals to electronic formats. In some cases Portable Document Format (PDF) versions of traditional manuals are made available via CD, network folder or the Internet. In some cases, maintenance manuals are being transitioned and upgraded as HTML manuals with full computer-based search-ability and usability. Electronic procedures have fewer standards about how they are organized and notes that reference other documents needed to comply with the procedures cannot be made on electronic procedures.

The transition to e-docs and electronic manuals poses a new opportunity and risk to aircraft maintenance organizations. Inactive paper copies become out of date, but continue to be used with warnings to support the use of electronic manuals. User IDs and passwords are difficult to manage. Training (in navigation, computer use, typing, etc.) has not been widely provided. Access to computer terminals can be limited or located far away from the aircraft and practice of maintenance. User friendliness and standards of design of electronic aircraft maintenance documents seems non-existent. These barriers contribute to electronic manuals not being used and procedures not being followed. This change is a significant change in how manuals and procedures will be used and could contribute to how procedures are used.

Discussion

The prototypical situations provided a contextual starting point for a discussion with frontline supervisors concerning the issue of not following procedures and the gap between procedure and practice. All twelve team leaders explained there is a gap between practice and procedure. The results indicate that team leaders do not blame 'not following procedures' on any one thing. In fact, blame, they explained, is associated with actions that intend to cause harm. AMEs do not intend to cause harm when they deviate from procedures. Team leaders see blindly following the procedures, when it does not make sense to follow the procedure (e.g. when the procedure is wrong, the data is accurate), as more problematic than deviating in such cases because blindly following a procedure that does not make sense or does not fit the specific context present is inefficient, ineffective and can be unsafe. AMEs intend positive results when they deviate from procedures. A more appropriate word to use, in place of blame, given the sentiment of the team leaders is attribute. To what do team leaders attribute not following procedures?

Evidence was found for four factors cited in the literature: features of the worker, features of the work, characteristics of procedures and goal conflicts. The one exception was outcome of performance; outcome was not a factor associated with the attribution of following or not following procedures in this study. The data suggest team leaders associate more with AMEs than with management and their involvement in maintenance work makes them more aware of the complexity of performing aircraft maintenance in the current system.

From the perspective of the team leaders interviewed in the study, AMEs and the team leaders view deviating from selected procedures (where it makes sense given the features of the work and the characteristics of the procedure) and not referencing the documented procedure in repetitive and routine situations while they work, as a normal part of aircraft maintenance work. These findings are consistent with McDonald (2006), McDonald, et al. (2002) and Daly, et al. (1997). There are a few examples cited by the team leaders where AMEs tried to follow the procedure as documented and could not complete the task because the procedure was wrong or the data was inaccurate. This provides some evidence to support the claim that proceduralization does not necessarily guarantee safety in complex, dynamic systems (e.g. Dekker, 2005; Hollnagel, 2003; Rasmussen, 1997; Snook, 2000; Wright & McCarthy, 2003). However, the examination of the incident database did not identify any cases where an AME followed a procedure explicitly and was involved in an occurrence. It is likely, given the types of prototypical situations presented, that AMEs deviate from an unworkable procedure before completing the unworkable procedure making the dataset almost impossible to generate. This provides more evidence for the phenomenon of intelligent adaptation discussed in Cook and Nemeth (2006), Dekker (2005), and McDonald (2006).

It would seem that team leaders form an organizational bridge between workers and management. However, in practice team leaders are much closer in work and perspective to the workers. Team leaders are members of the frontline maintenance team and as such view themselves as part of that team. The literature about not following procedures and natural, intelligent adaptation of work in practice is presented as a dichotomy between workers and management. Given that the team leaders identify themselves closer to the workers than with management, they share a similar perspective with the workers concerning not following procedures. It also seems that team leaders are acutely familiar and aware of the complexity of performing aircraft maintenance in the current system and therefore they cannot attribute not following procedures solely to the features of the worker.

Aircraft maintenance is complex, dynamic work. To perform aircraft maintenance work safely within the constraints of time, resources and the functional work environment it takes many different methods of managing risk. One chief (next higher management level to the team leaders) in a discussion external to the formal interviews with team leaders, expressed significant respect for the use of aircraft maintenance procedures as a defence against making errors and ultimately signing out an unsafe aircraft. At the same time he explained that in some situations the procedures do not fit the task to be done. The context of aircraft maintenance must always be discussed when discussing the factors that contribute or detract from creating safety in this environment. Researchers sometimes take an extreme view to make a point or to push research to question underlying assumptions. Practitioners work in the real environment with all the goal conflicts and varying quality and quantity of resources. Research on the hangar floor must respect and aim to understand the complexity in the real world, even as it tries to make improvements.

BRIDGING THE GAP

Analysis of the prototypical situations and the team leaders' responses to the prototypical situations demonstrates that team leaders understand that a variety of factors contribute to how aircraft maintenance work is accomplished. The team leaders work with the AMEs directly and as a team. The team leaders form a part of the maintenance team therefore they are present when the maintenance work is done. They see first hand when a procedure cannot be or is not followed. They are knowledgeable of the gap between procedure and practice, where it exists.

The team leaders perceive the tension between management and workers that results from the gap between procedure and practice. On one aspect they were consistent in how they manage this tension; team leaders work to close the gap by working with manufacturers when the problem is with the manufacture's procedure. This is an industry-wide issue (Goglia, 2010). Interactions with manufacturers to amend or correct procedures are a time consuming and necessary task of the team leader's role. A tension arises here for a number of reasons. First in this and many other aircraft maintenance organizations, an older fleet of aircraft is maintained. In cases like this it is normal that the manufacturer no longer supports the aircraft in terms of parts and procedures. For example, the King Air C90A fleet use a GPS unit that is no longer supported by the manufacturer (procedures and parts). The simple solution is to replace the units with modern versions. However, avionics upgrades require substantial work to obtain funding and approvals, procure parts and equipment, remove and reconfigure panels and the electronics behind the panels and testing before the aircraft is ready to fly again. With a fleet of 14 aircraft this is a massive undertaking as work like this must also be sequenced with heavy maintenance overhauls to have the least operational impact.

Three different situations emerged from the interviews with team leaders concerning the tension between management and team leaders that results from the gap between procedure and practice. Relationships cannot be proven with an exploratory study of this design. However it is important to explain the strategies employed in identified situations that team leaders use to bridge the gap between procedure and practice and how they perceive management behaves in these situations.

In situation 1, operational tempo was moderate and few goal conflicts existed. Team leaders used a variety of strategies to bridge the gap between procedure and practice and tension between management and workers was described as low. In situation 2, operational tempo was higher and more goal conflicts existed. AMEs worked within a larger gap and tension between management and the workers and team leaders was described as moderate. In situation 3, operational tempo was moderate and few goal conflicts existed except where paperwork was concerned. Team leaders used a variety of strategies to bridge the gap between procedure and practice and tension between management and workers was described as low, with the exception of paperwork.

Situation 1

The team leaders described situation 1 as having a moderate operational tempo, few goal conflicts and low tension between management and workers. In this situation, team leaders used a variety of strategies to bridge the gap between procedure and practice, when such gaps existed. The study design cannot identify if it is the situation that drives the actions of the team leaders, or if the team leaders' actions create the conditions of the situation, but it is important to describe their activities in these situations.

Team leaders in situation 1 use planning, communication and coordination to manage management expectations and to create a moderate work tempo that allows for sufficient time to work. (P1, P2, P4, P5). Planning includes strategic scheduling of audits, inspections and overhauls and local planning and coordination of work tasks on a monthly, weekly, and sometimes daily basis through computer and paper-based planning and regular meetings with AMEs and management. In these cases it was explained that staffing levels are appropriate for the work that exists.

Team leaders in situation 1 apply supervisory skills. Through reinforcement and clear expectations to AMEs, these team leaders have procedures followed, yet still recognizing the complexity of aircraft maintenance and the presence of a gap in some cases (P1, P2, P8). When there are lots of AMEs working together, the team leaders explained the most important thing to do is coordinate through the use of procedures. When procedures cannot be followed it is critically important to coordinate through communication of deviations using a documented format to provide a record that can flow between shift changes (P8). Team leaders also get to know their staff; their technical strengths and weaknesses, their personal situations, their personality, their ability to work with others, and they use this knowledge of the situation to coordinate work appropriately (P4, P5, P8). Team leaders in this situation also try to lead by example and provide teaching and mentoring where necessary (P2, P7). In some cases, a team leader will increase oversight depending on the size and scope of the maintenance task and the criticality of the system (P4, P8).

Team leaders in this situation are very active about addressing the situation when the documented procedures are problematic. The team leaders work with the manufacturer to have the procedures updated. This can be problematic when the manufacturer no longer supports the maintenance manuals because the aircraft type is an older generation (P2). These team leaders have knowledge of the organization, and the roles and responsibilities of different experts within the organization. Enlisting the help of experts (e.g. quality assurance inspectors, technical librarians) facilitates the solving of procedural problems (or potential gaps) quickly and efficiently (P2). Tam leaders also explained that they augment the documented procedures with notes specific to the aircraft (P5). Often they take photos, measurements, and make notes to exactly put the aircraft back together the way it was pulled apart (P2, P3).

Team leaders in this situation also use administrative safety nets in their normal work and ensure AMEs are using the administrative safety nets too. The use of safety nets (flagging, tagging, making entries in the Condition and Correction Sheet which documents work done and any deviations made, quality assurance, parts shelves organized, tools controlled and organized, when interrupted start back three steps) allows AMEs to bridge the gap, when there is a gap between the documented procedure and what needs to be done (P2).

When there is insufficient time or when the procedures are inaccurate, problematic, or ineffective, it is the team leaders' perception that management understands the gap rather than puts pressure on the team leader to close the gap. "I understand the gap, my manager understands the gap, his manager understands the gap. We do our best. AMEs are not deliberately not following procedures" (P1). In situation 1, through a combination of situational factors and strategies used by team leaders in these situations the gap between procedure and practice, where it exists, seems to be managed.

Situation 2

The team leaders described situation 2 as having a higher operational tempo, more goal conflicts and more tension between management and workers. In this situation, AMEs worked within a larger procedure-practice gap.

Team leaders in situation 2 explained that they recognize the tension, however it does not bother them. It exists and it is normal, "The disconnect on procedures doesn't bother me; it's a part of the business" (P6). In these situations, the tension is mostly in the form of deadlines, timelines and ways to share information. The team leaders explained that in these situations, management arranges deadlines without much input from the working level. "In every single thing they do they foster that attitude, for example, team leaders being involved very late in overhaul planning process" (P7). In these situations, team leaders feel management sets the schedule then plans how to meet the schedule. One team leader explained: "they [management] don't treat maintenance as an equal partner" (P12). It is situational, as the client sets the operational tempo.

Team leaders in these situations feel the pressure from above, however, they explained they are resistant to it and supervise and manage their AMEs accordingly. Some strategies these team leaders use to assure themselves that maintenance work is done well include applying direct oversight to specific maintenance work depending on the criticality of the work task and knowing and working directly with their individual AMEs (P6, P12). "I usually review the procedures to a big task before I assign it to an AME. I also consider and ensure communication about how one task on the aircraft will affect another in terms of safety and unintended damage" (P12).

Situation 3

The team leaders described situation 3, similar to situation 1 (e.g. moderate operational tempo, few goal conflicts and low tension between management and workers) with one key exception. Where paperwork is concerned, a substantial goal conflict exists that creates some tension with management, but the most tension is created with the quality assurance department and the regulatory authority.

In this situation, the team leaders explained the tension (given pressure from above to comply with procedures) and the pressure from below (to understand the daily working context) centers on documenting maintenance work. The tension is strongest between the regulatory authority (as enforced by the quality assurance division) and the team leaders. "Too much of my time is spent doing paperwork at the expense of supervising" (P5). This team leader explained that there is a transition happening within the regulatory authority. The regulatory inspectors are transitioning from technical inspectors who had much domain knowledge to general inspectors who have only enough knowledge to look for exact maintenance work documentation. "It takes a lot of time to reference exactly the way the general inspectors need it written" (P5). This team leader explained, "these general inspectors are driving strict, unintelligent procedure following because they don't have the knowledge and experience to understand the complexity of the system" (P5). These team leaders regularly deliver well-maintained aircraft, however, they do not agree paperwork is associated with safety therefore they feel little tension. They do not always heed the documentation and paperwork requirements.

Discussion

It was hypothesized that team leaders reconcile the tension between having to close the gap between procedure and work (due to pressure from management for procedures to be followed) and understanding that gap (due to pressure from AMEs to adapt to the situation) by evaluating the situation and actively managing the tension. The results explain that team leaders understand the gap between procedure and practice. The results also explain that in some situations, team leaders manage tension between workers and management, created from this gap, by bridging the gap using a variety of strategies. In some situations, they ignore the tension and this can widen the gap between procedure and practice for the AME and create tension between the workers and management.

It is possible that in the first situation described, there are adequate resources and few goal conflicts and these conditions provide adequate time to bridge the gap between procedure and practice and to manage any tension between management and workers. In situation 2, the higher operational tempo and greater goal conflicts reduce the time and resources available. The lack of resources may contribute to a breakdown in communications between management and workers, which contributes to the tension between them. This is consistent with the theoretical descriptions outlined by Dekker (2005) and McDonald (2006) and the empirical findings outlined by Daly, et al., (1997). AMEs achieve organizational goals in an environment of scarce resources and organizational goal conflicts. In doing so, they sometimes adapt their work practices to be efficient and safe. Sometimes this reduces the expected effectiveness of standardization thought to be brought about by strictly following procedures. The fact remains; AMEs cannot always strictly follow the procedures.

In situations where the operational tempo is moderate and goal conflicts are low, team leaders manage the tension between management and workers concerning the gap with supervisory skills and practices. It is unknown yet if it is through their supervisory practices that they achieve a moderate operational tempo and reduce goal conflicts or if the situation itself drives how they manage the gap. In situations where the operational tempo is high and more goal conflicts are present, team leaders explained they ignore the tension, creating a larger gap for the AME to "maximize capacity utilization but doing so safely, meeting technical requirements, but also deadlines" (Dekker, 2005).

AMEs are often promoted from within an organization into management levels. One of the reasons why the gap is understood and accepted is because, the team leaders and empirical evidence explains (e.g. Daly, et al., 1997), it is a normal aspect of aircraft maintenance. All AMEs have lived with the gap between procedure and practice in an environment of scare resources and goal conflicts. The failure of Alaska 261's elevator jackscrew and the crash that ensued is a key example of how normal practices that drift away from prescribed procedures slowly can affect the ability to recognize that there is something wrong with the way things are normally done (Dekker, 2005).

It was also hypothesized that performance outcome should sway the tendency to close the gap and understand the gap, resulting in a dynamic and context dependent supervisory job. As was explained earlier, performance outcome was not something the team leaders discussed in the interviews and therefore performance outcome seems not to affect team leaders. As was explained earlier this could be due to how close the team leaders are to the work and the AMEs. Another possible explanation is that the design of the study did not adequately study the contribution of performance outcome. This will be discussed more in the section of the limitations of the study.

Lastly it was expected that the same factors that contributed to AMEs not following procedures (features of the worker, features of the work, quality of procedures, and goal conflicts), were involved in how team leaders reconciled the tension. The results suggest that the same factors are involved. For example in situation 1, team leaders bridge some of the factors, namely the features of the work and goal conflicts. Whereas in situation 2 and 3, team leaders are affected by the features of the work and goal conflicts which contribute to a widening of the gap between procedure and practice and tension between workers and management.

