Safety Boards and the Evolution of Predictive Safety Management

By Michael Cunningham (MO4361), Transportation Safety Board (TSB) of Canada

Mike Cunningham *has been flying since 1979 and holds an Airline Transport Pilots License. Also possessing an undergraduate degree in psychology, he was hired by the TSB as a regional investigator in 1992 when they were developing their human performance investigation capabilities. In 2003 he became a senior investigator at the TSB Head Office where he gained experience in major investigations. He is currently the TSB Air Branch Atlantic Regional Manager in Halifax, Nova Scotia.*

Aircraft Accident Safety Boards have a very important role to play in the evolution of safety management from reactive to predictive. Our challenge is to look beyond the immediate causes of accidents and incidents to identify as many of the underlying unsafe conditions as possible. At the 40th annual ISASI seminar in 2009 Frank Del Gandio reminded us of the importance of our investigations in his introduction when he said: " your work and the well-documented reports that you produce will continue to be the source material from which analysts begin to understand what questions they need to ask of the data".

The philosophy and organizational tools of Safety Management Systems (SMS) have been in practical use in Canada for about 10 years. The TSB recognizes that an effective SMS will identify unacceptable risks and appropriate mitigations, and this is clearly stated, frequently, in our reports. Although the investigation of organizational issues is not a new subject for ISASI members, this presentation will review how the TSB Air Branch looks at organizational issues and the implementation of SMS. Hopefully our experiences in this area of investigation and a description of the tools we have in place will give investigators some additional insight and food for thought.

TSB Investigation Tools

Our TSB Manual of Investigations instructs us that: "the identification of safety deficiencies should not be limited to only those that contributed to the occurrence. Any safety deficiency with accident potential should be pursued to document and validate the deficiency." The TSB has repeatedly demonstrated a strong capability in past investigations to identify underlying organizational issues. Our guide for Investigating Organizational and Management Factors also provides us with additional direction.

> Given the importance of both organizational culture and the role of management in managing risks it makes sense to investigate for these factors as systematically as other factors in an investigation. We are talking about the organization's ability to effectively identify latent unsafe conditions and implement appropriate defenses. A greater long term safety pay off will be realized by focusing investigations on the factors underlying the unsafe acts. In this way, an accident investigation represents an opportunity to examine the effectiveness of the overall safety management within an organization.

As we begin to collect and analyze data we enter it into the TSB's Integrated Safety Investigation Methodology (ISIM) software (developed in 2000). ISIM provides a means to maintain an overall understanding of an occurrence while on-going data collection, analysis, and safety communication are carried out. Thus, ISIM is a kind of living account of the occurrence. Event analysis proceeds with the identification of safety-significant events to which risk analysis, defence analysis, and risk control option analysis is applied. In addition, ISIM is used to help structure the written investigation report and the safety communications.

TSB Investigation Report Findings

The way we write our report findings also helps us to identify safety issues beyond the immediate causes. In the early 1980s the Canadian Aviation Safety Board began writing Findings as to Cause and Contributing Factors and Other Findings related to relevant non-causal safety deficiencies. Our current report format, established in 1998, has three types of findings and is similar to ICAO guidance and the models used by some other safety boards.

The Findings as to Causes and Contributing Factors identify elements that have been shown to have operated in the particular occurrence and are related to the unsafe acts, unsafe conditions and safety deficiencies. Basically the main purpose for these findings is to explain why the occurrence happened. Our Findings as to Risk identify other significant issues which include risks that have the potential to degrade safety and describes a condition that is systemic in nature. Depending on the ISIM risk assessment, the finding itself may be sufficient to identify the residual risk. If not, then the TSB may produce a separate safety communication. Other findings identify non-systemic elements that have the potential to enhance safety, resolve controversy or provide a data point.

Investigator Knowledge Development and Training

In addition to having adequate investigation tools, investigators must have the necessary knowledge. The TSB has been providing ISIM training since we developed the software, and we continue to offer it each year. Around 2003, we started sending our investigators on SMS courses to learn how to identify the basic components and the process outcomes. After a few investigations with SMS issues we started to develop some in-house expertise on the subject. Like most investigations, you usually have to educate yourself about the issues by researching them yourself. TSB senior investigator, David Ross who presented at the 41st annual ISASI seminar developed a two-day training program on conducting SMS investigations for our investigators.

