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The Standardized Monolithic Repair Router:

Structure and Implementation Feasibility

by

Hilal Tetik

*Some figures in this project have been partially blacked out to protect GE proprietary information.

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The Standardized Monolithic Repair Router: A Structure and Implementation Feasibility Study at General Electric Aviation Engine Services

A Major Qualifying Project Report

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Hilal Tetik

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Sharon A. Johnson, Advisor

Abstract

This project explored the feasibility of designing and implementing a standardized master repair router across all GE Aviation service shops. Existing router structures, historical router work scope data, operations planning documents and repair substantiation packages were examined and analyzed to explore the areas of standardization. In light of the findings, a prototypical master repair router structure was created along with a practical plan of action to implement it worldwide.

Acknowledgements

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Alan Fretwell, Kristin Gantz, Alan Goforth, Billy Graham, Courtney Kasselman, Kelvin Ironside, Phil King, Mike Laing, Richard Martini, Joseph Rentrop, Dave Robertson, as well as all global liaisons for their invaluable input and untiring support to truly make me feel as a part of the team,

My advisor Professor Sharon Johnson whose valuable guidance helped develop and fulfill this project.

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1. Introduction

General Electric Aviation (GEAE) manufactures and services the majority of military and commercial aircraft in the world today. GE Aviation Engine Services has five overhaul and six component repair shops worldwide, all of which have specific capabilities and strengths to service engine parts. These shops each use different systems to manage their operations, adding up to eighty different shop floor execution systems globally. GEAE is now replacing these systems with one acknowledged Enterprise Resource Planning (ERP) solution: SAP. ERP solutions like SAP are implemented to unify and simplify operations within the business and collect master data in centralized databases. There is also a certain level of standardization that comes with this process, as SAP control centers and interactive screens replace disparate business portals. (Anderson 18) This brings improved functionality, a friendlier user interface and better access to relevant real time data. SAP also offers industry- specific packages that reduce the need for custom coding, a lengthy and expensive process. The major benefit businesses derive from such packages is the system functionality tailored to their needs with minimum customization effort.

One of the challenges of replacing the legacy systems with SAP is the reassessment and conversion of old tracking documents that relate to the legacy systems. The process of SAP standardization and automation necessitates review of old practices on the shop floor. In this case, automatically generating a repair workscope calls out for establishing a master repair router structure in SAP. The router is an important document that travels with a component through the shop and helps track the completion state of the overhaul or repair operations that must be performed on the part. The standardized repair router structure will eliminate the inefficiencies related to the issuance of multiple repair routers. Said inefficiencies include but are not limited to problematic repair operations sequencing and duplication of common operations.

The goal of this project was to determine the structure of a standardized master repair router for GEAE engine service shops and to present a feasible implementation plan of action across the business. Three objectives were determined to meet this goal. It was an important first task to understand how the routers were framed worldwide, and to determine any major structural discrepancies. To have a comparison vantage point, the second objective was to identify an intricate part that had numerous repairs and could provide a prototypical master repair router. The last step of data and document collection provided insight into the main differences in shops' repair router structures. Local repair routers and complementing shop documents were gathered, compared and analyzed. Generating ideas to overcome local differences helped create the standardized router prototype. The methodology constituted creating data collection sheets to pull data from all service shops, examining the engine shop manual and the component repair directory to determine the prototype part and contacting individuals at each shop to obtain different types of data to support the analysis.

The methodology is discussed more in detail in Chapter 3 and is structured to show the reader how each objective was met. The Results section in Chapter 4 illustrates the crucial findings that were obtained through quantitative and qualitative data analysis.

In light of the results, implementation possibilities are discussed in Chapter 5, the Conclusion section of this project.

2. Background and Literature Review

This chapter is intended to provide the reader with an overview of the service shops and operations as well as a general background on SAP and its implementation.