The Creation of Safety in Aircraft Maintenance

Having led the team leaders from context specific to increasingly conceptual questions, the question "What creates safety?" was asked. The question was elaborated to focus their answers: "Is it strict procedure following or intelligent adaptation or some combination?" It is worth repeating here that AMEs do not intend to cause harm when they deviate from procedures. AMEs intend positive results when they deviate from procedures. The responses of all twelve team leaders to the question "What creates safety?" focused on a combination of procedure following and intelligent adaptation. Most explained that the system helps but that it really comes down to "the professionalism" of the AME (P5). Procedures create a prescribed path to perform a task and inside this path, what achieves the work is human cognition and action.

The team leaders were very consistent in their explanation that the individual creates safety in aircraft maintenance work through their professional conduct of work. The team leaders described professionalism as knowledge and experience around applying the procedure when appropriate, and how to manage when a procedure is incorrect, inaccurate, dispersed in multiple documents, is missing data or attachments or there is insufficient time to get the task completed by the book. Furthermore, the professionalism of all involved including senior managers, managers, supervisors, AMEs and clients contribute to the creation of safety (P1, P4, P12). "In a modern aircraft maintenance organization you need to apply your experience and knowledge to decide, document, communicate locally and with the system about aircraft maintenance work, and especially deviations" (P10). Experience is necessary. One team leader explained given the system "that we've made so complicated and complex, people make things safe in spite of the system" (P12).

Every team leader cited communication and coordination as critical to creating safety in aircraft maintenance. Communication and coordination create safety in that these activities involve team leaders setting and communicating expectations, work standards, consequences for not meeting standard, coordinating work between AMEs around and in the aircraft, working together as a team, and doing what is supposed to be done (P7, P9). Aircraft maintenance engineers as a group tend to work very independently and therefore communication and coordination skills and practices are very important (P10, P12). In addition, depending on the task, AMEs will work independently on a task or together as a small team, but as a group they are all working to make the aircraft airworthy and this takes a lot of communication and coordination to accomplish the work and to do so safely.

The team leaders were consistent in their explanation of the features of the work that help AMEs work safely. Administrative safety nets like the Condition and Correction Sheet helps bridge any gaps between procedure and practice by providing a place to document what else other than what the procedure says to do, why, how and by whom. The team leaders resourcefully use other groups, for example the quality assurance division or the technical library, to locate information, references, accurate data, communicate with manufacturers and the regulator. They also expressed that the quality of the facilities (e.g. the hangar, their tools, any safety equipment) contribute. Training was also mentioned. Lastly planning and scheduling were cited as activities that contribute to safe work. This last point is important because as was discussed earlier, planning is an activity team leaders use to create enough time for the work to be accomplished.

Discussion

The literature explains from the worker's perspective, that the AME's role is to apply judgment founded on his/her knowledge, experience and skill, to get the job done (McDonald, 2006). The behaviour of AMEs is consistent with the emerging local practices that enable the management of goal conflicts. These achievements are important to the organization and AMEs are rewarded for successful outcomes (McDonald, 2006). Workers adapt to the local context of the situation including the resources available and successfully complete work most of the time (Cook & Nemeth, 2006).

In a recent study by van der Lely (2009) that explored the gap between procedure and practice in commercial flight operations, it was concluded that aircrews are subconsciously forced to bridge the gap between procedure and practice because the procedures do not synchronize with the dynamic reality of the environment. It was also concluded that in the wake of procedural under-specification, requisite imagination, sensitivity to dynamic variety and having experiences with both good and bad occurrences creates a foresight, which aircrews use to make their risk assessments in order to create safety. The resilience of flight crews expressed itself through the need for them to extemporize, even invent procedures to accomplish multiple active goals simultaneously and to manage the negative side effects of procedures. The study concluded by explaining that the industry is leaving this work to the aircrews themselves by not training them in these skills and allowing these situations to exist without sufficient respect or understanding by management. Eventually this process will ultimately break at a point where the sharp end is unable to cope with the diverse constraints and pressure exercised upon them (van der Lely, 2009).

The findings of the present study are consistent with the findings of van der Lely's (2009) research, yet from a frontline supervisor's perspective. The team leaders explained that planning, communication, and coordination, skills, experience, and knowledge all contribute to AMEs performing aircraft maintenance work safely. Standardization is important, but so too is human cognition and action to manage the normal work context. Van der Lely's (2009) research recommends the industry rethink its approach to equipping aircrews with training only to follow procedures and consider equipping aircrews with skills and knowledge about coping with diverse constraints and pressure. Aircraft maintenance is a different domain with a different work context and given the findings are similar between these two studies, it is important to consider the strategies that can be used to further improve the safety of aircraft maintenance work.

The interview data explain that aircraft maintenance work is a complex undertaking and work practices do not always follow prescribed procedures. From the team leaders' perspective many factors are involved in the creation of safety, but it is largely the AME who balances production and safety goals given the system in which he/she works. Team leaders understand the gap and the situational and individual factors that contribute to the gap. When operational tempo is moderate and goal conflicts are few, the system appears to work better. This points to a multifaceted approach to improving aircraft maintenance work that involves making improvements with respect to the four key factors studied: a) the features of the worker, b) the features of the work, c) the quality of procedures, and d) goal conflicts.

CONCLUSION

There exists a gap between procedures and practice in some situations in aircraft maintenance work. Procedures are one aspect of safe work in an aircraft maintenance organization as they contribute to standardization, coordination, communication and consistency. However, the work context (e.g. goal conflicts) and design of the system (e.g. features of the work) create situations where the human must use the procedure as a resource for action. Effective organizational communication and coordination is necessary for the system to function well and safely. In addition, the skills, knowledge, abilities and experience of AMEs and team leaders contribute to bridging the gap between procedure and practice.

Analysis of the prototypical situations and the team leaders' responses to the prototypical situations demonstrates that team leaders understand that a variety of factors contribute to how aircraft maintenance work is accomplished. The team leaders relate and work with the AMEs directly as a team. The team leaders are knowledgeable of the gap between procedure and practice, when it exists. The results demonstrate that the team leaders understand how work is done.

The results demonstrate that the myth about how work is accomplished has much to do with the situation in which the work takes place. The team leaders perceive the tension between management and workers that results from the gap between procedure and practice in different ways and they employ different strategies to manage the gap depending on the situational factors present.

Team leaders believe professionalism, explained as knowledge and experience around applying the procedure when appropriate (most of the time), and how to manage when a procedure cannot be used to accomplish the work given the constraints (some of the time), creates safety in aircraft maintenance. The creation of safety in a pursuit like aircraft maintenance depends on both standardization and maintaining a certain degree of flexibility and capacity to adapt to the work context. From the team leaders' perspective, people close and bridge the gap. The findings from this study provide a starting point for future research and practical projects to focus on improving the context of work and further equipping AMEs and team leaders to manage the gap when it is present.

Practical Steps to Create Safety in Aircraft Maintenance

Planning, Communication and Coordinating
In some situations, team leaders use planning, communication and coordination to ensure sufficient resources (time, people and aircraft parts) are available to support the work being done safely, to keep everyone involved (senior managers, middle managers, other team leaders, AMEs and clients) apprised of the status of aircraft maintenance work, and to coordinate the work and the workers. Long term (e.g. maintenance scheduling) and short term (e.g. Monday morning meetings with team) planning ensures sufficient resources are available for the job. Regular and timely communication with all stakeholders allows for the management of expectations and thereby reduces goal conflicts. Communication also reduces the goal conflicts. Coordination is another piece that supports the complex work that is aircraft maintenance. Team leaders coordinate work tasks with knowledge of the constraints and demands of the clients, the knowledge, experience, and wellness of AMEs, and knowledge and experience of the aircraft and the work.

From a safety management perspective, it is important that the entire management structure be involved in the planning, communication and coordination of aircraft maintenance work and that all managers recognize how their efforts with respect to planning, communication and coordination contributes to reducing goal conflicts. Working collaboratively through management layers bridges the management worker gap by ensuring goal conflicts are resolved early or prevented entirely.

Incident Investigation

One area where progress can be made is in the investigation of aircraft maintenance incidents. Work group norms (contributing factor Maintenance Error Decision Aid (MEDA) form) and issues associated with the use of aircraft maintenance information (contributing factor MEDA form) should be investigated in detail to understand and document the context around such actions. This research has demonstrated the contextual basis associated with why AMEs deviate from procedures and it is important for making progress to understand and document this context following incidents so that corrective actions can address the organizational factors that contributed.

Improving Procedures

Anarea for improvement concerning procedures is to improve the accountability of manufacturers for correcting procedures when problems and inaccuracies are identified. Currently there is little regulation or protocol concerning how manufacturers correct and update procedures, how often they do this and how long they have to correct identified problems (Goglia, 2010).

Limitations of the Research

Qualitative research methods are often used to study a topic in detail to understand a phenomenon or situation. It is possible that these findings are not transferable to other aircraft maintenance organizations. However, valid qualitative research methods were applied and the results are consistent with other similar research conducted in other organizations providing some assurance that the findings can be generalized to other organizations.

Another limitation of the research design is that it focused solely on team leaders. Research into the perceptions and views of the AMEs, middle managers and senior managers was beyond the scope of this research project and therefore, only the team leaders' perspective is elaborated. The gaps could be better explained and identified with a research project that is sufficient in size and scope to explore the perspective and views of all aircraft maintenance participants, including clients.

Lastly, qualitative research is predominantly exploratory or explanatory in design. Relationships cannot be proven with a research design of this nature. These exploratory findings identify areas for additional research to ascertain the direction of the relationship concerning the factors involved and actions of the team leaders in managing the different prototypical situations discussed in the chapter on Tension between Management and AMEs given the Gap. Despite this limitation, it is important to understand and describe the situational and individual factors that contribute and the actions and assessments of team leaders.

Areas for Further Research

Effects of the Gap

McDonald (2006) and Dekker (2005) describe a double bind situation in which AMEs can find him or herself. They explain when time and resources are limited, managers seem most concerned with success or failure of the job rather than how the outcome was achieved (Dekker, 2005; McDonald, 2006). Managers take for granted that the workers performed in accordance with the procedures. There is often shock and disapproval when an investigation identifies practices that deviated from the prescribed procedures. Management does not admit openly and may not realize that many times before, the same way of working resulted in the successful outcome they needed and rewarded.

McDonald (2006) and Dekker (2005) go on to explain to achieve a successful outcome in the local context, workers often must adapt. If they do not adapt and cannot get the job done, management often views them as difficult, disruptive, or incompetent. With repeated episodes, an employee who does not fit in the organization may be let go from the organization. When the outcome is successful, workers feel proud of their accomplishment and management rewards them for achieving the goal. When the process fails, an investigation into the occurrence often finds that workers did not adhere to the procedures. The recommended corrective action is for the worker to follow the procedures. Workers experience a double bind; they can follow the procedures, or get the job done. This leaves workers in an impossible situation.

Only one team leader in the present study described the situation of being placed in a double bind. It is unknown why only one team leader has experienced this situation, however the researcher supplies two explanations. It is possible that this situation is rare and that it only happens to individuals who demonstrate exceptional skill and knowledge of aircraft maintenance such that they can accomplish the task management desires and that being able to meet the demands of management is valued by the AME. Alternatively, it is possible that the research design was not sensitive enough to elicit this information from the other team leaders.

As this is an important effect of the myth about how work is done and the tension between management and workers given the gap between procedure and practice, the researcher recommends work continue to explore this area.

Electronic Procedures

Electronic procedures pose a new opportunity and risk for aircraft maintenance organizations. Many larger aircraft maintenance organizations have made the transition already, however they have the size and financial resources to provide the electronic and computer infrastructure, including the transition of paper-based internal procedures to electronic means. These large organizations also benefit from the fact that they are working on modern aircraft whose manuals are mostly published electronically. Smaller organizations do not necessarily have such resources and often these smaller organizations are working with aircraft that are much older. In the subject organization the aircraft are decades old and the diversity of manuals is vast. There are many advantages of electronic procedures, however new skills with respect to navigation and searching in electronic documents, and new infrastructure with respect to the presence and accessibility of computers and printers are important considerations to support this transition.

Much has been learned about the design and display of technical documentation in electronic format (e.g. Woods & Dekker, 2001). The researcher recommends any organization transitioning to a new technology consider the human factors aspects of such a transition and that the organization works to manage the transition taking into account human abilities and limits and the knowledge that exists about managing this kind of transition well.

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APPENDICES

Appendix A: Information Letter for Participants

The Team Leader View of the Performance of Work

Dear <insert name here>,

My name is <name of researcher> and I work in Safety Services.
I am a Human Factors Specialist, which means I specialize in understanding and improving human performance in complex systems, like aviation.
You recently met me during the classroom portion of our Introductory SMS training.

In light of our Maintenance Error Decision Aid findings and a general interest in the topic, I began reading about the issues around the use of procedures in aviation, and specifically in aircraft maintenance. I've read that:
Management believes procedures are always followed;
Yet I've also read (and through our own data observed) that workers often do their best to follow the procedures but they can't always do so and in some cases they adapt or use alterative practices.
In some cases the investigation report points to the AME not following procedures as the root cause, however, there is no further analysis about why the procedures were not followed.

In 1997, Daly, Corrigan and McDonald (researchers in Ireland who were studying aircraft maintenance organizations (AMOs) in Europe) conducted a study that explored the use of task procedures in aircraft maintenance.
286 AMEs completed questionnaires after they had completed a work task.
34% of respondents reported not following the official procedure for the task.
The most common reason given was that there was an easier way than the official method (45%) followed by 43% saying there was a quicker way.

Daly, et al.'s (1997) research provides evidence of a gap between procedure and work, however this study did not elaborate on management's perspective of the gap.
I am specifically interested in learning is how team leaders see this gap.
Do team leaders mainly blame *not following procedures* on features of the work and its environment or on the features of the worker?
Is this view dependent on the situation, the task, the procedure, etc.?

Who supports the research?
Approval for this research study was obtained from Senior Management and Regional Managers.
Interviews will be conducted during regular working hours and are considered regular work.

The interview data are collected within the scope of our safety management system, including within the scope of our safety policy and non-punitive reporting policy.
This research project is undertaken with the goals to manage risk, learn and continually improve.
The guiding principles for this research project are included in Section 3 Safety Oversight, 3.2 Proactive Hazard Identification, 3.2.3 Safety Study.

Appendix B: Informed Consent Form

Informed Consent Form

Date: <enter here>

Study Name: The Team Leader View of the Performance of Work

Researchers: Heather Parker (MASc) and Eder Henriqson (PhD Candidate)

Sponsors: xxxx

Purpose of the Research: The purpose of this research project is to develop a description of how team leaders understand the phenomenon of not following procedures and explain how team leaders reconcile the tension between having to close the gap between procedure and work and understanding that gap.

What You Will Be Asked to Do in the Research: I am seeking your voluntary participation in a 60-90 minute interview where I will ask you for your insight concerning AMEs and their use of procedures. To study this topic I have selected 4 prototypical maintenance tasks (FW or RW) for which normal practices exist and for which we have had incidents.