During our SMS course we cover how and when you need to do an assessment of SMS components. Often a partial assessment is all that's required. For example an investigation that reveals that most SMS components are producing reasonable products but non-punitive hazard reporting is deficient might lead to a single finding as to risk. We also cover the various international models of SMS but we focus on the SMS On-Site Review Guide developed by TC for their inspectors, which identifies their SMS expectations and evaluation methods. Our investigators are taught that they must take the stage of SMS implementation into account to form reasonable expectations. To do otherwise would be unfair. When

investigators are evaluating SMS outcomes they are also instructed to remind themselves about hindsight biases especially when it comes to hazard identification and risk assessment. James Reason sums it up as follows in his book, *Managing the Risks of Organizational Accidents*:

> With hindsight, it is nearly always possible to identify, prior to a disaster, the presence of warning signs which, if heeded and acted upon, could have thwarted the accident sequence…How could these warnings have been missed or ignored at the time? There are a number of possible reasons why this happens, but most of them have to do with the fact that after-the-fact observers armed with 20/20 hindsight, view events quite differently from the active participants who possessed only limited foresight.

During the annual TSB Air Safety Investigators Workshop we hold for our investigators and industry, we try to always have at least one SMS reality piece to increase our SMS knowledge. Industry safety representatives are asked to present on their experiences with safety management. We ask them to talk realistically about their successes using SMS, the challenges encountered and where they can see room for improvement.

Finally we always try to use our resources effectively and investigators from any office in the TSB that have significant experience with organizational issues and SMS can be requested to help on any investigation. We believe very strongly in teamwork and see our final reports as the product of the TSB team and not of one individual. This resource utilization may come in handy as a considerable amount of effort is usually required to properly validate organizational deficiencies and it may not be every investigators cup-of-tea. The following is a review of two extensive TSB investigations involving safety management. These are very limited reviews; please refer to the final investigation reports for specific details. The first investigation reviewed began five years ago and the good news is, already many corrective actions have been taken as a result of both these investigations.

Fox Harbour Investigation (A07A0134)

Figure 1. Bombardier Global 5000 (A07A0134)

On 11 November 2007, a Bombardier Global 5000 corporate jet touched down seven feet short of the runway at Fox Harbour, a private airstrip in Nova Scotia. The right landing gear collapsed and following a rough ride the aircraft came to a stop 1000 feet away. Two occupants suffered serious injuries and there were eight minor injuries. The Global 5000, a new, larger aircraft to the operator's fleet, had only 92 hours total airframe time and it suffered extensive structural damage. Two investigators from the TSB Atlantic office and the Investigator in Charge from Head office deployed to the site.

Business aviation has been regulated in Canada since 1983. In 1999 there were 121 companies with operations certificates issued under Canadian Aviation Regulation (CAR) 604. Transport Canada (TC)

provided safety oversight by conducting audits, pilot proficiency checks, safety visits and incident follow-up. Between 1999 and 2001, TC and the Canadian Business Aviation Association (CBAA), the advocacy group representing business aircraft operators, conducted two joint studies which concluded it was feasible to transfer the regulatory responsibilities for CAR 604 operators to the CBAA. A broad-based SMS approach would be used in prescribing safety standards for the CBAA's dues paying members. A functional SMS was required as a condition for issuance of an operations certificate and a company risk profile would be the basis used to develop the operator's SMS. The studies noted that the CBAA would have to audit the operators' compliance with the safety standards and the work carried out by the CBAA's accredited auditors. These auditors were not employed by the CBAA, instead they were hired, and were paid an audit fee, directly by the operator. For additional safety oversight, TC would conduct periodic audits on the CBAA and their approved auditors. By 2007 the CBAA had close to 300 operators certificated under their program.

Following a considerable amount of review and research, these studies along with the SMS guidance produced by the CBAA, TC and ICAO were the principle documents the TSB investigation would be based on. With these documents, a performance based assessment of the processes used by the operator, the CBAA and TC would be conducted to identify and validate if there were any safety deficiencies in organizational safety management. Defining appropriate models, standards and expectations for the evaluation of occurrence events is a key component in a TSB investigation looking at organizational issues.

