GE Aviation SMS Framework and Investigation Lessons Learned
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Executive Summary

1) GE Aviation has a continuously evolving safety culture that relies on the decision of safety teams versus individual safety decisions. GE Aviation believes it has an operating design and manufacturing SMS that meets the intent of ICAO Annex 19.
2) Safety management in large organizations is driven through assurance processes that drive recognition of policies and compliance to them. Reliance on these components is sufficient to assure organizational activities are acting in the interest of safety versus prescriptive regulatory organizational mandates.
3) Lessons learned from the design, development, and operationalization of products / services need to be institutionalized.
4) SMS is a best practice and therefore regulatory requirements will yield little overall improvement in aviation safety versus voluntary adoption.
5) The aviation quality standards serve as a model for implementing an "other" party SMS accreditation and international recognition of state safety programs.

SMS Development at an Engine Manufacturer

July 19, 1989 was a turning point for many in the Aviation Industry but in terms of culture, GE Aviation's safety culture has inextricable linkage to the Sioux City, IA crash of Flt 232. The center engine had a fan disk burst that resulted in the loss of aircraft hydraulics. The crew wrestled the aircraft to a crash landing where 185 people survived and 111 died (1). The investigation ultimately found that a hard alpha inclusion, undetectable at the time, was present in the disk. GE Aviation used the event as an opportunity to seek out lessons learned. One of the key results from this review was the creation of a formal safety policy and process. To this day, these form the core of what has become GE Aviation's Safety Management System. The most important lesson learned was that while safety is owned by all, no individual should make a unilateral safety concern closure decision. Safety is a team effort and safety decisions need to be vetted as a team.

Safety and quality are at the core of each product GE Aviation designs, manufactures and supports. Enhancing processes and standards is an ongoing endeavor. GE Aviation actively seeks out improved methods and technologies that will make products even safer; build upon the standards of the past; and take advantage of lessons learned in service. GE Aviation also works closely with organizations like the International Civil Aviation Organization (ICAO) and the Federal Aviation Administration to implement programs that will keep the flying public safe.

In 2006, ICAO recommended that all aviation authorities implement Safety Management System (SMS) regulatory structures, to identify their aviation risks and avoid them. Following the Colgan Air accident in 2009, The United States Congress signed the Airline Safety and Federal Aviation Administration Extension Act, which requires US airlines to have an SMS. The FAA also drafted a series of proposed rules requiring SMS for design (Type) and manufacturing (Production) certificate holders; the exact requirements and methods of oversight are still being negotiated as of this writing.

GE Aviation has been working with the regulatory authorities since 2006, helping structure SMS expectations and requirements that will provide an effective and efficient framework for product safety. In January 2013, GE Aviation introduced its own voluntary SMS, structured around an internationally agreed framework (ICAO Annex 19), to provide a robust product safety framework at GE Aviation.

The GE Aviation Safety Management System:

- Makes sure policies support a product safety approach. It has a policy that covers our Product Safety philosophy at a high level, and then implementing procedures that explain the details of executing the Safety Management System. It is important to note that rather than having a centralized command-and-control of daily engineering activities, the system relies on having a highly delegated approach to empowering individuals to apply situation-specific judgment and personal expertise, within the broad controlling parameters laid down by policy.
- Standardizes the Safety Risk Management process. Safety Program Management Teams (SPMTs) are the focal points for managing safety risk. They evaluate each safety concern against pre-set criteria, to see whether immediate action is needed to reduce risk to acceptable levels. Engine manufacturers are able to use Advisory Circular 39-8 Continued Airworthiness Assessment and Methodology (CAAM) for guidance (3). Where appropriate, they develop and implement risk control programs. The team includes members from Safety, Engineering, Programs, and Product Support.
- Assures that product safety policy and procedures are followed, and that the safety work is effective in controlling risk. The Flight Safety and Reliability organization oversees the safety process compliance and effectiveness so that the right measures are in place to ensure product safety.
- Shares important information about product safety. Flight Safety and Reliability works with Design Boards, Quality and Product Support to make sure lessons learned are communicated throughout the organization and captured for future product development.