1. First I will ask you to sign a consent form indicating your voluntary participation in this study.
2. Second, I will ask you to complete a short background questionnaire.
3. Third we will discuss the prototypical situations and the factors that you believe were involved in how the task was practiced.
4. Forth I will ask you some questions regarding how you supervise in this context.

Risks and Discomforts: We do not foresee any risks or discomfort from your participation in the research.

Benefits of the Research and Benefits to You: Individually, you will benefit from participating in this research project by contributing your experience and knowledge to this important topic. Collectively as an organization, we will benefit from applying what we learn through this research project to improving the selection of corrective action following incidents, the development of procedures and their use in our organization.

Voluntary Participation: Your participation in the study is completely voluntary and you may choose to stop participating at any time. Your decision not to volunteer will not influence the nature of the ongoing relationship you may have with the researcher or supporters of the research either now, or in the future.

Withdrawal from the Study: You can stop participating in the study at any time, for any reason, if you so decide. Your decision to stop participating, or to refuse to answer particular questions, will not affect your relationship with the researcher or any other group associated with this project.

Confidentiality: All information you supply during the research will be held in confidence and unless you specifically indicate your consent, your name will not appear in any report or publication of the research. Your data will be safely stored in a locked facility and only research staff (Ms. Parker and Mr.

Henriqson) will have access to this information. Confidentiality will be provided to the fullest extent possible by law.

1. The identities of participants will be protected by the assignment of a participant number and the destruction of the any information linking the participant's name with the participant number at the completion of the study by June 30, 2010.
2. A transcript of your interview will be written and sent to you for verification and approval for inclusion in the study. Remember all interview data will be de-identified, coded and aggregated for analysis. Your transcript will not be included as part of the report.
3. Prototypical situations that have been formally investigated and analysed through our safety reporting process and the MEDA investigation methods will be used as a basis for discussion.
4. Two informants will review the final thesis report to look for any information that has the potential to identify a participant.
5. Quotations will only be used the permission of the individual and would cite their participant number.

Questions About the Research? If you have questions about the research in general or about your role in the study, please feel free to contact Dr. Sidney Dekker either by telephone at +46 435-445434 or by e-mail (Sidney.Dekker@tfhs.lu.se).

This research has been reviewed by Dr. Sidney Dekker, Professor of Human Factors and System Safety at Lund University, Eder Henriqson, Ph.D. (in progress) at Federal University of Rio Grande do Sul, UFRGS, Brazil, with collaborative period in Lund University School of Aviation, Grantee of Brazilian Education Agency (CAPES), and senior management.

Legal Rights and Signatures:
I *(fill in your name here)*, consent to participate in *(insert study name here)* conducted by *(insert investigator name here)*. I have understood the nature of this project and wish to participate. I am not waiving any of my legal rights by signing this form. My signature below indicates my consent to participate.

Signature ______________________ **Date** ______________________
Participant

Signature ______________________ **Date** ______________________
Principal Investigator

Appendix C: Background Questionnaire

Background Questionnaire

Please describe your professional background in the table below.

Qualification and Experience	Years (Rounded up)
Number of years licensed as an AME?	
Endorsement?	
Number of years employed with our organization?	
Number of years employed in another government operator?	
Number of years employed in private industry?	
Number of years working as a Team Leader?	

Appendix D: Prototypical Situations

Prototypical Situations

Task 1: Electric Trim Servo Replacement on a C90 King Air Airplane (QA 2009-12)
Defect resolution
Procedures obtained
Part was received wired for a different installation than for the C90 and this known, but abnormal wiring was not detected through checks resulted in the airplane flying with the electric trim control reversed.

Task 2: Landing gear functional checks, thrust reverser deployment checks, and a brake bleeding on a Cessna Citation II Airplane (QA 2008-11)
Routine maintenance
Procedures obtained
The three checks were sequenced in a routine, but not documented or approved way and a step to secure a switch was missed prior to swinging the landing gear which resulted in damage to the switch when it moved into the gear swinging area.

Task 3: Engine Overheat Warning System Check on a Challenger Airplane (QA 2009-09)
Preventative maintenance (following a defect resolution)
Procedures obtained
On closing the compartment where he did the work, the AME inserted the pit pin (that secures the cowl strut bar in the closed position during flight) upside down. This combined with undetected wear on the pit pin enabled the pin to release during flight, interrupting fuel flow and resulting in loss of fuel to one engine and an in-flight engine shutdown.

Task 4: Inspection of the Aileron Control Cable Tension on a Twin Otter Airplane (QA 2008-08)
Routine maintenance
Procedures obtained
The task is done by one AME instead of two AMEs due to organizational and environmental factors and therefore, some of the steps have been modified. An unrelated task (removal of the cannon connector) was completed to gain access to the aileron control cable to accomplish the main task of checking and adjusting the tension in the aileron control cables. The cannon connector was not reconnected and power resulting from that connector was lost, interrupting the autofeather test the next day.

Task 5: Float Packing and 180 Day Inspection of Floats on a Bell 206L Helicopter (MEDA QA 2007-07)
Routine maintenance
Procedures obtained
Previous 180-day inspection was done without inflating the lines to the floats and therefore a previous error (packing the floats with a kink in the line) was not detected.

Task 6: Preparation of the Liferaft for Installation on a BO-105 Helicopter (MEDA QA 2007-04)
Routine maintenance
Procedures obtained

Cord to inflate the liferaft from the CO2 cylinder was improperly attached to the CO2 container resulting in the liferaft not inflating during an emergency rescue.

Task 7: Fuel Check Valve Replacement on a BO-105 Helicopter (QA 2009-07)
Unknown
Procedures obtained
A fuel check valve was disassembled, cleaned, reassembled and installed in the helicopter. Fuel check valves are normally replaced, and not disassembled, cleaned, reassembled and reinstalled, however many maintenance parts are maintained this way.

Task 8: Routine maintenance (cleaning, inspection, and re-installation of the oil filters) on an S61 Helicopter (QA 2009-05)
Routine maintenance
Procedures obtained
An AME was interrupted from the task of cleaning, inspecting, and re-installing the oil filters on an S61 helicopter. When he returned from dealing with the interruption he skipped the step in the procedure to refill the oil reservoir.

Appendix E: Interview Protocol

Interview Protocol

Prior to or upon arrival to the interview, the team leader will complete a consent form and background questionnaire. The consent form will explain the purpose of the study and how the researcher will manage and protect research data. The consent form will also note who can be contacted for any concerns with the research project. The background questionnaire will capture some basic background information such as years of experience, endorsements, and general working history (e.g. years with our organization, years with other government operator, years with private industry).

PART 1:

The interviewer will present to the team leader a card with the following information:

Task 1: Maintenance Task 1

1. Procedure: <to be documented>
2. Normal Practice Successful: <normal description>
3. Normal Practice Incident: <incident description>

- *This is how it has been described to me that this task is done. Is this correct or can you offer any further description? Do you see a gap between procedure and work with this task? Can you tell me in practice how this task is done? How different is this than how the procedure says to do it?*

The interviewer will then ask the team leader:

- *Can you explain to me why the task was done this way in the incident case? Is the incident related to this gap?*

If necessary the interviewer will prod the team leader:

- *What factors contribute to AMEs not following the procedure (i.e. context of work, features of the individual, procedural characteristics, goal conflicts)?*
- *What contributes or is at the heart of the gap? Is it the worker? The task? The procedures? The environment?*

The interviewer will repeat the exercise with a second prototypical situation of the team leaders choosing.

- *Are there any other cases that you want to share that demonstrate the gap?*

PART 2:

The interviewer will then present to the team leader:

- *You are a frontline supervisor – how do you manage the gap? Is there a tension? How do you manage the tension?*
- *Given what you've just explained to me with respect to a number of specific cases, how do you, personally, reconcile the tension between having to close the gap between procedure and work (given expectations from management and regulatory requirements) and understanding that gap (due to pressure from above to get the job done and pressure from below to be efficient)?*

- *Is management sometimes firm, directing 'the procedures must be followed'? If yes when?*
- *Is management sometimes focused on the schedule, directing 'the truck is here' or 'the machine must be available'?*
- *How tightly or loosely do you supervise your team?*
- *Do different <u>factors</u> affect how close your AMEs follow the procedures (i.e. difficult tasks, unfamiliar tasks, familiar tasks, during audits, program validations, when things are really busy, immediately following an occurrence, etc.).*
- *Do different <u>procedures</u> affect how close your AMEs follow the procedures (i.e. safety nets, poor procedures, good procedures, usefulness and usability of manuals and documents, etc.)?*

PART 3:

- *What for you creates safety? Following procedures, intelligently adapting or applying knowledge and experience to work using a combination of both?*
- *What changes would you see that could improve the safety of our operations, concerning the use of procedures?*

If there is still time remaining, the interviewer will close with the question:

- *You were once an AME on the floor. How did you see the gap then? Have you changed your understanding given your move into a supervisory role? Can you elaborate on the factors that contributed to this change in perspective?*

Appendix F: Procedures

Maintenance Control Manual - Procedure 30

Procedure 30 outline work performance procedures that apply to all aircraft maintenance work in the subject organization.

Table Of Contents - Procedure No. 30

30.0 Work Performance Procedures
30.1 General
30.2 Safety Wire On Cannon Plugs
30.3 Torque Seal Use
30.4 Independent Check Requirements
30.5 Critical Task Requirements
30.5.1 Fire Zone Lines
30.5.2 Fuel Tank Air Vent Lines
30.5.3 Fuel Tank Access
30.5.4 Static Ports and Pitot Openings
30.5.5 MBB BO-105 N2 Control System Integrity
30.5.6 Mast Nut
30.5.7 Bell 206 Series Disk Pack Couplings
30.5.8 Bell 212 Cargo Hook Rigging
30.5.9 Post Heavy Maintenance Inspection
30.5.10 Other Critical Tasks
30.5.11 Critical Task Sign-Off Requirements
30.6 Occurrences - Fuel Quality Sampling
30.7 Aircraft Ground Operations
30.8 Aircraft Dispatch Requirements
30.9 Static Electricity
30.10 Electrostatic Sensitive Devices (ESD)
30.11 Made Repair Parts
30.12 Post Wash Inspection
30.13 Use of Teflon Tape in Pitot-Static Systems
30.14 Avionics Wiring Modifications

30.0 WORK PERFORMANCE PROCEDURES

30.1 GENERAL

This procedure outlines Aircraft Services' requirements to meet work performance rules contained in CAR 571.

30.2 SAFETY WIRE ON CANNON PLUGS

All cannon plugs (except for self-locking designs) in the engine compartments, that have provisions, must be safetied with a minimum gauge of safety wire. If it is not a maintenance manual requirement to lockwire
and the locking mechanism is lost, the lock wiring of the cannon plug can be carried as a deferred item until the next Ops Check. For all other locations on the aircraft, it is an ASD “standard maintenance practice” that when possible, all cannon plugs designed with provisions will be safetied as stated above.

30.3 TORQUE SEAL USE

Following any disassembly of flight / engine control system or “B” nuts of lines in a fire zone, including APU enclosure, torque seal is to be applied.
More specifically, following any disassembly, removal and re-installation of:

- bolts, nuts, etc., used in flight and engine control systems, and
- B-nuts of oil, fuel, hydraulic and pressurized pneumatic lines within the fire zone, including APU enclosure.

Torque seal is to be applied to all attachment hardware of the finished assembly as a witness after they have been assembled and tightened to the appropriate torque prior to any function / leak check. Torque seal is not required on any "B” nut (or similar connection device) or flight / engine controls that have provisions for a locking device and the locking device has been installed, after work is performed. Any hardware that does not have a locking device such as a control surface travel stop jam nut or lines within the fire zone, including APU enclosure, must have torque seal installed after being torqued.

As an ASD “standard maintenance practice” when possible, torque seal is to be applied to any “B” nut regardless of location, as a witness after they have been assembled and tightened to the appropriate torque prior to any function / leak check. Torque seal is not required on any "B” nut (or similar connection device) that have provisions for a locking device and the locking device has been installed, after work is performed.

30.4 INDEPENDENT CHECK REQUIREMENTS

The following are the minimum work performance standards for completing independent checks. In addition to the CAR 571.10 requirements for the independent check of the affected system for correct assembly, locking, and sense of operation, following any maintenance that could have an affect on the basic rigging of the affected system, the inspection shall also include the verification of the parameters specified by the applicable maintenance instruction such as clearances, interferences and range of travel.

Note: *The final fits, clearances or limitations as specified by the maintenance instruction shall be documented on the applicable technical record (i.e. work card, Condition and Correction sheet, etc.) as part of the task signoff.*

30.5 CRITICAL TASK REQUIREMENTS

The following are the minimum work performance standards for tasks deemed critical and therefore requiring a Critical Task sign-off:

30.5.1 **Fire Zone Lines**

Following any disassembly, removal, and re-installation of lines within the fire zone (including APU enclosure), this visual inspection and functional check must be completed to ensure that the line is installed in accordance with the Maintenance Manual. Refer to Appendix One of this Procedure for fire zone diagrams.

The intent of this requirement is to ensure the security of critical installations within the fire zone and includes all oil, hydraulic, fuel, and pressurized pneumatic lines. The requirement encompasses both a visual and a functional check. For all unsafetied “B-nuts”, the individual who performs the work is required to install torque seal as they have been torqued. The inspection is a visual inspection for conformity and confirmation of safety wire, locking devices and torque seal on the B-nuts.

Any B-nut found without torque seal will require the person performing the critical task inspection to verify its torque with a wrench. Secondly, a functional check shall be carried out to ensure there are no leaks; this functional check will be performed at the normal maximum operational pressures of the system, except when extenuating circumstances do not permit normal maximum operational pressures to be obtained.

Caution: *This critical task inspection is a visual only confirmation for the installation of safety wire, locking devices and torque seal on B-nuts. The inspection does not confirm torque values where a visual indicator exists. For this reason, it is very important that the visual reference be applied at the time the connection is torqued and not as a task at the end of the job. This later practice has been found to lead to untorqued connections being marked or safetied, and then goes undetected by the critical task inspection.*

For the purposes of this requirement, a B-Nut is defined as a type of tubing nut that is used to hold a piece of flared tubing to a threaded fitting. B-nuts are used with a sleeve that is slipped over the tubing before the tubing is flared. The B-nut forces the sleeve tight against the flare, which seals against the flare cone of the male fitting. Although this definition is biased towards a solid line, the use of the term Bnut

applies to all hoses and tubing whether flexible or solid.

30.5.2 **Fuel Tank Air Vent Lines**

When fuel tank air vent lines have been blocked for the purposes of carrying out pressure or vacuum tests, or during aircraft washing or painting, visual inspections are to be carried out to ensure that they are cleared on completion of such operations.

30.5.3 **Fuel Tank Access**

When maintenance involves internal access to the fuel tank, prior to the access panels being installed, a visual check is to be carried out to ensure the tank is clean and free of contaminates, tools, rags, etc.