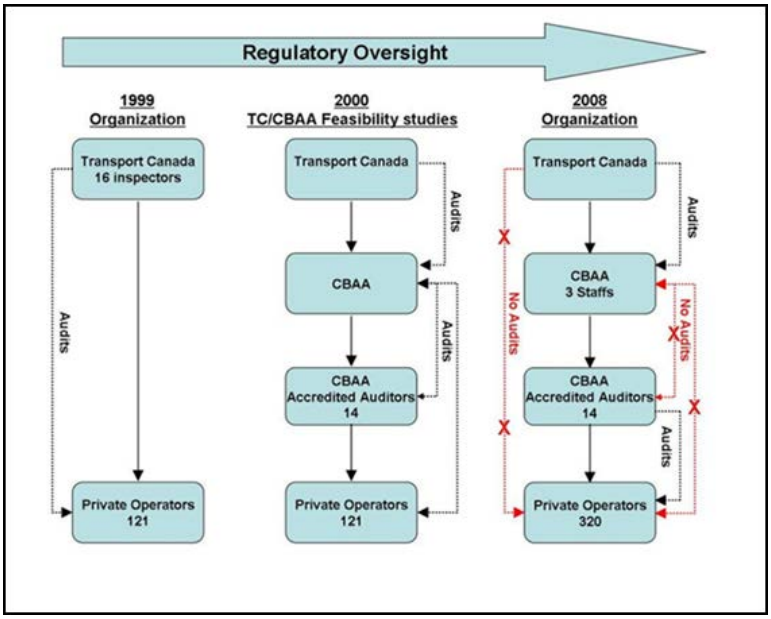

Figure 2. Evolving business aviation safety oversight model in Canada

Defining Standards

Using our ISIM process, events in the occurrence sequence are identified as potential safety significant events, worthy of further investigation by asking three questions. Is the event undesirable (e.g., from a safety risk perspective); is the event linked as an antecedent to an undesirable event, and finally; is the event non-standard. The models, standards and expectations used in determining if the event is non-standard and therefore safety significant are defined by the various regulations, standards, guidelines, and manuals in place at the time of the accident. Also material developed by subject matter experts in the field of organizational error and safety management may also be used.

Occasionally, other parties to the investigation may have a different perspective about the event being non-standard especially when it comes to voluntarily implementation of programs such as SMS.

According to the Oxford English Dictionary a standard is defined as: a required or agreed level of quality attainment. In some investigations the regulator or operator will consider only this definition, where a minimum regulatory standard exists, in forming their perspective of what the scope of a safety board investigation should be. This is a regulatory audit perspective. The second part of the definition says: "…something used as a measure, norm, or model in comparative measures." This is the definition the TSB uses in our assessment of non-standard events which may be safety significant. SMS models/expectations put in place by ICAO, regulators and transportation associations give Safety Boards the means to effectively assess organizational performance in safety management. These assessments will help organizations with strong safety cultures, to form realistic expectations and provide the data they need to make SMS improvements.

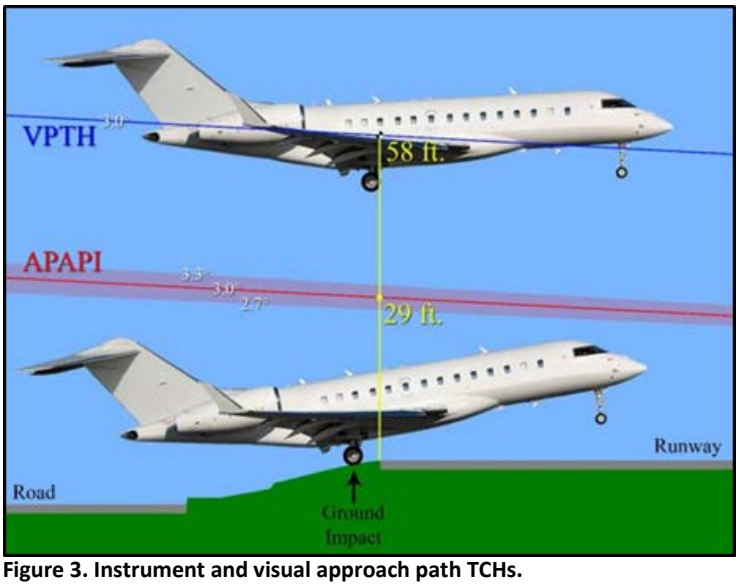

Figure 3. Instrument and visual approach path TCHs.