SMS Assurance

GE Aviation's internal Safety Management System was developed leveraging existing processes as much as possible, to make the best possible use of expertise already in place and to minimize disruption to systems which are working well. The safety oversight of the product type design was already being addressed by the certification process and by our Design Review system, in which the best expertise in the company assesses the design for robustness and functionality. The safety oversight of the production system was already addressed by the Quality Management System, focused on ensuring conformance to the type design. The continued operational safety of our products in service was addressed by the Safety Program Management Teams, cross-functional teams aligned by product model, which control the safety risks of our engines in accordance with the process documented in AC39-8. The Safety Program Management Teams receive oversight by the Product Safety Review Board, which is composed of vice-presidents and other senior executives.

The Flight Safety and Reliability office provides oversight to the SMS as a whole, checking both that SMS processes are being followed and that they are effective. Specific assurance measures introduced to ensure smooth integration of legacy processes into a single SMS include:

- Focused SPMT process metrics, providing visibility to senior management of timeliness in addressing concerns and fidelity to planned risk abatement programs.
- Audits of SPMTs, verifying that they are following the prescribed process.
- Audits of company policy and product safety training/communications, verifying they support the ICAO Annex 19 framework elements.
- Culture survey, testing durability of training, and credibility of process for reporting safety concerns.

Audits were conducted by Flight Safety and Reliability staff, and positioned as an opportunity to learn and improve, rather than be a punitive exercise. Each identified gap was met with a corrective action. The effectiveness of gap closure actions will be assessed during a second audit cycle, in 2015. The results showed good alignment with ICAO Annex 19 and with the company policy; opportunities for improvement were seen in the areas of documentation, of communication between engine programs, and of integrating lessons learned into the overall knowledge base of the company. In each case, corrective actions have been introduced to address the gap going forward. A few aspects of Annex 19 are difficult to interpret from a Design/Manufacture perspective; GE Aviation is caucusing with the AIA/GAMA membership to develop common solutions to these difficulties.

The audits to date have highlighted that safety management, in large organizations such as GE Aviation, is driven through assurance processes that drive recognition of policies and compliance to them. Audits bring awareness and visibility and therefore reliance on them is arguably sufficient to assure organizational activities are acting in the interest of safety versus prescriptive regulatory organizational mandates.

SM ICG Tool Evaluation Summary

There have been concerns expressed from stakeholders that variance in SMS requirements among countries could lead to difficulties with exporting products or services. Potentially, the Design and Manufacture (D&M) organization might need its SMS approved by a large number of regulatory authorities, to permit exports to those countries. Mutual recognizance of each accredited SMS would remove this redundant effort; but would require a firm basis for the mutual recognizance – a common international expectation of what an SMS looks like.

In response to the industry need for a single international expectation for SMSs, the regulatory authorities of many countries have been working together in the forum of the Safety Management International Collaboration Group (SMICG) to develop a common approach. A promising outcome has been the SMICG evaluation tool (4), which is based upon ICAO's Annex 19 Appendix 2.

Several major D&M organizations have voluntarily adopted SMS's based upon their understanding of Annex 19 in advance of any regulatory requirement. Review of the internal SMS through the lens of the ICG tool provides valuable insights into the expectations of the regulators versus the hands-on interpretation of Annex 19, providing a valuable opportunity for dialog.

GE Aviation conducted such a review in late 2013, scoring our internal SMS with the SMICG tool. We limited our scoring to a binary pass/fail approach, rather than discriminating between four levels of compliance as proposed in the tool. Our voluntary SMS complied with sixty of the sixty-nine "indicators of performance", and thirty-seven of the fifty-four "best practices" (which are not as closely aligned with Annex 19). The main areas of difference were in the scope of safety assurance activities and in the management of organizational change (see Figure 1). The primary area of variance was related to safety objectives. GE has chosen to set safety objectives in very general terms (a portion of our purpose statement: "Bring Them Home Safely") so that each employee can bring their own context and apply the objective to their own task.

GE Aviation believes that the tool itself requires some refinement, to enable consistent findings among a wide range of auditors but it does form the basis for a standard evaluation tool that can be used across state boundaries. The evaluation tool does depend upon the subjective judgment of the auditor and therefore any application requires appropriate training of the auditors in order to avoid potential variation in findings.

Safety Program Management Team Process

A critical lesson learned from the Sioux City event was that while every individual is responsible for safety, the resolution of safety concerns should be done on a team basis. One person unilaterally should not be making decisions related to safety issue resolution. This recognition drove the formation of product line based, Safety Program Management Teams (SPMTs). These teams consist of voting representatives from Safety, Engineering, Product Support, and the Program. Typically, the program member serves as the SPMT chair. The rhythm of meetings varies but policy requires that an SPMT meeting is held at least once a month. Field events that are potential safety concerns can be brought to an emergency SPMT if required.