30.5.4 **Static Ports And Pitot Openings**

Whenever a pitot static system has been leak tested or functionally exercised for maintenance reasons, a visual check is to be carried out to ensure all static ports and pitot openings are free from any

obstructions.
30.5.5 **MBB BO-105 N2 Control System Integrity**
When an N2 Teleflex cable is disconnected at the forward engine firewall for any reason, two persons shall carry out a functional check of the engine N2 control system. With the main rotor blades unfolded, one person at the controls will move collective up and down while the second person visually verifies actual movement of the governor control lever. Prior to flight the pilot shall perform a functional check of the engine N2 control system.
30.5.6 **Mast Nuts**
Whenever a mast nut is removed for any reason, upon reinstallation the mast nut will be inspected for correct locking.
30.5.7 **Bell 206 Series Disc Pack Couplings**
After each installation of a disc pack coupling 32721-1, a second person will verify the minimum torque required for the fasteners and ensure torque seal is applied. As this is an alternate means of compliance with the BHT-206A/B-SERIES-MM-1 Section 5-00-00 requirements, this is a mandatory inspection and must be completed prior to flight. If the inspection is not completed prior to flight, then MAPS must be contacted immediately and the torque check programmed as per the Bell requirements.
30.5.8 **Bell 212 Cargo Hook Rigging**
Following installation of the cargo hook or after any maintenance that could have affected the basic rigging of the cargo hook, an inspection will be made to verify the required clearances and alignment marks are correct.
30.5.9 **Post Heavy Maintenance Inspection**
As part of the final completion of each Heavy Maintenance Inspection, the Person of Primary Responsibility (PPR) must ensure a final overview inspection of the aircraft is completed using the Post Heavy Maintenance Inspection Check Sheet ASD-P30-01. This inspection must ensure that all work has been completed as recorded in the technical record; the aircraft is airworthy and operationally configured for dispatch. Refer to MCM Procedure No. 9 – Technical Records for instruction on the required entry.
30.5.10 **Other Critical Tasks**
Any other critical tasks as required by any contracted Air Operator’s MCM.
30.5.11 **Critical Task Sign-Off Requirements**
CRITICAL TASK REQUIRED CERTIFYING AUTHORITY
Fire Zone Lines Any ACA or appropriately endorsed LCA
Fuel Tank Air Vent Lines Appropriately endorsed ACA or LCA
Fuel Tank Access Any ACA or appropriately endorsed LCA
Static Ports and Pitot Openings Appropriately endorsed ACA or LCA
MBB BO-105 N2 Control System Integrity Appropriately endorsed ACA or LCA
Mast Nuts Appropriately endorsed ACA or LCA
Bell 206 Series Disc Pack Couplings Appropriately endorsed ACA
Bell 212 Cargo Hook Rigging Appropriately endorsed ACA
Post Heavy Maintenance Inspection Appropriately endorsed ACA

30.6 OCCURRENCES - FUEL QUALITY SAMPLING
In the event of an occurrence where fuel quality could be a contributing factor, the PPR is responsible to ensure that a fuel sample is taken, labelled, and quarantined. The control and the release of the sample is the responsibility of the Responsibility Centre Manager (RCM) directly responsible for the aircraft.

30.7 AIRCRAFT GROUND OPERATIONS
Aircraft shall be handled and operated within the following standards:
a) Following any disassembly, removal, and re-installation of flammable lines, the ground operator shall ensure a fire watch is posted adjacent the effected area of the aircraft at the first startup and as further felt necessary. Special diligence and alternate emergency procedures shall be established when the aircraft’s fire extinguishing systems have been compromised
b) Where the standard latching devices on panels and cowlings have been compromised, all ground handlers and operators are responsible to ensure alternate measures are taken to preclude wind and operation damage.

30.8 AIRCRAFT DISPATCH REQUIREMENTS

The following standards apply:
MBB 105 - When cargo hook operations are being carried out, prior the first flight of the day and immediately following each aircraft refuelling, a visual and tactile inspection of the cargo hook assembly is required. Check the cargo hook, suspension system and emergency release cable for condition, security and operation (manually and electrically). Particular attention should be paid to the swage ends of the emergency release cable. As there is often little visual evidence that the emergency release cable swaging has failed, a physical pull is recommended to reveal a slipped swage. In addition, verify that the red witness mark on the mechanical arm lines up with the red witness mark on the housing.

30.9 STATIC ELECTRICITY
Static electricity is a constant problem and must be considered a major safety consideration by all personnel engaged in any activity associated with an aircraft or aeronautical product. To reduce the risk of accident resulting from static electricity the following policies must be adhered to:
a) aircraft being refueled, defueled, undergoing maintenance or parked within the hangar shall be grounded. Grounding methods shall be in accordance with the manufacturer's requirements; and
Note: *Where the aircraft has been disassembled to the point where the sources of ignition have been removed (e.g. fuel cells), the requirements of a) do not apply.*
b) personnel working on or adjacent to aircraft areas, which contain flammable materials, must wear footwear that does not contain metal cleats, nails, studs etc.; and
c) when considered necessary by the supervisor responsible for specific projects, personnel will be advised to wear anti-static parkas and/or overalls.

30.10 ELECTROSTATIC SENSITIVE DEVICES (ESD)
Many electronic aircraft components manufactured today are sensitive to static electricity discharge. To ensure these sensitive components are not damaged while in storage or on installation or removal, the precautions of MCM Procedure No. 19.5 – Stores and Purchasing shall be adhered to.

30.11 MADE REPAIR PARTS
In accordance with AWM 571.06, when a repair to an aircraft requires a “made repair part”, the following standards will apply:
a) the requirements of AWM 571.06(5)(a), (b), (c) and AWM 571.06(6) or MCM Procedure No. 39.15 shall be adhered to, and
b) the process or data used to establish the attributes of the part shall be referenced in the technical record entry, and
c) the “made” part shall be marked with indelible ink using the part number specified in the type design with the prefix ASD. In addition, the shop work order number shall also be indicated. When there is no manufacturer part number specified in the IPC, then the repair part shall be marked with a part number consisting of ASD and the work order number/condition and correction sheet report number. For small parts where it is not possible to show this information on the part, the technical record will include the required information.

30.12 POST WASH INSPECTION
A post wash inspection is required when an aircraft is washed by a non-ACA, and the requirement will be recorded in the journey logbook as a defect. The post wash inspection is a visual check to ensure all static ports and pitot openings are free from any obstructions and that any installed covers or plugs installed e.g. APU inlet plug, have been removed.

30.13 USE OF TEFLON TAPE IN PITOT-STATIC SYTEMS
If the fittings are not damaged and are torqued properly, the use of Teflon tape should not normally be required to prevent system leaks. However, some fittings are nylon with coarse threads (Cessna 182, 206), and some are tapered pipe fittings, so the thread surfaces in contact to form a seal might not be sufficient to prevent leaks. In these cases Teflon tape may be used, if required to eliminate a leak, ensuring that the following procedure is followed when applying it to the fittings, to prevent any obstructions to the orifices, or ingress of foreign material into the internal parts of the instrument or lines. Wrap the tape (maximum of 3 wraps) by starting two threads back from the orifice end that will be

inserted into the mating fitting, or instrument. Ensure that the tape is tightly bound to the fitting to prevent unwrapping as the fitting is tightened into it’s mating fitting. Wrap the tape in a direction that it will tend to tighten up onto the fitting as it is screwed into place, most unions are usually right hand thread, so putting the tape on in the opposite direction will ensure that the tape tightens onto the union.

30.14 AVIONIC WIRING MODIFICATIONS

When on-aircraft avionic wiring modifications are performed, the following process will be utilized to standardize the procedure used to control the progression of the modification:

a) Wiring drawings will be issued to personnel who are removing, relocating or installing wires on an aircraft.

b) There will be two sets of drawings maintained, one by the Team Leader and one at the aircraft.

c) The following color coding will be utilized at all times to show when a wire has been removed, added, relocated, rung out or power checked in order to show job status:

i) Removals – orange

ii) New installed or relocated – blue

iii) Ring outs – green

iv) Power checks – pinks

d) The individual performing the work is to sign off the drawing showing the work they have carried out **on a daily basis**. All working drawings are to be returned to the Team Leader or designated location (i.e. aircraft working copy binder) at the end of the workday. Once weekly, or at the frequency requested by the Team Leader, the master drawing copy shall be updated to reflect the current status of work.

e) Upon receiving, revised drawings shall be entered into the appropriate binder (M - Mechanical, D - Details, R - Rework, W - Wiring, drawings) and an entry made into the binder log. Upon insertion, the drawing shall be reviewed to identify relevant changes and to ensure all deviations / alterations from the previous copy are incorporated, if not, they must be carried forward and identified.

Maintenance Manual Procedures for Task 1 – Defect Resolution and Installation of an Electric Trim Servo on a King Air C90

These procedures and diagrams are the procedures for installing and electric trim servo on a King Air C90 aircraft. Parts Group IX + 3 drawings.

PITCH TRIM SERVO - 1C469-6-456

PARTS GROUP IX

Drawing No. 69D1179

1. The (item 1) 1C469-6-456 Pitch Trim Servo is to be installed in the second bay forward of the forward cabin door and under the floorboards on the left side of the aircraft. This location is just forward and adjacent to the bulkhead at Fuselage Station 216.00. Remove the left seats, carpet, and inspection plate to gain access to this area.

2. Temporarily attach the slotted end of the (item 1) pitch trim servo base plate to the (item 2) 7B1569 bracket with two (item 4) 3S215 bolts, four (item 6) 4S134 washers and two (item 5) 2S38 nuts. Position the servo/bracket assembly into the aircraft, as shown on Drawing No. 69D1179, with the upper elevator trim cable in line with the center of the two idler pulleys and in contact with the center of the pulley grooves.

3. Using the (item 2) bracket as a guide, mark and drill two .166 dia. (No. 19 drill) holes in the stringer. Reference dimensions called out on Drawing No. 69D1179. Secure the (item 2) bracket to the aircraft structure with two (item 9) 3S464 screws, two (item 11) 4S205 washers and two (item 10) 2S34 nuts.

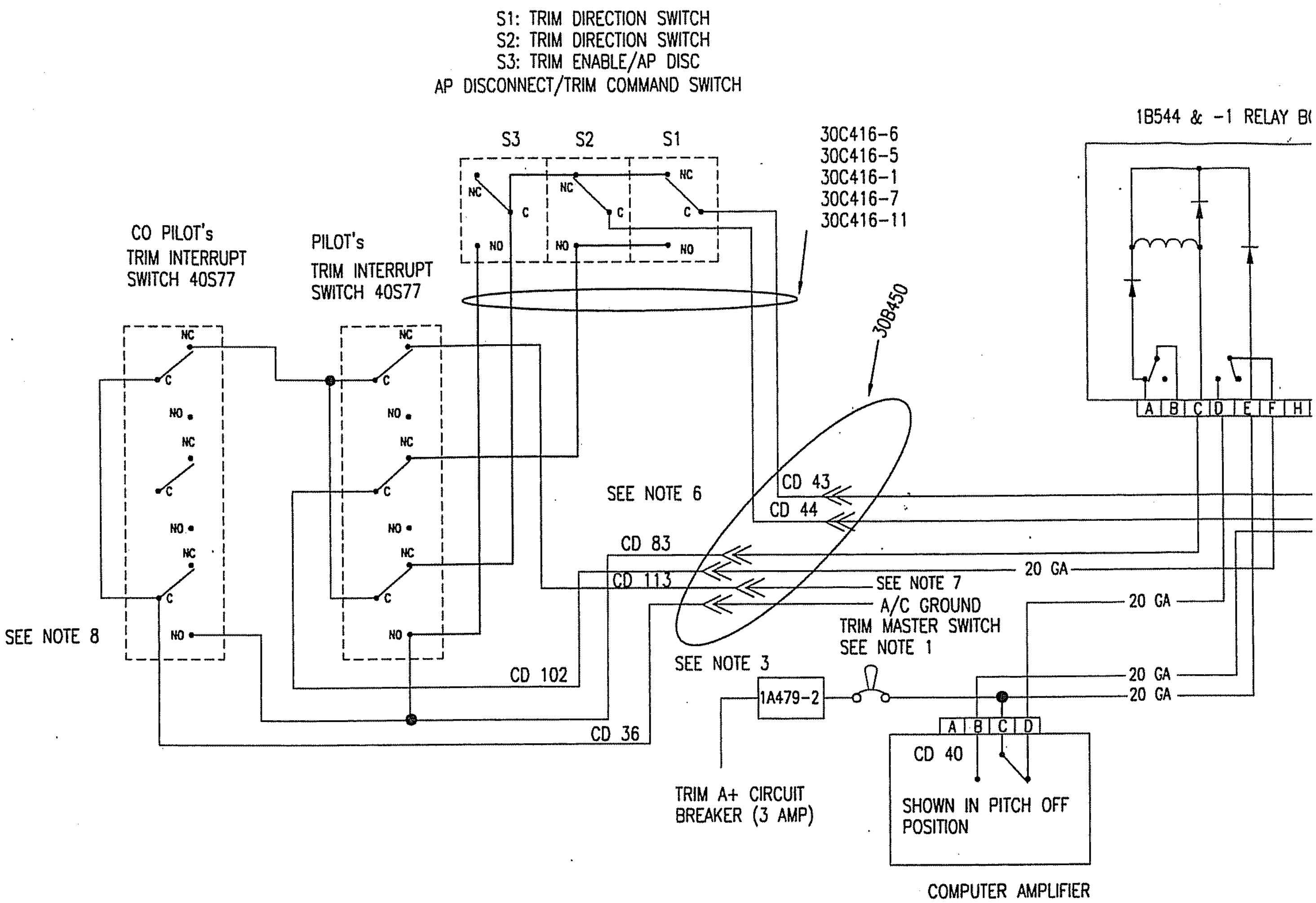
4. Attach the (item 3) 7B1570 bracket to the upper end of the servo base plate with two (item 9) 3S464 screws, two (item 11) 4S205 washers and two (item 10) 2S34 nuts. Using the (item 3) bracket as a guide, mark and drill two .166 dia. (No. 19 drill) holes in the bulkhead at Fuselage Station 216.00 and secure the (item 3) bracket to the bulkhead with two (item 9) 3S464 screws, two (item 11) 4S205 washers and two (item 10) 2S34 nuts.

5. Attach one end of the (item 8) 7B1313 bracket to the (item 2) bracket as shown on drawing with one (item 9) 3S464 screw, one (item 11) 4S205 washer and one (item 10) 2S34 nut. Using the (item 8) bracket as a guide, mark and drill one .166 dia. (No. 19 drill) hole in the stringer and secure the (item 8) bracket to the stringer with one (item 9) 3S464 screw, one (item 11) 4S205 washer and one (item 10) 2S34 nut.

6. Remove the access panel from the lower aft section of the fuselage. Loosen the turnbuckle barrel in the right hand elevator trim cable in the aft section of the fuselage to provide slack in the trim cable at the trim servo. Route the upper trim cable through the idler pulleys and trim servo capstan as shown on Drawing No. 69D1179, it will be necessary to loosen pulleys to route trim cable around capstan. After wrapping the cable, tighten the idler pulley attaching bolts to 13 ± 1 in. lbs. Position the cable guard to within 1/32" of capstan O.D. and secure. Install the (item 7) 30A254-3 cable splice in the right elevator trim cable in the aft section of the fuselage at the point where this cable is connected to the two trim tab cables ("Y") coming from the trim tabs. Use the existing hardware on one end of the splice with one AN380-2-3 cotter pin, and use one AN23-8 bolt, one AN960-10 washer, one AN320-3 nut and one AN380-2-3 cotter pin on the other end.