Fox Harbour Investigation Continued

During the Fox Harbour investigation among the many documents we reviewed was the operators' eight page SMS program and we identified a number of deficient elements. In the company risk profile all operational elements, even with the new, larger Global 5000 being added, were assessed as having a low risk. While SMS models typically identify that potential hazards should be assessed for both severity and probability to determine risk, the operator had assessed one set of operational factors for severity only, while assessing probability for an entirely different set of factors.

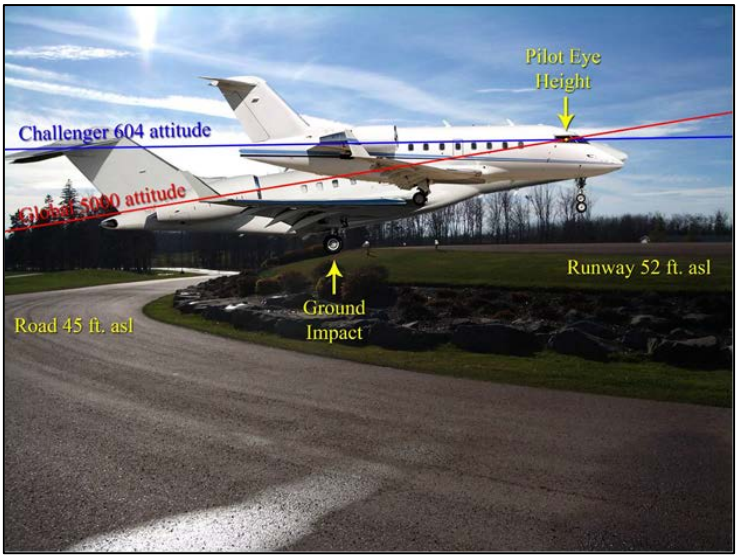

Figure 4. TCH comparison at same eye reference height for both aircraft

On the accident flight the approach profile was flown using visual cues established on previous flights in the Challenger 604, resulting in the early touchdown. A formal risk assessment of operating the Global 5000 into Fox Harbor, an airport with previously identified hazards, had not been done. A minimum safe threshold crossing height (TCH) with the instrument and visual references to assure it, were not established. To the TSB it seemed reasonable to expect a more through risk assessment from an operator with a functional SMS in its third year of implementation.

The CBAA exercised limited oversight of auditor activity, they did not review audit reports and only collected the audit cover sheet. Although the operator had a number of deficient SMS elements they had successfully passed three audits. The operator also had its management systems assessed by two independent audit organizations, on three separate occasions, all resulting in favorable assessments. These independent audits were also reviewed as part of the TSB's investigation. The TSB determined that, at the time of the accident, notwithstanding several successful audits, the operator was still following a traditional approach to safety management and not a reasonable model for an SMS.

A TC assessment of the CBAA program, early in 2006 also identified oversight deficiencies and the lack of a quality assurance component. The assessment was eventually closed without any final corrective action being documented. The TSB's investigation concluded that without the appropriate regulatory oversight, inadequate SMS audits may not be identified. As a result the TSB recommended (A09-06) that; "The Department of Transport ensure that the CBAA implement an effective quality assurance program for auditing certificate holders."

The CBAA did not believe it was responsible for enforcing regulatory compliance and therefore did not enforce a timetable for private operators to implement the various levels of SMS. Therefore the TSB recommended (A09-05) that "the CBAA set safety management system implementation milestones for its certificate holders."

The TSBs final report was released on 10 November 2009. On 16 March, 2010 the Transport Minister announced that they were taking back certification and oversight functions of business aircraft from the CBAA effective April, 2011. The Minister cited the 2007 crash at Fox Harbour as one example of the need for change.

Cougar 91 Investigation (A09A0016)

On 12 March 2009 a Sikorsky S-92A off the coast of Newfoundland had a total loss of oil in the transmission's main gear box (MGB) resulting from a broken titanium mounting stud on the filter bowl assembly. Approximately 35 nautical miles from St. John's, about 10 minutes after first warning, the tail rotor drive failed. During the attempted ditching the helicopter struck the water in a high rate of descent. One passenger survived with serious injuries and the other seventeen occupants of the helicopter died of drowning.