All safety concerns raised for a specific product line are brought to a SPMT meeting for disposition to determine if the concern meets safety criteria or not following. All product lines follow the SPMT process as shown in Figure 2. The first phase is the "Under Investigation" phase. In some cases, this disposition may require additional information before a safety decision can be reached. Items that do not meet the safety criteria are closed non-safety. An item that is determined to be a safety issue moves to the Root Cause Analysis / Control Program Phase. The determination of root cause follows the Team Oriented Problem Solving 8D process (TOPS8D). The "D's" are the steps and tools used. This can be a lengthy process so for many issues some level of Control Program may also be required while root cause is being determined. Common short term mitigations include inspections, shorter interval component lives, operational procedures, and part replacements. The speed of these actions is typically driven by the AC39-8 guidance and customer requirements. Once root cause is determined, a final corrective action plan needs to be defined so the safety issue moves to the Corrective Action / Compliance Tracking Phase. For safety issues, on the commercial product lines, this corrective action will usually be communicated to the field with an FAA Airworthiness Directive that calls out an Alert Service Bulletin that contains the Corrective Action. Once released, the corrective action is tracked to full compliance where practical. Once a field plan is implemented and a controlling document is in place (such as an Airworthiness Directive) the safety concern can be "Closed – Safety" if the SPMT desires.

The SPMT process and the product line SPMT's form the working foundation of the safety process. To assure visibility of their activities, GE Aviation also holds a series of reviews at increasing levels of management to assure that the visibility of all items reaches as broad of scope as possible. These reviews are noted in Figure 3 and start at the SPMT level with a weekly/monthly rhythm and go up to the President, CEO of GE Aviation on an annual basis. This visibility provides a means to assure that lessons learned are both institutionalized and communicated across the full breadth of the organization.

Lessons Learned Examples

GE90 Transfer Gearbox (TGB) IFSD Event

Event Date:	February 2013
Engine Model:	GE90
Brief Description:	TGB pinion gear through crack leading to IFSD (see Figure 4)
Control Program:	Identify suspect lot & inspect / de-twin fleet. On-wing inspection was available. Fleet de-twin completed in five days. Introduced enhanced inspections and shot peening.
Root Cause Analysis:	Imperfections in temporary copper plating during gear processing led to local decarburization which acted as stress risers leading to cracks.
Corrective Action:	Change atmosphere in furnace to eliminate possibility of decarburization.

Discussion: The above event brief at first glance oversimplifies the actual SPMT process path that was almost a one year effort. As noted above, the initial mitigation via field program was executed in a matter of days. However, the path to root cause was complicated. At first there were suspicions that the removal of shot-peening during the manufacturing process had resulted in stresses that allowed crack propagation and growth. Decarburization of the part was then indicated so the focus moved to the austenitizing furnace atmosphere. The solution was ultimately defining an austenitizing furnace protective atmosphere which avoided decarburization regardless the copper plating thickness. The furnace protective atmosphere is more effective than shot peening (mainly because some gear area could not be shot peened). It was noted that copper plating measurements are not fully reliable and handling damage could lead to insufficient copper thickness. Lessons learned are being applied to other applications via addressing copper plating thickness checks and design requirements.