(CONTINUED)

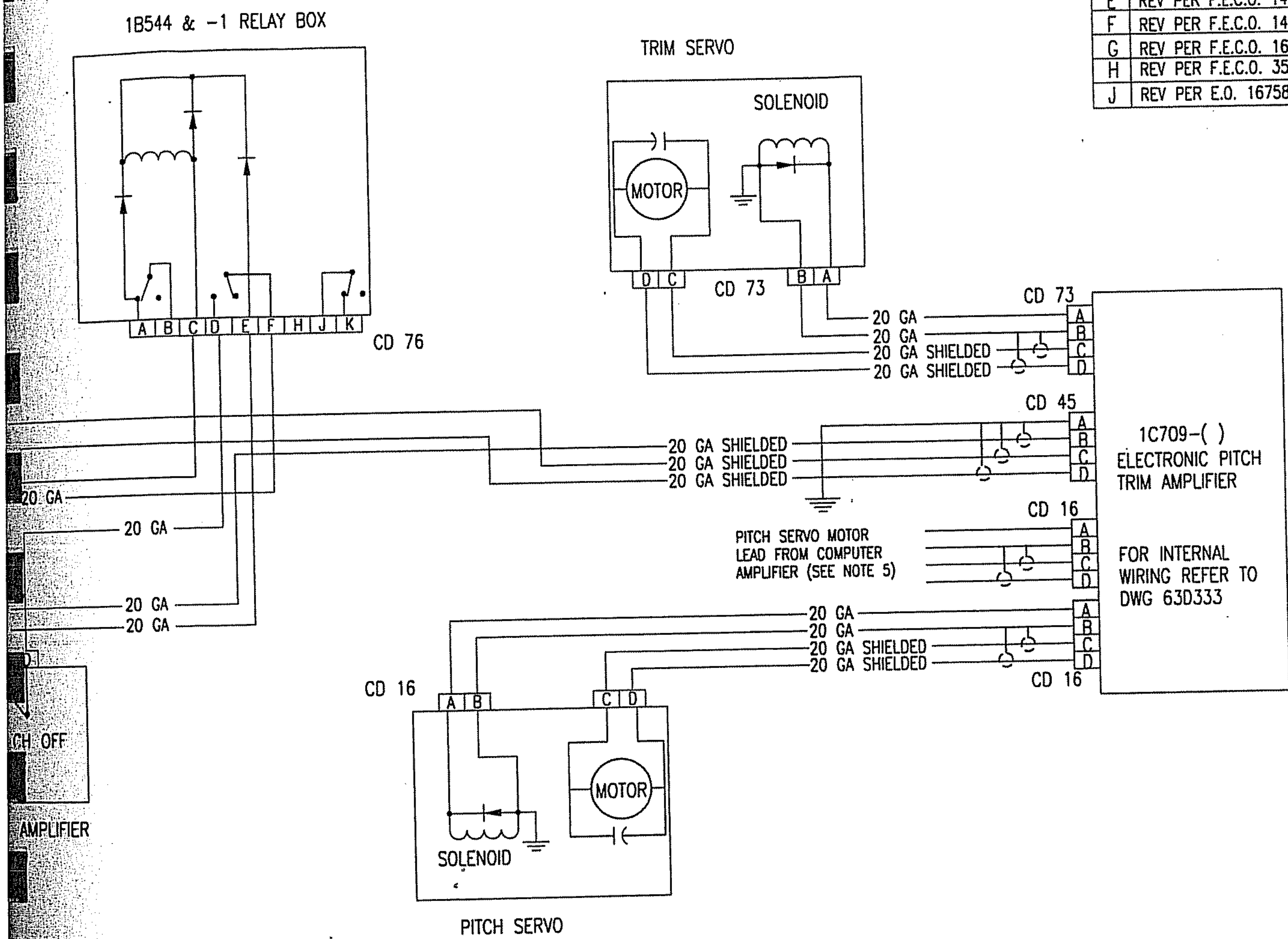
7. Using the turnbuckle previously loosened, adjust the elevator trim cable tension to the high (max.) side of the tolerance called out by the Aircraft Manufacturer for this model. Re-safety the turnbuckle. Check the elevator trim tab travel and adjust as necessary to the proper travel called out by the Aircraft Manufacturer. Operate the elevator trim system through it's complete range of travel and check for any binding or restriction due to this servo installation. Tighten the bolts and nuts temporarily installed in Step 2.



NOTES:

1. SOME INSTALLATIONS REQUIRE A TRIM MASTER SWITCH. REFER TO THE INSTALLATION BULLETIN FOR APPLICABILITY.
2. THE FOLLOWING SEQUENCE MUST BE FOLLOWED TO DETERMINE OR CORRECT THE DIRECTION OF THE TRIM SERVO:
   A. DETERMINE THAT THE PITCH SERVO IS ACTUATING IN THE PROPER DIRECTION (AUTOPILOT ON). IF NOT REVERSE DIRECTION OF PITCH SERVO BY REMOVING SERVO DUST COVER AND REVERSING THE BLACK AND RED SERVO MOTOR WIRES AT THE TERMINAL POST.
   B. DETERMINE THAT THE TIRM SERVO TRIMS IN THE PROPER DIRECTION IN AUTOMATIC MODE (MUST FOLLOW PITCH SERVO). IF NOT REVERSE DIRECTION OF TRIM SERVO MOTOR BY REMOVING THE TRIM SERVO DUST COVER AND REVERSING THE RED AND BLACK SERVO MOTOR LEADS AT THE TERMINAL POST.
   C. DETERMINE THAT TRIM SERVO TRIMS IN DIRECTION COMMANDED BY CONTROL WHEL TRIM SWITCH (AUTOPILOT OFF). IF NOT REVERSE DIRECTION BY REVERSING CD 43 AND CD 44 AT THE TRIM SWITCH CABLE ASSEMBLY.
3. INSTALL NOISE FILTER WHEN REQUIRED AS INDICATED IN THE PARTS LIST OF THE INSTALLATION BULLETIN.
4. ALL WIRE TO BE MIL-W-5086A, 22 GA. MIN. UNLESS OTHERWISE NOTED.
5. THIS 4 - PIN CONNECTION AND ASSOCIATED WIRING IS PART OF THE CENTURY IV AUTOPILOT/FLIGHT DIRECTOR CABLING AND IS SHOWN ON WIRING INTERCONNECT DRAWING NO. 63C314.
6. THESE CONNECTIONS EXIST ONLY WHEN SWITCH & CABLE ASSEMBLY 30C416-5,30C416-6 OR 30C416-11 IS USED. WHEN 30C416-1 OR 30C416-7 IS USED THESE CONNECTIONS WILL NOT BE PRESENT. WHEN USING 30C416-6 SWITCH & CABLE ASSEMBLY, THE 30B450 CABLE ASSEMBLY WILL NOT BE USED. REFER TO INSTALLATION BULLETIN.
7. REFER TO YAW DAMPER INSTALLATION BULLETIN FOR CD 113 CONNECTION.
8. INSTALLED ON BEECH AIRCRAFT C90's S/N LJ-1053 AND AFTER (AK 456/FD). (ALCO SWITCH MPG-106F SWITCH MAY BE USED IF BLACK CAP IS REPLACED WITH A RED CAP.)

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED
—	REL. PER E.O. 7657	1-14-74	BLB
A	REV PER F.E.C.O. 199	1-30-74	JS
B	REV PER E.O. 7766	5-6-74	JS
C	REV PER F.E.C.O 275	8-16-74	JS
D	REV PER F.E.C.O. 1370	7-7-77	JCP
E	REV PER F.E.C.O. 1440	9-7-77	JCP
F	REV PER F.E.C.O. 1457	9-16-77	JCP
G	REV PER F.E.C.O. 1627	1-24-78	SMP
H	REV PER F.E.C.O. 3588	12-14-82	RMcW
J	REV PER E.O. 16758	4-22-98	S.C.



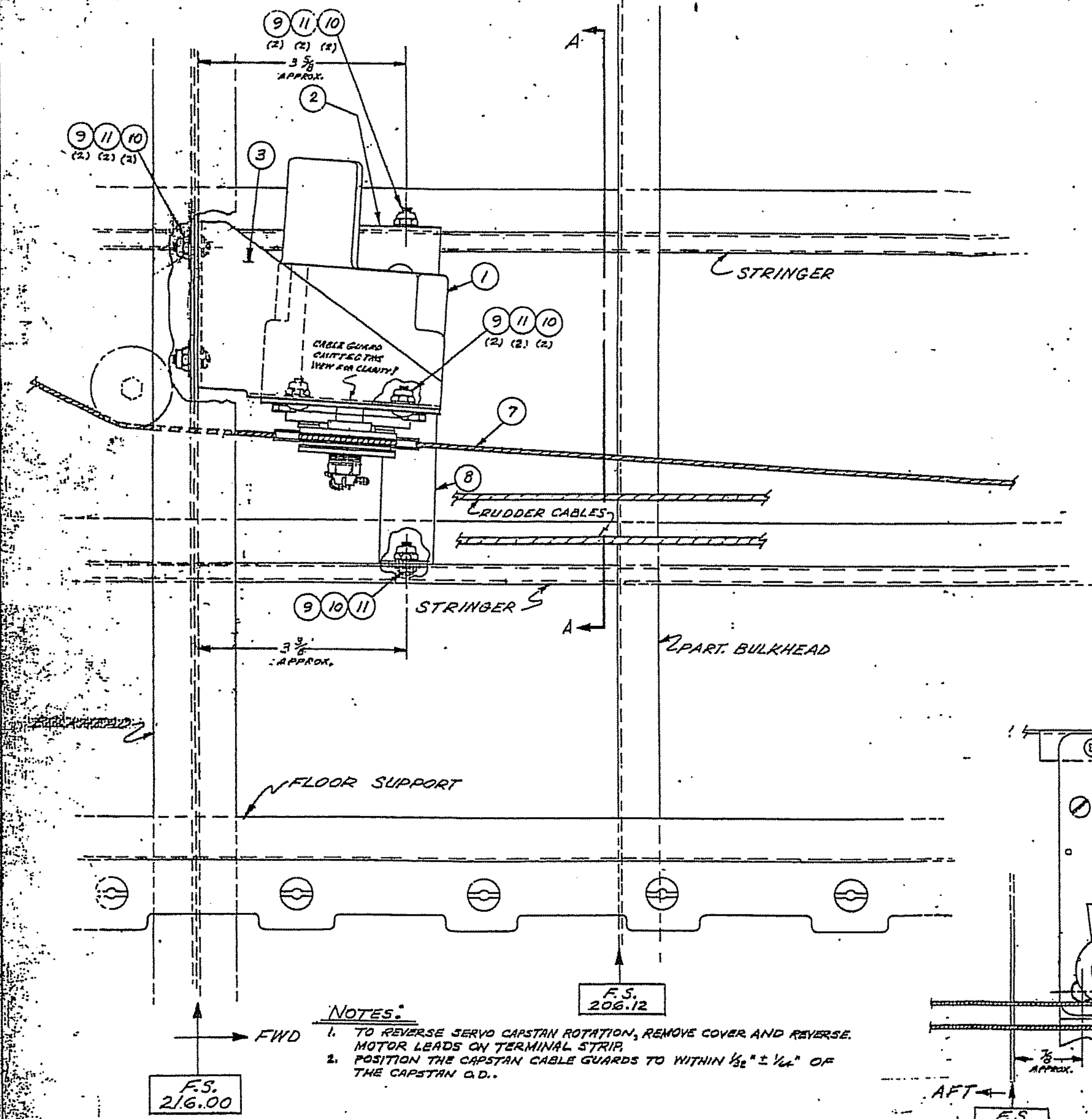
	AK 687/FD	AK 579/FD	AK 477/FD
	AK 686/FD	AK 556/FD	AK 466/FD
	AK 685/FD	AK 525/FD	AK 456/FD
	AK 684/FD	AK 503/FD	AK 443/FD
	AK 674/FD	AK 500/FD	AK 449/FD
	AK 668/FD	AK 499/FD	AK 448/FD
AK 728/FD	AK 662/FD	AK 496/FD	AK 447/FD
AK 700/FD	AK 621/FD	AK 494/FD	AK 446/FD
AK 688/FD	AK 585/FD	AK 492/FD	AK 438/FD
USED ON	USED ON	USED ON	USED ON
APPLICATION			

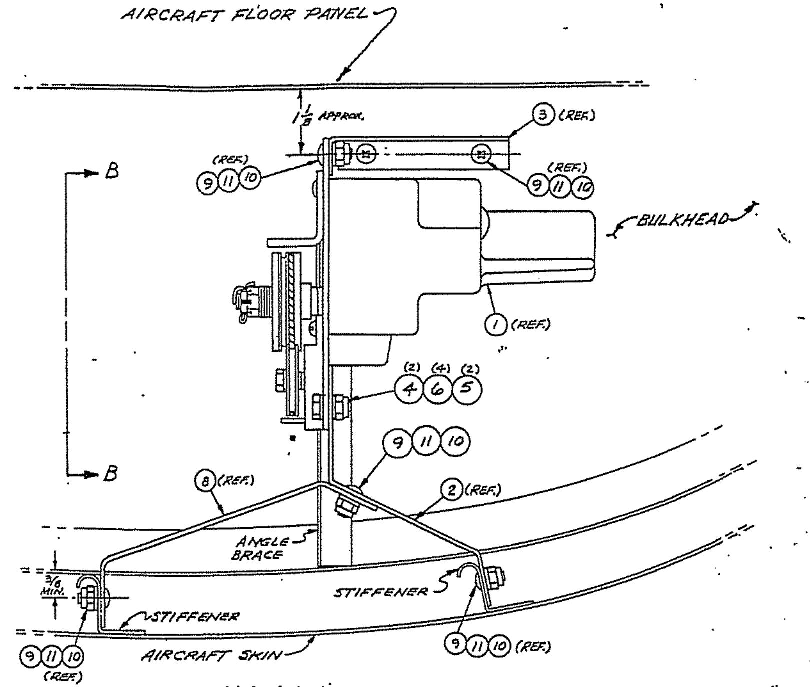
DRAWN	J. SWINSON 1-14-74
CHECKED	B. BARRETT 1-14-74
ENGINEER	E. CAMERON 1-14-74
APPROVED	J. IRWIN 1-14-74
FILE NAME	63D324.DWG

CENTURY ®
FLIGHT SYSTEMS, INC. BOX 610, MUNICIPAL AIRPORT MINERAL WELLS TX. 76067

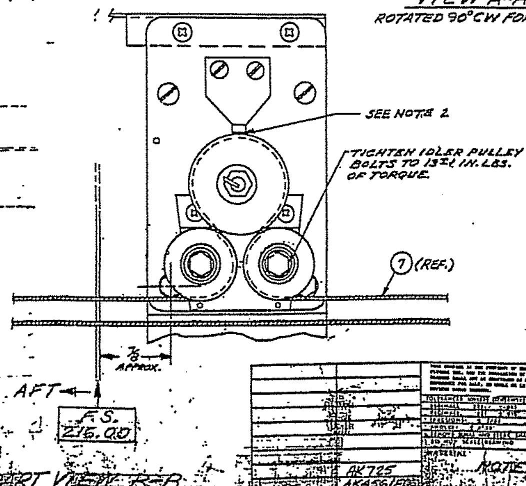
TITLE
SCHEMATIC COMMAND/ AUTOMATIC TRIM SYSTEM (TYPE 15)

SIZE	DWG NO.	REV
D	63D324	J
SCALE 1:1	FILE: H:\USERS\DRAWING\SIZE_D	SHEET 1 OF 1





VIEW A-A
ROTATED 90° CW FOR CLARITY



PART VIEW B-B

NOTES:

1. TO REVERSE SERVO CAPSTAN ROTATION, REMOVE COVER AND REVERSE. MOTOR LEADS ON TERMINAL STRIP.
2. POSITION THE CAPSTAN CABLE GUARDS TO WITHIN 1/32" ± 1/64" OF THE CAPSTAN O.D..