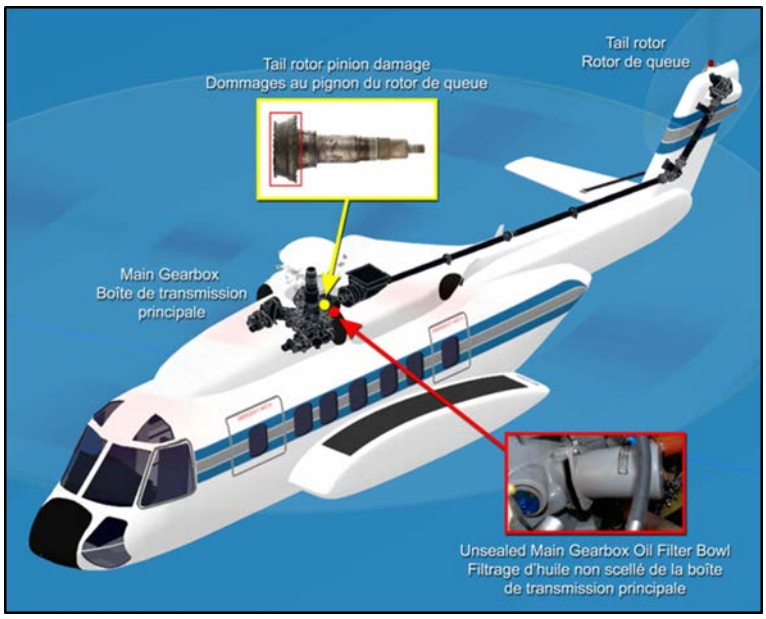

Figure 5. S-92A location of MGB filter bowl and tail rotor pinion

This was not the first time a total loss of MGB oil had happened to an S-92A. On 02 July 2008, an S-92A en route from an Australian offshore oil facility had an almost identical failure. With land directly ahead, an immediate descent was initiated and the helicopter was safely down approximately seven minutes later. Two of the three MGB oil filter bowl titanium mounting studs had fractured and the oil was lost; however there was no damage to the MGB. Both the operator and the manufacturer began a review of the circumstances. In the 6 years the S-92A had been in service this was the first reported instance of a MGB total loss of lubricant.

The manufacturer had selected titanium alloy studs as fasteners on the S-92A oil filter bowl due to its corrosion resistance and lighter weight as compared to steel. As well they had been used before and there was no reported history of stud failures. The S-92A had anodized titanium alloy filter bowl studs and silver-plated steel nuts. Anodizing and plating increases resistance to corrosion, wear and galling. Galling is a type of adhesive wear, whereby material is removed or displaced from a surface. The Selection and Use of Titanium, A Design Guide, provides the following information about titanium galling:

Figure 6. S-92A broken MGB filter bowl mounting stud

> The surfaces of titanium and of all commercially produced alloys of titanium have relatively poor wear resistance. In particular, titanium surfaces in contact with each other or with other metals readily gall under conditions of sliding contact or fretting. Even with light loading and little relative movement, complete seizure of surfaces can occur.

The S-92A oil filter anticipated replacement period was 500 hours, so in theory an oil filter bowl would be unfastened only five times on the 2700-hour life of the MGB. However, if the impending bypass button popped, indicating the filters were beginning to clog, the filters were changed earlier. On average, S-92A operators were experiencing impending bypass conditions about every 220 hours and the Cougar 91 aircraft already had its MGB oil filter replaced 11 times. The root cause for the frequent impending bypass conditions remained undetermined. The TSB's examination of new exemplar

Figure 7. Cougar 91 wreckage layout.

studs found that even with a coating to prevent galling, damage to the threads developed after the first installation of a nut and became more severe each time the nut was removed and re-installed.

The manufacturer had a safety management program integrated into its operation. The program utilized several processes to identify hazards and manage risk. Once potential hazards were identified, the level of risk was assessed and mitigating actions were determined. When a mitigation plan was arrived at and a corrective action put in place, the safety process loop was closed by monitoring the outcome.