CF6-80C2 Undercowl Fire

Event Date:	May 1994
Engine Model:	CF6-80C2
Brief Description:	Undercowl fuel leak and fire leading to an IFSD and release of both fire extinguishing bottles. The undercowl fire was extinguished and the fire warning went out. The aircraft dumped fuel and returned to the airport. Heat/fire distress to engine and thrust reverser components was evident. The fuel leak was isolated to a fuel/oil heat exchanger bolted fuel joint consisting of four bolts and a gasket seal. A section of the gasket seal had been extruded/cut leading to large fuel leak which was ignited by the hot engine cases in the core compartment. The heat exchanger had been changed the night before the event flight. A five minute idle leak check was accomplished following the maintenance action with no leaks noted.
Control Program:	A once through the fleet inspection of the fuel joint was accomplished. GE also issued a bulletin to operators emphasizing the importance of performing a visual check of the joint following maintenance in the area to ensure that the flange and gasket seal were properly aligned and seated and that the bolts were securely fastened. Maintenance manual revisions were coordinated with the airframers to clarify the assembly of this joint and emphasize inspection of the joint after assembly.
Root Cause Analysis:	The bolted fuel joint consisted of a swivel flange resting on the tube ferrule and a gasket seal between the swivel flange and heat exchanger. The joint was held together with four bolts. The joint also supported a number of brackets and a spray shield (see Figures 5 and 6). Limited visibility and accessibility exacerbated a difficult assembly. Witness marks on the parts indicated that the swivel flange got hung-up on the shoulder of the tube ferrule during installation. This allowed the four bolts to be fully torqued and held the tube ferrule tightly against the gasket seal which allowed the joint to pass the idle leak check. The improperly assembled joint was also masked from view by the spray shields, brackets, and adjacent hardware. The swivel flange slipped off of the ferrule shoulder during takeoff which reduced the clamping force on the joint and allowed the high pressure fuel to extrude/cut the gasket and leak into the core compartment.
Corrective Action:	GE issued a service bulletin introducing a new four-bolt swivel flange with an increased chamfer and tighter hole tolerances to prevent the possibility of hang-up and subsequent fuel leak. GE also simplified the joint assembly by combining multiple brackets and the spray shield into one. Also, the spray shield was abbreviated to improve joint visibility.

Discussion: The operator categorized this event as maintenance error following the initial investigation. While this was technically accurate, the joint design made proper assembly of the joint very difficult. A records search revealed nine prior fuel leaks at this joint, most of which followed maintenance action which disturbed the joint. Improved swivel joint design was the major improvement; however, it was still a complicated joint to assemble. The simplified bracket design and smaller spray shield eased the assembly burden and improved visibility of the assembled joint. The designs of all similar bolted joints were reviewed and modified to eliminate the possibility of swivel flange hang-up. GE design practices were modified to include the lessons learned from this event. Brackets supported by bolted fluid joints are limited to very rare instances and the bracket-to-bolted joint interface is strictly controlled. Spray shields are eliminated where practical and their size as small as possible to allow better visibility of the joint. GE continues to work with our partners and airframers to eliminate the need for spray shields. Bolted joints are only used where the tubes are too large to allow the use of a simple B-nut style joint due to B-nut torque requirements. GE continues to improve the reliability of flammable fluid systems. Simple, visible, accessible joints are the most reliable. As part of our SMS program, we have established a Human Factors group to evaluate designs, processes, assemblies, and instructions in an attempt to reduce maintenance related operational issues.

CFM56-3 Dual Engine Oil Loss

Event Dates:	July 1988, February 1995, April 2005, May 2011 (Forced Landing)
Engine Model:	CFM56-3
Brief Description:	Before the flight, borescope inspection (BSI) of both engines was performed and the covers on the hand cranking pads of both Accessory Gear Boxes (AGBs) were not reinstalled after BSI. This allowed engine oil to leak leading to low oil quantity on both engines and a forced landing. The engines operated for approximately 18 minutes with less than minimum oil pressure. Figure 7 shows a cross-section of the area.
Control Program:	Several actions were implemented including adding a lanyard to the cover plate and adding a caution plate. Cautions were put in the maintenance manuals. Communications were sent recommending that all operators consider instituting a policy of avoiding maintenance on similar or dual systems using the same personnel during a single maintenance visit.
Root Cause Analysis:	The AGB hand crank pad cover includes the seal which prevents oil leakage. Changing to an oil dynamic seal assembly prevents oil leakage even if the cover is left off.
Corrective Action:	The SMS process led to the introduction of an oil dynamic seal assembly. The SMS process required monitoring of the implementation rate on the existing fleet which was found to be low. Efforts were made to drive the implementation into the fleet. EASA released AD 2012-0209 requiring implementation of the oil dynamic seal assembly at next shop visit. The FAA released AD 2013-26-01 requiring an independent inspection to verify re-installation of the AGB hand cranking pad cover after any maintenance that involves the removal and re-installation of the AGB hand cranking cover with the optional installation of the oil dynamic seal assembly as closing action for the AD. Note that for the purpose of this AD, an Independent Inspection means a second inspection by a qualified individual who was not involved in the original re-installation of the AGB hand cranking pad cover following maintenance to confirm that the cover is installed correctly.