REVISIONS

LTR	DESCRIPTION	DATE	APPROVED
—	RELEASED PER E.O. 8156	1-24-75	
A	REMOVED SAFETY WIRE PER FECO 7102	9-8-76	
B	REVISED PER FECO 7625	1-23-79	

LIST OF MATERIALS

QTY	ITEM	PART NUMBER	DESCRIPTION
8	11	4S205	WASHER, AN960-8
8	10	2S34	NUT, AN365-832
8	9	3S464	SCREW, AN525-832R8
1	8	7B1313	BRACKET
1	7	30A254-()	CABLE SPLICE
4	6	4S134	WASHER, AN960-10
2	5	2S38	NUT, AN365-1032
2	4	3S215	BOLT, AN3-3A
1	3	7B1570	BRACKET
1	2	7B1569	BRACKET
1	1	1C469-6-456	PITCH TRIM SERVO

DRAWN C. KITCHENS 1/22/75
CHECKED D. BARRETT 1-23-75
ENGINEER E. CAMERON 1-24-75
APPROVED

CENTURY FLIGHT SYSTEMS, INC.

TITLE PITCH TRIM SERVO

AK725
AK456

69D1179 B

Maintenance Manual Procedures for Task 2 – Heavy Maintenance Landing Gear Functional Checks (combined with Thrust Reverser Deployment Checks and Brake Bleeding on a Cessna Citation II Aircraft)

These procedures and diagrams are the procedures for conducting the landing gear functional checks combined with thrust reverser deployment checks and brake bleeding on a Cessna Citation II aircraft. Procedures 32-00-710 (Landing Gear Hydraulic Systems Adjustment/Test), and 78-31-00-710 (Thrust Reversers Operational Test), 32-42-09-710 (Emergency Brake System Operational Test), and 32-42-00-710 (Antiskid Brake System Operational Check).

Task 32-01-00-710

3. Landing Gear Hydraulic Systems Adjustment/Test

A. General.

NOTE: The landing gear is controlled electrically, and is hydraulically actuated during normal extension and retraction operation. The auxiliary extension is manually operated by cable/uplock release and gear free fall. The pneumatic (emergency) gear extension is controlled manually and pneumatically actuated.

B. Tools and Equipment.

NOTE: Equivalent substitutes may be used for the following items.

(1) External Power Unit - MH32-200K24M.

(2) Hydraulic Service Unit - CJMD129-002.

(3) Jacks Pad Kit - 5520151-2.

(4) Tail Stand - CJMD107-004.

(5) Tripod Jack (Nose Gear) - CJMD107-001 or CJMD107-006.

(6) Tripod Jack (Main Gear) - CJMD107-002 or CJMD107-007.

(7) Hydraulic Service Unit (Portable) - CJMD112-001.

C. Functional Test.

NOTE: Landing gear hydraulic actuators have built-in downlocks which eliminate the requirement for external downlock pins and mechanical locks during maintenance.

NOTE: This procedure consists of several checks. If it is desired to perform only one of these checks because of a specific problem, the airplane must be properly configured prior to the test and restored after completing the test.

(1) Systems Preparation and Test.

NOTE: Both hydraulic firewall shutoff valves must remain in open position to prevent excessive pump shaft seal back pressure.

(a) Jack airplane until tires clear the ground. Refer to Chapter 7, Lifting - Maintenance Practices .

(b) Verify the following.

1 Engage RH BUS NO 1, NO 2 and NO 3 circuit breakers.

2 Engage WARN LTS 1 and WARN LTS 2 circuit breakers.

3 Engage LH BUS NO 1, NO 2 and NO 3 circuit breakers.

4 Engage LDG GEAR circuit breaker.

5 Engage GEAR CONTROL circuit breaker.

(c) Verify the following.

1 Disengage SPEED BRAKE circuit breaker.

2 Disengage LH THRU REV and RH THRU REV circuit breakers.

(d) Apply external direct current (DC) power to the airplane.

NOTE: Gear down and locked, green lights should be on.

CAUTION: Ensure that the airplane ground suction source quick connect fitting is securely connected to the service cart return line or hydraulic purifier inlet line fittings. Failure to do so could cause damage to the reservoir by over pressurizing it.

(e) Connect the hydraulic ground service unit to the appropriate airplane couplers.

(f) Provide a drip pan or container below hydraulic reservoir air vent to catch possible leakage.

(g) Check that the landing gear control handle coincides with the actual position of the gear before energizing the hydraulic ground service unit.

WARNING: Ensure personnel are clear of landing gear area, speed brake area and thrust reversers before applying hydraulic pressure to the airplane systems.

(h) Adjust the hydraulic service unit to zero flow and turn on electrical power.

(i) Open supply on service unit until hydraulic flow is 3 gallons per minute.

(j) When return hydraulic fluid is free of air, retract and extend the landing gears several times or until the returning hydraulic fluid is again free of air.

NOTE: Each time the gears are operated, the amber HYD PRESS ON light should illuminate on the annunciator panel.

(k) During landing gear cycling, observe that the green gear down and locked lights are all illuminated at the completion of gear extension cycle and the GEAR UNLOCKED light is illuminated during gear travel.

NOTE: All gear lights should be extinguished when the gear is up and locked.

(l) Extend landing gear.

NOTE: During operation of any hydraulic service, a hydraulic slam may occur at the instant the service terminates. This phenomenon is related to the sudden release of line pressure through the loading valve. On occasion, the amplitude will reach greater than normal proportions. If the system has completed all functional tests specified without fault except for the termination slam, it may be considered safe for flight.

(m) Visually check the airplane system for leakage and excessive leakage at actuator seals.

(2) Downlock and Uplock Paralleling Circuit Test.

(a) Verify that landing gears are down and locked.

(b) Verify NOSE, LH, and RH gear down lights are illuminated.

(c) Select LDG GEAR handle to UP.

1 Verify HYD PRESS ON annunciator light illuminates.

2 As each respective gear unlocks, verify illumination of GEAR UNLOCKED light and extinguishing of NOSE, LH and RH gear down lights.

WARNING: Ensure landing gear handle is positioned to and remains in the neutral position (midway between up and down) whenever required in this

procedure. Failure to do so may cause the gear to move to the selected handle position, resulting in personal injury or loss of life.

(d) As soon as the downlock lights extinguish and GEAR UNLOCKED light illuminates, but prior to gear reaching up and locked position, select LDG GEAR handle to neutral. Gear movement should cease, leaving all three gears in mid-travel position.

(e) Physically push the left and nose landing gear to the down and locked position while restraining the right gear. Verify NOSE and LH gear down lights and GEAR UNLOCKED light are illuminated.

(f) Select LDG GEAR handle DOWN.

1 Verify HYD PRESS ON annunciator light illuminates.

2 Verify right landing gear hydraulically moves to down and locked position.

3 Verify all gear down lights are illuminated and GEAR UNLOCKED light is extinguished.

(g) Select LDG GEAR handle to UP.

1 Verify HYD PRESS ON annunciator light illuminates.

2 As each respective gear unlocks, verify illumination of GEAR UNLOCKED light and extinguishing of NOSE, LH and RH gear down lights.

(h) As soon as the downlock lights extinguish and GEAR UNLOCKED light illuminates, but prior to gear reaching up and locked position, select LDG GEAR handle to neutral. Gear movement should cease, leaving all three gears in mid-travel position.

(i) Physically push the right and nose landing gear to the down and locked position while restraining the left gear. Verify NOSE and RH gear down lights and GEAR UNLOCKED light are illuminated.

(j) Select LDG GEAR handle DOWN.

1 Verify HYD PRESS ON annunciator light illuminates.

2 Verify left landing gear hydraulically moves to down and locked position. Verify all gear down lights are illuminated and GEAR UNLOCKED light is extinguished.

(k) Select LDG GEAR handle to UP.

1 Verify HYD PRESS ON annunciator light illuminates.

2 As each respective gear unlocks, verify illumination of GEAR UNLOCKED light and extinguishing of NOSE, LH and RH gear down lights.

(l) As soon as the down lock lights extinguish and GEAR UNLOCKED light illuminates, but prior to gear reaching up and locked position, select LDG GEAR handle to neutral. Gear movement should cease, leaving all three gears in mid-travel position.

(m) Physically push the left and right landing gear to the down and locked position while restraining the nose gear. Verify LH and RH gear down lights and GEAR UNLOCKED light are illuminated.

(n) Select LDG GEAR handle DOWN.

1 Verify HYD PRESS ON annunciator light illuminates.

2 Verify nose landing gear hydraulically moves to down and locked position. Verify all gear down lights are illuminated and GEAR UNLOCKED light is extinguished.

(o) Select LDG GEAR handle to UP.

1 Verify HYD PRESS ON annunciator light illuminates.

2 As the gear unlocks, verify illumination of GEAR UNLOCKED light and extinguishing of NOSE, LH and RH gear down lights.

3 Following the gear in transit, verify that gear moved to the up and locked position. Verify HYD PRESS ON annunciator light and GEAR UNLOCKED light are extinguished.

WARNING: Ensure landing gear handle is positioned to and remains in the neutral position (midway between up and down) whenever required in this procedure. Failure to do so may cause the gear to move to the selected handle position, resulting in personal injury or loss of life.

CAUTION: Use reduced flow or pressure to prevent gear slam during retraction.

(p) Select LDG GEAR handle to neutral and verify GEAR UNLOCKED light has not illuminated (there is a deadband prior to illumination).

WARNING: Gear is heavy. Exercise care when releasing.

NOTE: Access cable inboard of uplock hook. To facilitate manual release of uplock hook, push up on gear while pulling on uplock hook release cable.

(q) Release right gear uplock hook by pulling on right uplock hook release cable and allowing gear to fall.

1 Verify GEAR UNLOCKED light is illuminated.

(r) Select LDG GEAR handle to UP.

1 Verify HYD PRESS ON annunciator illuminates.

2 Ensure right landing gear hydraulically moves to up and locked position and HYD PRESS ON annunciator light and GEAR UNLOCKED light extinguish.

(s) Select LDG GEAR handle to neutral and verify GEAR UNLOCKED light has not illuminated (there is a deadband prior to illumination).

WARNING: Gear is heavy. Exercise care when releasing.

NOTE: Access cable inboard of uplock hook. To facilitate manual release of uplock hook, pushing up on gear while pulling on uplock hook release cable.

(t) Release left gear uplock hook by pulling on left uplock hook release cable and allowing gear to fall.

1 Verify GEAR UNLOCKED light is illuminated.

(u) Select LDG GEAR handle to UP.

1 Verify HYD PRESS ON annunciator illuminates.

2 Ensure left landing gear hydraulically moves to up and locked position and HYD PRESS ON annunciator light and GEAR UNLOCKED light extinguish.

(v) Select LDG GEAR handle to neutral and verify GEAR UNLOCKED light has not illuminated (there is a deadband prior to illumination).

(w) Open access panel 211FZ . Refer to Chapter 6, Access Plates and Panels - Description and Operation .

WARNING: Gear may extend rapidly after uplock release. Let go of cable immediately after pulling, to keep shimmy damper or other gear components from striking hand.

(x) Release NOSE gear uplock hook by pulling on nose uplock hook release cable through access panel 211FZ opening and allow gear to fall.

1 Verify GEAR UNLOCKED light is illuminated.

(y) Select LDG GEAR handle to UP.

1 Verify HYD PRESS ON annunciator illuminates.

2 Ensure nose landing gear hydraulically moves to up and locked position and HYD PRESS ON annunciator light and GEAR UNLOCKED light extinguish.

(z) Select LDG GEAR handle to DOWN. Verify that HYD PRESS ON annunciator illuminates.

(aa) As gear unlocks, verify that GEAR UNLOCKED light illuminates.

(ab) Ensure all gear hydraulically moves to down and locked position.

(ac) Verify gear handle is in DOWN position.

1 Verify NOSE, LH and RH gear down lights are illuminated and GEAR UNLOCKED light is extinguished.

(3) Slow Cycle Test.

NOTE: This test is designed for use when checking the landing gear for obstructions, chafing or rubbing, and when checking the nose gear with full right and left rudder deflection.

(a) Retract the gear.

WARNING: Personnel should not enter the wheel well areas while the gear is in motion. The speed that a gear is moving during retraction may suddenly increase when one of the other gears reach full travel and all hydraulic pressure is applied to one actuator.

1 Place gear control lever in up position.

2 Slowly increase service unit pressure until gear actuator down locks release.

3 Reduce service unit pressure until pressure is just sufficient to retract gear.

4 Close supply valve on hydraulic service unit to stop retraction cycle at several intermediate positions and inspect all gear assemblies to ensure proper clearance and lack of all obstructions.

5 Open supply valve on hydraulic service unit and allow gear to continue the cycle to up and locked position.

6 When gear reaches up and locked position, close supply valve on service unit. Inspect all wheel wells to ensure gear is not striking obstructions and that no chafing or rubbing exists.

7 Verify that uplock rollers are bottomed in uplock hooks and hooks clear trunnion.

8 With the main gears up and locked, confirm that the wire bundle from the wheel speed transducer falls into the half-moon shaped region of the wing panel. Inspect to confirm positive clearance between the wire bundle and the wing panel.

9 Place landing gear control lever in DOWN position.

10 Open supply valve on service unit and increase pressure until uplocks release.

11 Allow gear to proceed to down and locked position.

12 Reposition or repair any equipment causing obstructions before continuing with test.

13 Position rudder pedal to full left rudder deflection position.

WARNING: Personnel should not enter wheel well areas while gear is in motion. The speed that a gear is moving during retraction may suddenly increase when one of the other gears reach full travel and all hydraulic pressure is applied to one actuator.

14 Place landing gear control lever in UP position.

15 Using the supply valve, increase the service unit pressure as required to release down locks. When down locks have released, reduce service unit pressure as low as possible and keep gear moving toward UP position.

NOTE: It is not necessary for all three gears to move at the same time. The slower the gear moves, the more accurate the inspection will be.

16 Stop gear movement at various intermediate positions and ensure that shimmy damper does not strike or chafe any lines in the wheel well area. Verify tire chine clears nose gear door at maximum rudder pedal deflection.

NOTE: With full left rudder, the shimmy damper may touch (0.12 inch maximum deflection) the nose gear free-fall cable during gear retraction.

NOTE: If shimmy damper is chafing hydraulic lines, lower gear and reposition lines to provide clearance. If line is chafing and more than 10 percent of the wall thickness is removed, line should be replaced.

17 Position rudder pedal to full right rudder deflection position.

WARNING: Personnel should not enter wheel well areas while gear is in motion. The speed that a gear is moving during retraction may suddenly increase when one of the other gears reach full travel and all hydraulic pressure is applied to one actuator.