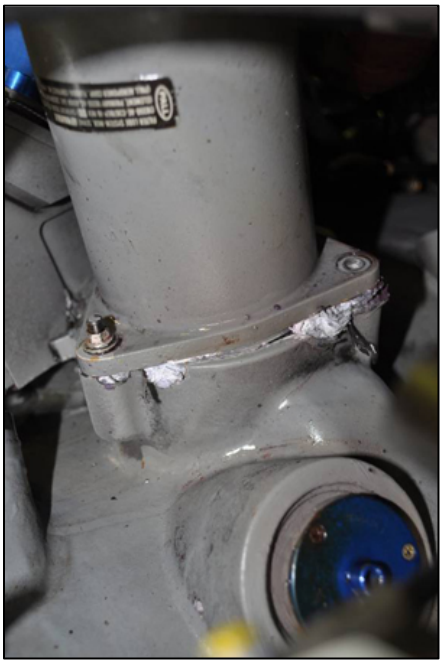

Figure 8. Cougar 91 missing filter bowl stud

Following the Australian incident the manufacture began taking a number of steps to mitigate the chance of another similar occurrence. An examination in August 2008 determined the most probable cause for the stud fracture was inadequate preload on the nut, possibly caused by galling on the titanium studs threads. During regular webcasts with S-92A operators following the Australian incident the manufacturer advised that extra attention be given to the condition of filter bowl fasteners. None of the S-92A operators expressed any concern about the condition of the titanium studs on their helicopters. Meanwhile plans were underway to replace the titanium studs with stronger steel ones, more resistant to galling.

The manufacturer determined that the immediate risk of a reoccurrence could be mitigated by modifying existing maintenance procedures. On 08 October 2008 they issued a safety advisory about upcoming changes to the maintenance manual which included an enhanced visual examination of the studs. On 05 November 2008, these enhanced inspection procedures became mandatory industry-wide. If any thread galling was detected, the titanium studs were to be replaced immediately.

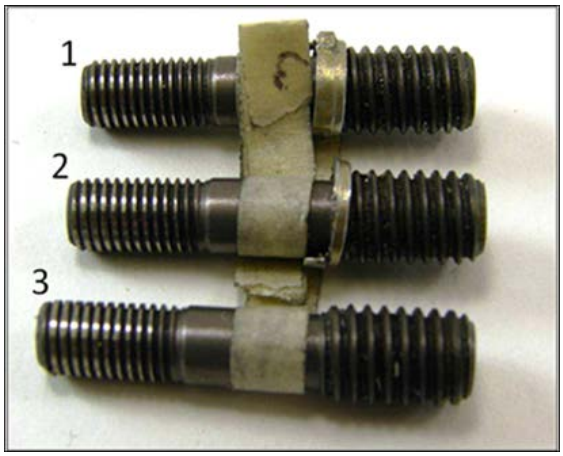

Figure 9. Filter Bowl studs returned with thread galling

On 28 January 2009, Sikorsky issued Alert Service Bulletin (ASB) 92-63-014 requiring the replacement of the MGB filter bowl titanium mounting studs with steel studs, within 1250 flight hours or 1 year. It stated:

> Undetected damage to an oil filter stud can lead to failure of the stud. Enhanced procedures are being added to the maintenance manual to help identify potentially damaged studs. To further enhance reliability of this connection, the titanium studs are being replaced with steel.

About six weeks later Cougar 91 crashed. Eventually 59 studs from various operators were returned to the manufacture and they all had varying degrees of galling of the threads. It was concluded that most S-92A operators had not followed the new maintenance procedure; therefore, damaged studs were not detected and replaced. The TSB report theorized that the low compliance rate for these mandatory procedures could be attributed to the possibility that operators did not clearly understand the underlying reasons and appreciate that a failed MGB filter bowl mounting stud would lead to the failure of the MGB.

The Cougar 91 final report, released on 09 February 2011, contained 16 Findings as to Cause and Contributing Factors, 26 Findings as to Risk and 4 Other Findings. The principle one of interest to us here today was that galling prevented adequate preload on the nut which lead to fatigue cracking of the mounting stud. The Cougar 91 report did not have any findings related to SMS deficiencies. In an attempt to develop reasonable expectations for practical SMS application it did however note that:

> an effective SMS can be instrumental in detecting and mitigating deficiencies before they contribute to an accident if those processes are applied thoroughly and without biases. A fully functioning safety management process would be expected to rigorously challenge and validate any underlying assumptions about safety risks. Neither the FAA nor the manufacturer had specifically considered a failure in the MGB oil filter bowl assembly, or its attaching fasteners as possibly leading to a total loss of lubricant. Following the Australian occurrence, the manufacturer identified and mitigated the risk of galled studs with revised maintenance procedures. However the communication of the rationale for this revision and the associated guidance proved ineffective in stressing the potential consequences of non-compliance.