Discussion: Corrective action for early events were implemented but were later proven to be less than 100% effective. This discovery was in part due to the size of the fleet. A smaller fleet may never have had a second event showing the inadequacy of the corrective action. A robust SMS process should include review of all available pertinent information. For a relatively small fleet, the SMS should expand the scope and take advantage of industry wide data for similar applications to better evaluate the potential frequency and consequences of a failure. The initial corrective actions were considered prudent and adequate when implemented; however, the exposure of the large fleet showed that the corrective actions did not eliminate the possibility for human error. The final fix is effective even if the cover plates are left off which essentially eliminates the failure mode and is a much more robust solution.

While three examples are noted above, the lessons learned process is active on a daily basis. GE Aviation currently reviews on the order of 35000 event notifications per year. The evaluation of this information provides areas of focus to improve safety and reliability by grouping the data for systems, such as oil, fuel, controls, and others to enhance both our field processes but also design practices. The key is that as an organization, the lessons learned process throughout the design, development, and operationalization of products / services needs to be institutionalized.

"Other Party" Considerations for International SMS Recognition

In the United States, the FAA has yet to enact rulemaking related to SMS for D&M organizations. A "Part 5" definition exists that parallels the ICAO Annex 19 Appendix 2 four pillars (Policy, Promotion, Risk Management, and Assurance). The FAA had a pilot program with twelve industry members in the 2011-2013 timeframe which has resulted in several of the participants proceeding from pilot programs to voluntary SMS programs. As additional organizations move to voluntary SMS's, the ability to impact safety via rulemaking becomes less effective and the SMS concept moves to an industry best practice. The fundamental challenge with a voluntary SMS is recognition and acceptance that the program meets the intent of the regulatory authorities for both an ICAO level and state authorities. As noted above, self-assessment by using the SMICG evaluation tool is one method that provides a clear view of an organization's progress. Industry's desire is to avoid potentially burdensome requirements from individual state safety program requirements and so an internationally recognized accreditation or validation is needed.

The aviation quality standards serve as a potential model for implementing an "other" party SMS accreditation with international recognition. For familiarization, several organizations are linked with this standards activity. The International Organization for Standardization (ISO) 9001 defines the quality systems model for quality assurance in design, development, production, installation, and servicing. The International Aerospace Quality Group (IAQG) defines the aviation quality standards. These standards, AS9100/AS9110, are international standards that include the ISO 9001 Quality Management System (QMS) requirements as well as additional specific requirements for the aerospace industry. IAQG is an international organization with twenty-six council voting members. IAQG also has regional sub-groups such as the Americas Aerospace Quality Group (AAQG).

The "Other Party" concept for a QMS is based on:

- The use of identical or equivalent international, sector and national standards based on the 9104/1/2/3 trilogy of standards
- An industry oversight system at international, sector and national levels to ensure that scheme's requirements are fulfilled
- Auditors authenticated against identical requirements

The "trilogy" of standards noted in the first bullet above are (5):

AS9104-1 Requirements for Aerospace Quality Management System

- Certification/Registrations Programs
- Globally harmonized standard defining the certification / accreditation process.

AS9104-2 Requirements for Oversight of Aerospace Quality Management System Registration/certification Programs

- Globally harmonized standard defining the surveillance and oversight processes.

AS9104-3 Requirements for Aerospace Auditor Competency and Training Courses

- Globally harmonized standard defining the auditor qualification and auditor training processes.

The standards trilogy provides the requirements, the oversight, and the auditor qualification. An "Other Party" SMS would follow a similar model:

Requirements for Safety Management System

- Based on FAA Part 5 and/or ICAO Annex 19

Oversight of Safety Management System

- SMS ICG Evaluation Tool

Auditor Competency and Training Courses

- Analogous to IAQG

For the FAA, a similar order to 8120.12A "Production Approval Holder Use of Other-Parties to Supplement Their Supplier Control Program" could be used as an outline for Design Approval Holder SMS. If this was insufficient for recognition, an alternate proposal is to have the FAA initially certify an organizations SMS and then move to "other Party" for continuous evaluation. The bottom line is that these aviation quality standards serve as a model for implementing an "other" party SMS accreditation and international recognition of state safety programs.