18 Place landing gear control lever in UP position.

19 Using the supply valve, increase the service unit pressure as required to release down locks. When down locks have released, reduce service unit pressure as low as possible and keep gear moving toward UP position.

NOTE: It is not necessary for all three gears to move at the same time. The slower the gear moves, the more accurate the inspection will be.

20 Stop gear movement at various intermediate positions and ensure that shimmy damper does not strike or chafe any lines in the wheel well area. Verify tire chine clears nose gear door at maximum rudder pedal deflection.

NOTE: With full right rudder, the shimmy damper may touch (0.12 inch maximum deflection) the nose gear free-fall cable during gear retraction.

NOTE: If shimmy damper is chafing hydraulic lines, lower gear and reposition lines to provide clearance. If line is chafing and more than 10 percent of the wall thickness is removed, line should be replaced.

21 Verify gear handle is in DOWN position.

a Verify NOSE, LH AND RH gear down lights are illuminated and GEAR UNLOCKED light is extinguished.

(4) Emergency Gear Extension Test.

NOTE: This test should be accomplished when a complete landing gear check is in order and/or after the landing gear hydraulic system and gear rigging are complete.

NOTE: Both hydraulic firewall shutoff valves must remain in open position to prevent excessive pump shaft seal back pressure.

(a) Retract gear, leave landing gear handle in UP position, and shut off hydraulic power unit.

WARNING: Ensure personnel are clear of landing gear area, speed brake area, and thrust reversers before applying hydraulic pressure to the airplane systems.

(b) Verify all personnel are clear of landing gear areas.

(c) Verify the emergency air bottle pressure is indicating within the green arc on the pressure gage. Fill if necessary.

(d) Pull emergency gear T-handle full out to stop and lock in position by rotating clockwise 45 degrees.

1 Slowly pull the emergency landing gear release T-handle.

2 Verify that the nose gear releases first, then both main gears release.

3 Verify that both main gears appear to release at the same time when pulling the T-handle slowly.

4 Verify that pull on T-handle does not exceed 75 pounds.

5 Ensure that a minimum of 0.50 inch of T-handle travel is available from the release point of the main landing gears to the end of the T-handle travel.

NOTE: Releasing the uplocks with the gear control handle in the RETRACT position and hydraulic power applied returns the gear to the UP position.

NOTE: The next two actions check the function of the dump valve by forcing it to operate. Air bubbles visible at the hydraulic service unit are an indication of a leaking actuator seal. A small burst of fluid or mist (fog) expelled from the airplane reservoir relief line is normal as long as there is not a continuation of either fluid or mist.

(e) Pull the round (pneumatic emergency) knob out to its stop. High pressure air positions the dump valve to dump hydraulic retract pressure to return. High pressure air is also directed into the landing gear actuators, extending the landing gear to a down and locked position. All green landing gear lights will illuminate.

(f) IMMEDIATELY move the landing gear control handle to the DOWN position after the last green light has illuminated.

1 Verify GEAR UNLOCKED light is extinguished.

(g) Pull the control lever release knob or, depending on the type of control valve installed, push control lever release button on pneumatic bottle and return the control lever to the closed (normal) position.

(h) Return the pneumatic emergency landing gear control knob to the normal position. This relieves the trapped pressure from the landing gear pneumatic extend system. A small burst of mist (fog) should be vented overboard.

(i) Return the T-handle to the normal position.

(j) Cycle the gear a minimum of 6 times to purge the hydraulic system of air.

(k) Service air storage bottle. Refer to Chapter 12, Gear and Brake Pneumatic System - Servicing .

(l) Restore airplane to original configuration.

End Task

Task 78-31-00-710

4. Thrust Reversers Operational Test

A. Tools and Equipment.

(1) External Power Unit - MH32-200K24M or equivalent.

(2) Hydraulic Service Unit - CJMD129-002.

NOTE: This check is designed to ensure that the thrust reversers will not deploy in the air mode and that the cross-wiring is satisfactory. If any anomalies are observed, troubleshoot and correct the cause of the incorrect operation.

B. Preparation.

NOTE: Operational Test of the thrust reversers should be accomplished concurrently with the Landing Gear Functional Test. Refer to Task 32-01-00-710 for test procedure.

(1) If not already accomplished, jack the airplane to activate squat switches. Refer to Chapter 7, Lifting and Shoring.

(2) Connect the hydraulic service unit to the airplane.

CAUTION: Ensure that the airplane's ground suction source quick connect fitting is securely connected to the service cart return line fittings. Failure to do so could cause damage to the reservoir by over-pressurizing it.

(3) Connect and apply external electrical power (28.5 VDC, +0.5 or -0.5 VDC) to the airplane.

CAUTION: Failure to set circuit breakers and switches as indicated will cause engine damage.

(4) Disengage CLOCK, LH IGN, RH IGN, LH BOOST, RH BOOST, LH START and RH START circuit breakers.

(5) Set LH IGNITION and RH IGNITION switches to NORM position.

(6) Set LH FUEL BOOST and RH FUEL BOOST switches to OFF position.

(7) Place DC POWER switch to BATT position.

WARNING: Make sure that all personnel and equipment are clear of the thrust reverser areas while hydraulic power is applied. Thrust reversers operate quickly. Failure to observe precautions may result in personal injury or equipment damage.

C. Check Thrust Reversers.

CAUTION: Both hydraulic firewall shutoff valves must remain in the open position to prevent excessive shaft seal back pressure.

NOTE: While thrust reversers are operating or while one or both are deployed, the thrust reverser hydraulic system is continuously pressurized and the HYD PRESS ON light should be illuminated.

(1) Apply hydraulic power and adjust to provide a flow of 3 gallons per minute.

(2) Adjust hydraulic service unit reservoir return system back pressure valve to maintain 15 PSIG, +3 or -3 PSIG back pressure on the system.

(3) Working one at a time, place each engine throttle lever in and out of the idle thrust position several times. Leave throttles at idle thrust.

(4) Lift the thrust reverser levers approximately 30 degrees to arm the system. Attempt to deploy thrust reversers by pulling back and holding for approximately one minute.

(a) Verify that the thrust reverser levers cannot be moved further aft.

(b) Verify that the HYD PRESS ON annunciator and the ARM indicator light on the fire tray are illuminated. Ensure that the MASTER WARNING lights activate and flash at approximately three flashes per second. Reset MASTER WARNING light.

(c) Verify that the thrust reverser doors have not deployed.

WARNING: Ensure airplane is not lifted off of airplane wing jack while performing the following step. Transfer from air to ground mode normally occurs with 0.10 to 0.20 inch of strut compression. Keep personnel clear of airplane while performing this procedure.

(5) Using floor jack, jack left strut until both thrust reversers deploy.

(a) Observe that left and right ARM, UNLOCK, and DEPLOY indicator lights illuminate.

(b) As soon as the DEPLOY indicator lights are illuminated, move the thrust reverser levers full aft.

(c) Verify that thrust reversers deploy fully and do not scissor. If the doors do overlap (scissor), Nordam Service Bulletin Kit 78-8 should be installed. Order Service Bulletin through Citation Parts Distribution. One service bulletin should be ordered per thrust reverser assembly.

(6) Move both thrust reverser levers to the full forward position to stow reversers.

(a) Verify that both thrust reversers stow.

(b) Verify that left and right ARM, UNLOCK, and DEPLOY indicator lights extinguish.

(c) Verify HYD PRESS ON annunciator light is extinguished.

(7) Using thrust reverser levers, deploy the thrust reversers.

(a) Observe that both ARM, UNLOCK and DEPLOY indicator lights illuminate.

(b) Ensure that HYD PRESS ON annunciator light is illuminated.

(c) Lower floor jack until clear of strut.

(d) Disregard and reset MASTER WARNING if it flashes.

(8) Disengage LH THRUST REVERSER circuit breaker.

(a) Observe left ARM indicator light extinguishes.

(9) Position left emergency stow switch to EMER STOW.

(a) Observe that left thrust reverser stows.

(b) Observe that left UNLOCK and DEPLOY indicator lights extinguish, while left ARM indicator light illuminates.

(10) Position right emergency stow switch to EMER STOW.

(a) Observe that right thrust reverser remains deployed.

(b) Observe that the right ARM indicator light extinguishes.

(11) Push both thrust reverser levers full forward.

(a) Engage the LH THRUST REVERSER circuit breaker.

(b) Observe that right thrust reverser stows.

(c) Reset left and right emergency stow switches to NORMAL.

(d) Observe that all ARM, UNLOCK and DEPLOY indicator lights extinguish.

(e) Observe that HYD PRESS ON annunciator light is extinguished.

(12) Lift the thrust reverser levers approximately 30 degrees to arm the system. Attempt to deploy thrust reversers by pulling back and holding for approximately one minute.

(a) Verify that the thrust reverser levers cannot be moved further aft.

(b) Verify that the HYD PRESS ON annunciator and the ARM indicator lights on the fire tray are illuminated. Ensure that the MASTER WARNING lights activate and flash at approximately three flashes per second. Reset MASTER WARNING light.

(c) Verify that the thrust reversers have not deployed.

WARNING: Ensure airplane is not lifted off of airplane wing jack while performing the following step. Transfer from air to ground mode normally occurs with 0.10 to 0.20 inch of strut compression. Keep personnel clear of airplane while performing this procedure.

(13) Using floor jack, jack right strut until both thrust reversers deploy.

(a) Observe that left and right ARM, UNLOCK and DEPLOY indicator lights illuminate.

(b) As soon as the DEPLOY indicator lights are illuminated, move the thrust reverser levers full aft.

(14) Move both thrust reverser levers to the full forward position to stow reversers.

(a) Verify that both thrust reversers stow.

(b) Verify that left and right ARM, UNLOCK and DEPLOY indicator lights extinguish.

(c) Verify HYD PRESS ON annunciator light is extinguished.

(15) Using thrust reverser levers, deploy the thrust reversers.

(a) Observe that both ARM, UNLOCK and DEPLOY indicator lights illuminate.

(b) Ensure that HYD PRESS ON annunciator light is illuminated.

(c) Lower floor jack until clear of strut.

(d) Disregard and reset MASTER WARNING if it flashes.

(16) Disengage RH THRUST REVERSER circuit breaker.

(a) Observe right ARM indicator light extinguishes.

(17) Position right emergency stow switch to EMER STOW.

(a) Observe that right thrust reverser stows.

(b) Observe that right UNLOCK and DEPLOY indicator lights extinguish, while right ARM indicator light illuminates.

(11) Remove external electrical power.

(12) Position ANTI-SKID switch (S175) to OFF.

(13) Disengage SKID CONTROL (CB47) circuit breaker.

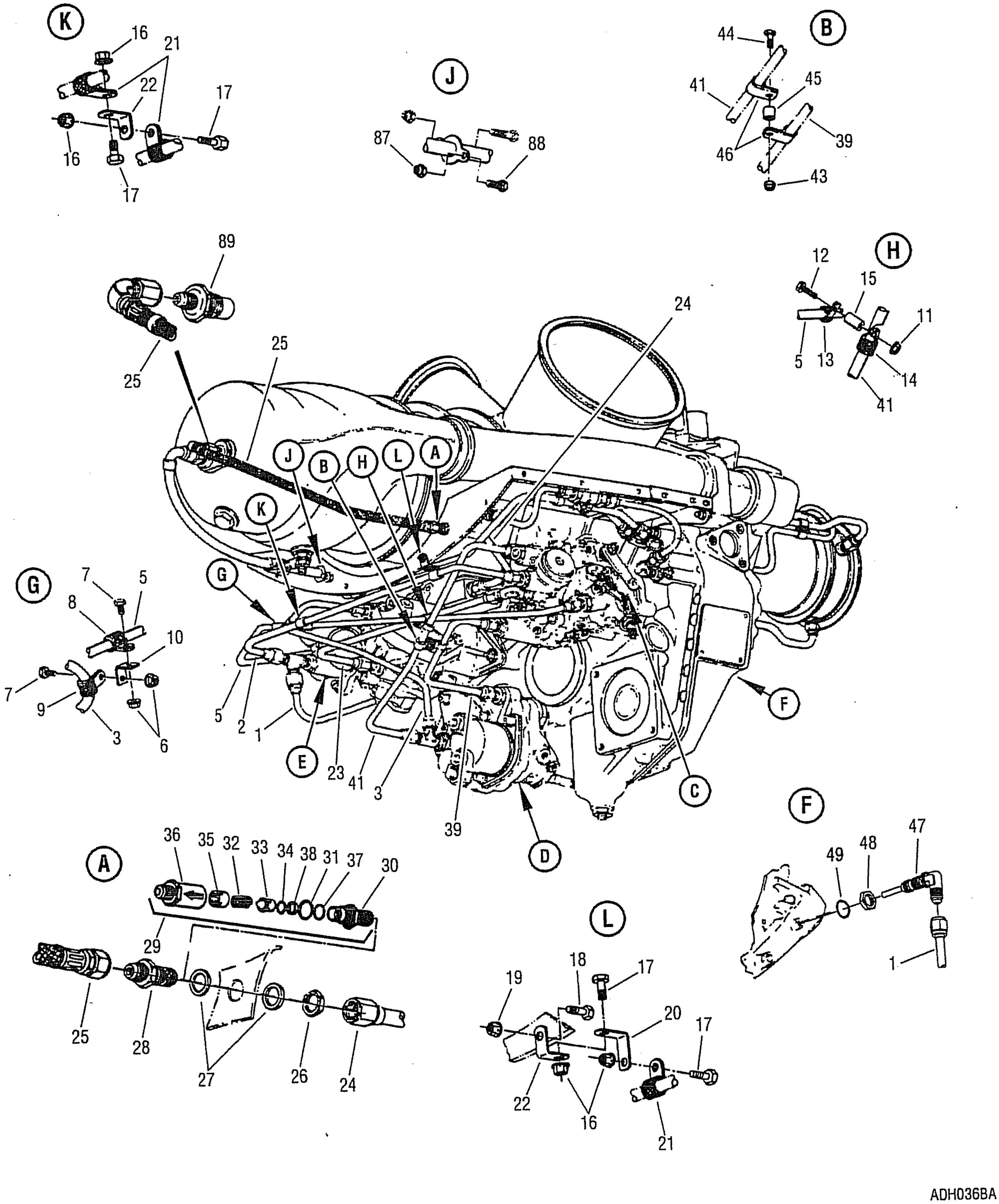
(14) Visually inspect hub caps and drive clips for cracks. Refer to Figure 203 .

(15) Inspect drive clips for security of attachment, proper clip opening dimension and wear.

(16) Install main gear wheel drive hubcaps and safety wire.

(17) Verify transducer drive clip properly engages transducer drive bar.