The operator had been in the process of implementing modern safety management concepts into its operations for several years. Their SMS was not a regulatory requirement, so it had not been assessed by TC. However, the operator was subject to external oversight, and their SMS had been audited several times in the past with no significant deficiencies identified. The TSB's investigation took all this into account, including hind sight biases, to form what we felt were reasonable expectations for the SMS in place at the time of the accident. As a result, the report concluded the SMS program was not fully implemented and all the proactive elements were not yet being utilized effectively. Despite the operator's commitment to SMS, some additional risks associated with its operation went undetected prior to this occurrence. These residual risks were identified among the 26 Findings as to Risk in the report.

While SMS can reduce the potential of accidents by applying proactive safety processes, it would be unrealistic to expect that an SMS could prevent every accident. This occurrence highlights that vulnerability, as seen by the fact that both the manufacturer and the operator had safety management and risk management processes.

Summary of Challenges

The TSB released its first safety Watchlist in 2010 identifying the implementation of SMS in all modes of Canadian transportation as one area of concern. Our most recent Watchlist released 14th June 2012 has

identified that SMS implementation is still a concern in Canadian aviation. Although Canada's large commercial carriers have had SMS regulations in place since 2005, implementation has been delayed for smaller operators, such as air taxi operations and commuters. Yet together, this group incurred 91 percent of commercial aircraft accidents and 93 percent of commercial fatalities from 2002 to 2011. The TSB has indicated we will continue to monitor how new regulations address the establishment of SMS implementation and SMS oversight for aviation operators.

Following the TSB's mandate and the direction given by senior management is always important when it comes to the investigation of organizational issues. One of our Board members, Kathy Fox, has a Master of Science in Human Factors and System Safety from Lund University in Sweden. You need competent investigators trained in the investigation of organizational issues, knowledgeable about modern safety management concepts and equipped with effective investigation tools. You must use all available standards and models for SMS, considering the stage of program implementation in order to form practical, unbiased findings. The TSB also knows a comprehensive investigation will uncover many of the underlying factors of accidents and incidents. Our Chair Wendy Tadros summed this up very nicely during the Cougar 91 public release.

> The investigation into Cougar Flight 91 was one of the most complex the Board has ever undertaken. It involved many, many experts, dozens of engineering tests, and thousands of hours of research and analysis. Today's report is the culmination of two years of work. ….this tragedy was about more than failed titanium studs, and had our investigation stopped there, that would have been too simplistic. So in the months that followed, we dug deeper, and we found many underlying problems.

This being said, in times of dwindling operating budgets, you are challenged to make sound decisions regarding the scope and depth of any investigation. At the 37th annual ISASI seminar, Nick Stoss, former Director of the TSB Air Investigations Branch talked about this.

> When a lack of resources will dictate that the investigation team cannot investigate all deficiencies or ambiguities discovered during the investigation, hard decisions have to be made. Important criteria for these decisions should be the relationship of the potential investigation area with the identified safety significant events of the occurrence, as well as on the potential of the additional investigation work to result in significant enhancements to aviation safety.

With all these challenges successfully managed Safety Boards can make meaningful contributions to the advancement of safety and the evolution of safety management. A better practical understanding of the capabilities of SMS can be achieved so the best of its products can be used in an effective proactive manner. Earlier I mentioned the Cougar 91 report concluded "it would be unrealistic to expect that an SMS could prevent every accident." That statement is true in that it is unrealistic to think that any SMS could predict the complex interaction of 16 separate factors contributing to an accident. However the good news is an effective SMS doesn't have to! Again our Chair Wendy Tadros hit the nail on the head during her opening remarks at the Cougar 91 press conference when she noted:

> We have identified 16 factors that contributed to this accident. Take any one of them out of the equation, and we likely would not be here today.

Mature, robust safety management programs will be able to better mitigate the risks identified in the aftermath of Cougar 91. Some systems may even be capable of evolving from reactive to predictive abilities as a result of research and development by experts in organizational management, fuelled with the results of comprehensive safety board investigations.

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