Summary / Conclusions:

GE Aviation has a continuously evolving safety culture that relies on the decision of safety teams versus individual safety decisions. Technical lessons learned are institutionalized as well as the compliance mechanisms to support safety assurance. The current evolution of the GE Aviation SMS is a move towards human factors in all areas (Quality, Engineering, and Environmental, Health & Safety (EHS). In addition, lessons learned will be elevated to a higher level process based format. The reliance on these components and their flexibility to evolve is sufficient to assure the organization is acting in the interest of safety. The core SPMT process was reviewed and three examples of Lessons Learned using this process were highlighted. SMS is quickly becoming an industry best practice and therefore prescriptive regulatory requirements will yield little overall improvement in aviation safety versus adoption of an industry standard for requirements. A short term solution to international recognition of voluntary SMS is based on using the aviation standards QMS model for implementing an "other" party SMS accreditation.

References:

1. Sioux City Accident Investigation Report NTSB
   https://www.ntsb.gov/investigations/summary/AAR9006.html

2. "SMS Roll-out at an Engine Manufacturer", SAE 2013 Safety Management Systems Symposium (for Aerospace Design and Manufacturing), 20 March 2013

3. AC39-8 Continued Airworthiness Assessment Methodology http://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/22951

4. SM ICG SMS Evaluation Tool http://www.skybrary.aero/index.php/SM_ICG_SMS_Evaluation_Tool

5. International Aerospace Quality Group http://www.sae.org/iaqg/organization/council.htm

6. FAA Order 8120.12A http://www.faa.gov/regulations_policies/orders_notices/index.cfm/go/document.information/documentid/315669

Figures and Photos

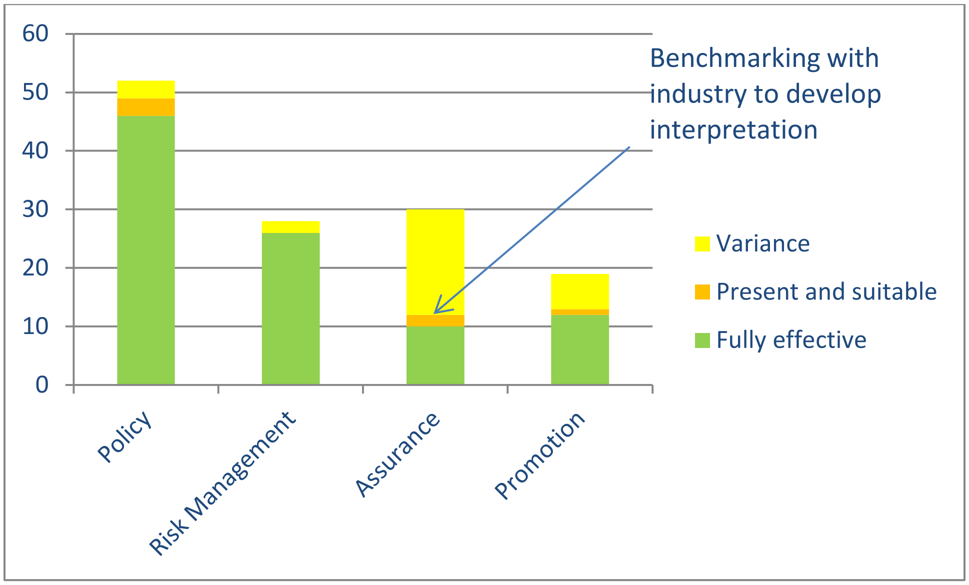

Figure 1: GE Aviation SMS vs ICG Evaluation (self-assessment 2013)