End Task



ENGINE FUEL SYSTEMS (GOODRICH CONTROLS) (250-C20, -C20B, -C20J)
FIGURE 1 (SHEET 1 OF 3)

R

FIG-ITEM	PART NUMBER	NOMENCLATURE 1234567	EFFECT CODE	UNITS PER ASSY
019	6859880	.NUT, SLFLKG, HEX, 0.164-36		1
- 019	6843624-836	..NUT, SLFLKG, 0.164-36		1
- 019	6828827-836	..NUT, SLFLKG, 0.164-36		ALT
- 019	6843620-86	..NUT, SLFLKG, 0.164-36		ALT
020	MS9165-04	.BRACKET, 90°		1
021	23039030-03	.CLAMP, CUSHIONED, 0.250 IN. (6.35 MM) ID		3
022	MS9165-02	.BRACKET, ANGLE, 90°		2
		---*---		
023	6875632	.TUBE ASSY, FUEL CONTROL TO POWER TURBINE GOVERNOR		1
024	6875634	.TUBE ASSY, FUEL CONTROL TO FIRESHIELD		1
- 025	6844703-047137	.HOSE ASSY, FIREWALL SHIELD TO FUEL NOZZLE FRO 6851549		1
- 025	6851549	.HOSE ASSY, FIREWALL SHIELD TO FUEL NOZZLE FRO 23005205 DISC.		1
025	23005205	.HOSE ASSY, FIREWALL SHIELD TO FUEL NOZZLE REF 250 CEB A-1319 DISC.		1
026	AN924-4J	.NUT, 0.438-20		1
- 026	AN924-4K	.NUT, 0.438-20		ALT
027	AN960-716	.WASHER, 0.438 IN. (11.11 MM) ID		2
028	AN832-4J	.UNION, 0.438-20 SB 6895171, PER 250 CEB 1101		1
- 028	AN832-4K	.UNION, 0.438-20 SB 6895171, PER 250 CEB 1101		ALT
029	6895171	.VALVE ASSY, CHECK S AN832-4C S AN832-4J S AN832-4K		1
030	32807T	..END PIECE V91816		1
031	32805L	..STATIC GASKET V91816		1
032	32802	..SPRING V91816		1
033	32806T	..POPPET V91816		1
034	4011-32	..O-RING, DYNAMIC V91816		1

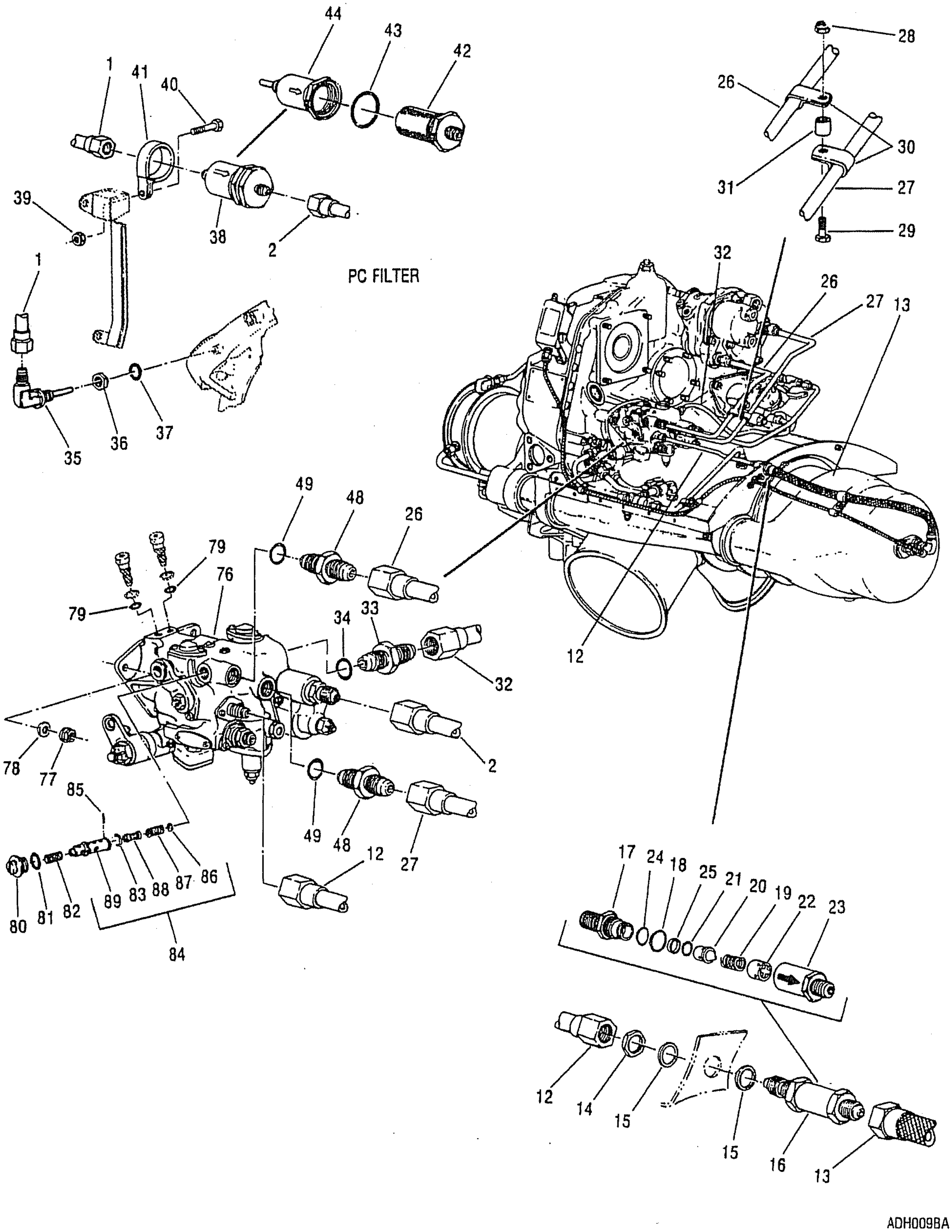
-ITEM NOT ILLUSTRATED
SEE APPENDIX D FOR MODEL APPLICABILITY CODES

R

FIG-ITEM	PART NUMBER	NOMENCLATURE 1234567	EFFECT CODE	UNITS PER ASSY
035	32801T	..GUIDE, SPRING V91816		1
036	32800T	..HOUSING V91816		1
037	32804T	..RING, BACKUP V91816		1
038	32803T	..SHROUD V91816		1
039	6875633	.TUBE ASSY, FUEL PUMP TO CONTROL UW SINGLE ELEMENT-TYPE PUMP & FILTER ASSY SB 6893626 & 6893627, PER 250 CEB A-1095		1
040	6875636	.TUBE ASSY, FUEL PUMP TO CONTROL UW DUAL ELEMENT-TYPE PUMP & FILTER ASSY SB 6893628 & 6894106, PER 250 CEB A-1095	AB	1
041	6853473	.TUBE ASSY, FUEL CONTROL TO PUMP BYPASS UW SINGLE ELEMENT-TYPE PUMP & FILTER ASSY		1
042	6853457	.TUBE ASSY, FUEL CONTROL TO PUMP BYPASS UW DUAL ELEMENT-TYPE PUMP & FILTER ASSY		1
		- ATTACHING PARTS -		
- 043	6810063-1032	.NUT, SLFLKG, HEX, 0.190-32 FRO MS21043-3		1
043	MS21043-3	.NUT, SLFLKG, 0.190-32		1
044	AN101013	.BOLT, 0.190-32 X 0.812 IN. (20.63 MM)		1
045	6857866	.BUSHING, SLEEVE, 0.210 ID X 0.250 OD X 0.375 IN. (5.33 X 6.35 X 9.53 MM) REF 250 CEB 1042		1
046	23039030-04	.CLAMP, CUSHIONED, 0.312 IN. (7.92 MM) ID		2
		---*---		
- 047	6850921	.ELBOW, PRESSURE PROBE, COMPRESSOR SCROLL SB 23073525, PER 250 CEB A-1374 DISC.		1
047	23073525	.ELBOW, PROBE, COMPRESSOR SCROLL SERV USE & SPARE PARTS PROC ON C20 REF 250 CEB A-1374		1
048	NAS509-7	.NUT, 0.438-20		1
049	AS3208-04	.PACKING, 0.351 IN. (8.92 MM) ID S AS3084-04		1
050	AN804-4J	.TEE, 0.437-20		1
- 050	AN804-4K	.TEE, 0.437-20		ALT
051	AN924-4J	.NUT, 0.438-20		1
- 051	AN924-4K	.NUT, 0.438-20		ALT

-ITEM NOT ILLUSTRATED
SEE APPENDIX D FOR MODEL APPLICABILITY CODES

R



Bendix Fuel System Components 250-C20S, -C20W
Figure 203 (Sheet 1 of 3)

Legend for Figure 203

1. Scroll-to-Pc filter tube
2. Pc filter-to-Governor tee tube
3. Nut
4. Bolt
5. Clamp
6. Bracket
7. Governor-to-fuel control tube
8. Not used
9. Not used
10. Not used
11. Not used
12. Fuel control-to-fireshield tube
13. Firewall shield-to-fuel nozzle hose
14. Nut
15. Washer (2)
16. Check valve assembly
17. End piece
18. Static gasket
19. Spring
20. Poppet
21. Dynamic Packing
22. Spring Guide
23. Housing
24. Back-up ring
25. Shroud
26. Fuel pump-to-fuel control tube
27. Fuel control-to-pump tube
28. Nut
29. Bolt
30. Clamps
31. Bushing

32A. Fuel control-to-governor Py tube

32. Fuel control-to-governor Py tube
33. Union
34. Packing
35. Pressure probe elbow
36. Nut
37. Packing
38. Pc filter
39. Nut
40. Bolt
41. Clamp
42. Filter element
43. Packing
44. Housing
45. Accumulator (0.7 cubic in.)
46. Union
47. Packing (2)
48. Union (4)
49. Packing (4)
50. Bushing
51. Packing
52. Fuel Control-to-Accumulator Pg Tube
53. Nut
54. Bolt
55. Spacer
56. Clamp
57. Nut
58. Elbow
59. Elbow
60. Packing
61. Accumulator (6 cubic in.)
62. Clamp
63. Check valve-to-governor hose
64. Governor
65. Nut (3)
66. Washer (3)
67. Packing
68. Fuel pump (single element)
69. Nut (3)
70. Washer (3)
71. Gasket
72. Packing
73. Packing
74. Filter element
75. Packing
76. Fuel control
77. Nut (3)
78. Washer (3)
79. Packing (2)
80. Plug
81. Packing
82. Spring
83. Clip
84. Filter assembly
85. Pin
86. Washer
87. Spring
88. Strainer
89. Sleeve
90. Not used
91. Fuel Nozzle

Table 14 (cont)

(1) P/N 6854292, 6857548, 6877719, 6856250 and 6876803 not complying with Rolls-Royce Commercial Engine Bulletin 250-C20 CEB-1051.

WARNING: MANDATORY COMPLIANCE DATE FOR 250-C20 CEB-1051 WAS AUGUST 30, 1980.

(2) Pumps which have complied with 250-C20 CEB-1051.

WARNING: MANDATORY COMPLIANCE DATE FOR 250-C20 CEB 1164 WAS JANUARY 1, 1985 FOR P/N 6895653 OCTOBER 31, 1985 FOR ALL OTHER P/N SINGLE ELEMENT PUMPS

(3) Pumps which have complied with 250-C20 CEB 1164.

(4) CECO fuel control and power turbine governor part numbers with "less issue" numbers have the same TBO as part numbers without "less issue" numbers. For example: CECO fuel control P/N 104000A11-A10 and P/N 104000A11 have the same TBO.

Table 15

On-Condition Accessories and Components[1]
Accumulators (Fuel System Pneumatic)
Anti-ice Valve
Burner Drain Valve
Combustion Liner
Compressor Discharge Air Tubes
Double Check Valve
Fuel System Check Valve
Igniter Lead
Igniter Plug
Ignition Exciter
Outer Combustion Case
P_c Air Filter
Tubes and Hoses (Fuel, Lube and Air)
Turbine Oil Check Valve

(1) May remain in service provided operation and condition is satisfactory. Refer to Inspection Check-sheet, Table 602, and Special Inspections, Table 604, 72-00-00, Engine-Inspection/Check, for inspection requirements.

Table 101
Troubleshooting (cont)

Item	Trouble	Probable Cause	Remedy
2 (cont)	Engine fails to light off (cont)	Insufficient fuel in tanks.	Fill tanks with fuel.
		Gas producer fuel control remains in cutoff.	Check linkage.
		Lightoff adjustment too low. (CECO control system only.)	Make lightoff adjustment. (Refer to para 3.F., 73-20-04.)
		Insufficient fuel pressure to fuel pump.	Turn on aircraft boost pump.
		Spark igniter firing intermittently	Check input voltage to exciter. Check ignition exciter by replacing temporarily with a known satisfactory unit.
		Fuel nozzle valve stuck	Replace fuel nozzle.
		Fuel pump inoperative (Fuel vapor will not be observed leaving the exhaust.)	Check pump for sheared drives or internal damage. Check for air leaks at in-let or fluid leaks at outlet.
		Water or other con-taminant in fuel	Check a sample of fuel from the bottom of the tank, if contaminated, disconnect the fuel line at the fuel nozzle, drain all fuel then flush the system with clean fuel.
		Fuel nozzle orifice clogged	Check fuel pump filter, re-place nozzle. (Refer to Filter Element Replacement, para 2.C., 73-10-01 or para 2., 73-10-05 and Fuel Nozzle, para 1., 73-10-03.)
		In-line fuel check valve fails to open	Replace in-line fuel check valve.
3	Early lightoff	Fuel control cutoff valve not closed	Make a fuel control cutoff valve operational check. (Refer to Cutoff Valve Operational Check-Bendix Fuel System, para 3.D., 73-20-02 or para 3.E., 73-20-03, or Cutoff Valve Operational Check-CECO Fuel System, para 3.D., 73-20-04.)

(18) Position left emergency stow switch to EMER STOW.

(a) Observe that left thrust reverser remains deployed.

(b) Observe that left ARM indicator light extinguishes.

(19) Push both thrust reverser levers full forward.

(a) Engage the RH THRUST REVERSER circuit breaker.

(b) Observe that left thrust reverser stows.

(c) Reset left and right emergency stow switches to NORMAL.

(d) Observe that all ARM, UNLOCK and DEPLOY indicator lights extinguish.

(e) Observe that HYD PRESS ON annunciator light is extinguished.

(20) Shut down and disconnect the hydraulic service unit.

(21) Remove external power.

(22) Place DC POWER switch to OFF.

End Task

Maintenance Manual Procedures for Task 8 – Routine Maintenance Oil and Filter Change

These procedures describe how to remove and install oil filters on the aircraft. (Filters – Maintenance Practices).

FILTERS - MAINTENANCE PRACTICES

1. Removal/Installation Filters.

   A. Prepare for Removal.

      (1) Special Tools and Equipment.

         (a) Caps and plugs (for filters and lines)

         (b) Container

   B. Remove Filters.

      (1) Hinge down left transmission service platform.

      (2) Hinge down large access door in aft rotary wing fairing.

      (3) Drain fluid tank by removing cap from tee under tank.

      (4) Remove clamps securing filters to panel.

      (5) Disconnect hydraulic lines and remove filters.

      NOTE: Observe direction of flow as indicated by arrow on filters for later installation.

      (6) Remove fittings. Install clean caps and plugs on hydraulic lines and filters.

   C. Prepare for Installation.

      (1) Consumable Materials.

         (a) Fluid, Hydraulic, Specification MIL-H-5606

   D. Install Filters.

      (1) Remove caps and plugs from hydraulic lines and filters. Install fittings and filters.

      CAUTION: TO INSURE PROPER OPERATION, INSTALL FILTERS WITH ARROW POINTING IN DIRECTION OF FLOW.

      (2) Secure filters to panel with clamps.

      (3) Service fluid tank.