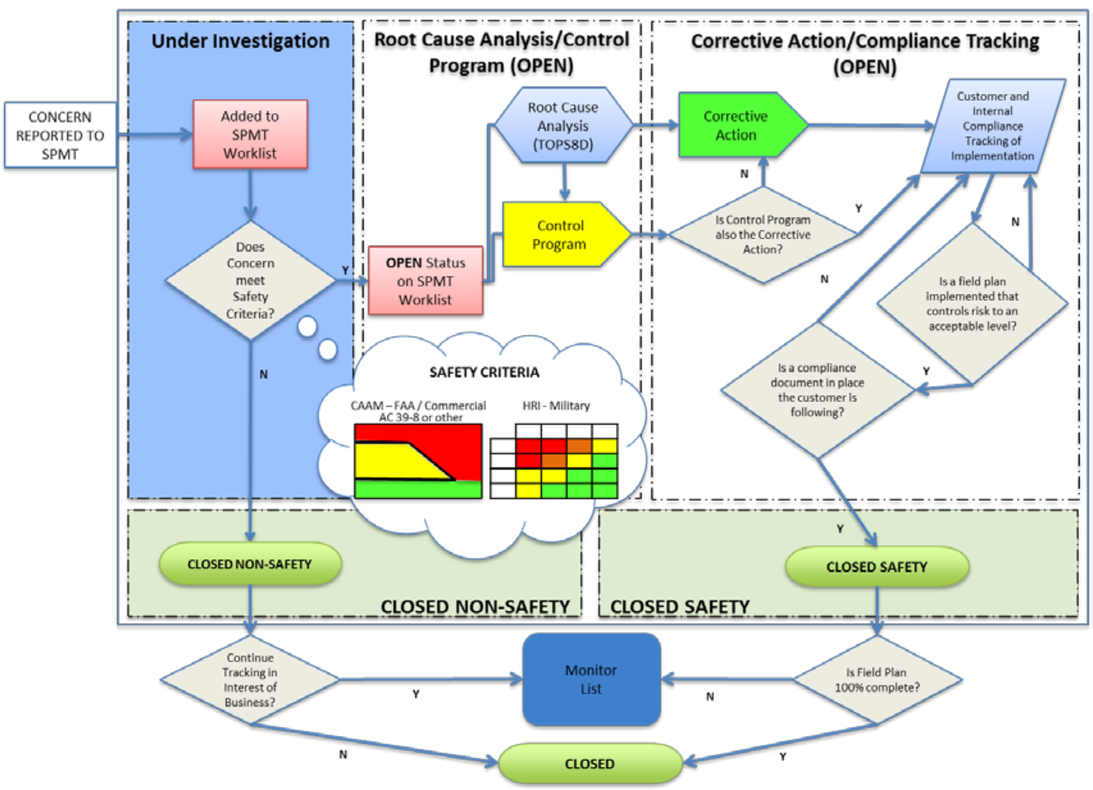

Figure 2: SPMT Worklist Process: Path from Identification to Closure and Monitor Concept

Figure 3: GE Aviation Safety Management System Reviews

Figure 4: GE90 Transfer Gearbox Pinion Gear

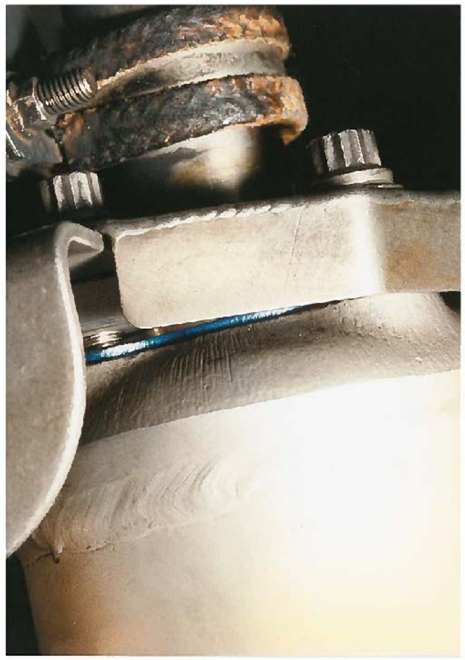

Figure 5: CF6 Gap at Leaking Flange

Figure 6: CF6 Wet Motor Leak Test

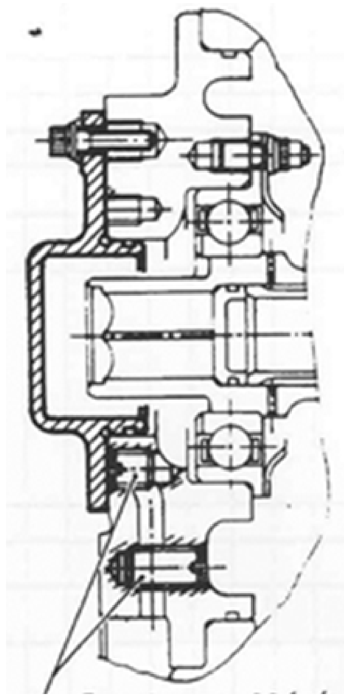

Figure 7: CFM56 Hand Cranking Pad Schematic