2.1. GE Aviation

GE Aviation is a part of Infrastructure and one of the six businesses owned by General Electric. These businesses are Infrastructure, Industrial, Commercial Financial Services, NBC Universal, Healthcare, and Consumer Finance. GE Aviation is headquartered in Evendale, Ohio. Apart from manufacturing engines, GE Aviation also services these engines through overhaul and component repair. Overhaul helps elongate the life of the engine by taking it apart, cleaning and inspecting it and when a part within the engine is not serviceable, repairs or replaces it. Overhaul procedures require diligent examination of the parts and use the newest technologies to detect common damages like cracks and scratches. These technologies may include magnetic particle, ultrasonic, eddy current and x-ray methods. (Gamauf) Reparability of engines is an essential component of keeping the life-cycle costs low, and manufacturers of the aviation industry strive to develop the most reliable and cost effective overhaul and component repair methods for these engines. The competitive advantage in this industry comes from overhauling the engine and returning it to the customer in a perfectly serviceable and reliable state. In the meanwhile, costs also need to be kept low to keep the competitive advantage.

GE Aviation has maintained and secured this competitive advantage in the market and is the world's leading provider of aviation services for both military and commercial engines.

2.2. Engineering Center of Excellence (COE)

The Engineering Center of Excellence is a recently founded central authority that will handle parts, processes and technical data during and after SAP Implementation. The role of the Engineering COE consists of coordinating shop teams to give and receive regular feedback on incremental changes in technical publications and all technical revisions. If need be, COE will also be responsible for negotiating shop requests to change central data elements or processes. The scope of this project falls under the "Processes" function of the COE. The Engineering COE will therefore be responsible for following up with and implementing the recommendations that are outlined in the final section of this project.

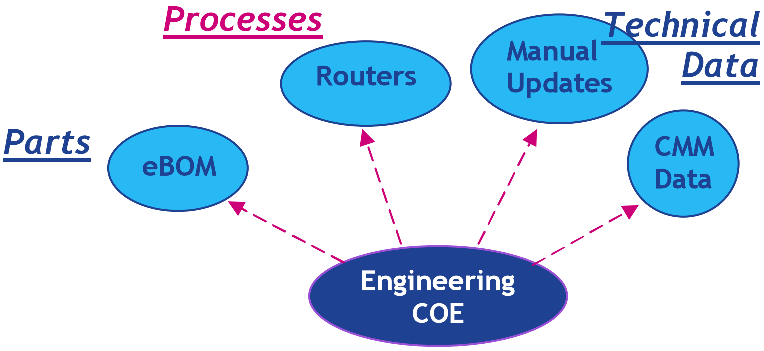

Figure 1) Engineering COE Functions

2.3. Overview of the Global Shops

Figure 2 shows both overhaul and component repair shops worldwide. The locations marked in blue are the overhaul shops and the ones marked in yellow are the component repair shops. A more detailed overview of the component repair is outlined below.

Figure 2) Global Shops

2.3.1. McAllen

McAllen in Texas repairs LPT Nozzles, LPT Blades and HPC Vane Sectors. They perform the following repairs on these components: Inner/ Outer Spool Replacement, Inner/ Outer Plenum Replacement, Vane Sectors Replacement and full repairs.

2.3.2. Tri-Remanufacturing

Tri-Reman, the “Center of Excellence for Honeycomb Repairs”, uses Honeycomb Replacement, Plasma Spray and Weld Repair techniques on their components. They service Honeycomb seals and segments as well as LPT cases and frames.

2.3.3. ACSC

ACSC is comprised of several shops located closely to each other in northern Cincinnati.

Symmes Road services HPT and LPT nozzles as well as HPT shrouds, hangers and seals. They use the following repairs: Split Vane, Airfoil Replacement, Leading Edge restoration and HPT Shroud restoration, also known as Puck repair.

Glades Park uses Rejuvenation/ Enhanced rejuvenation, expanded tip and full repair methods to service HPT blades, fan blades and LSP.

Container Place is a component repair shop that handles unique parts. They use EGT enhancement, Rotating parts COE and frame assembly repairs to service structures, cases, rotating parts and perform NDT inspection. Container Place has provided a good area of observation for this project, as it develops new repairs and houses the components from the 80C2 McDonnell Douglas line, which were used to create the monolithic router structure prototype in this project.

2.3.4. Hungary

The Hungarian component repair shop handles Fan components, Pipes and tubes, Composite OGV’s and Liner Panels, LPT seals and shrouds as well as HPC shrouds with the following repair methods: CF6 aluminum OGV lug repair, RB211 Engine Mount repair and CF6 LPT Seal shim repair.

2.3.5. GEASO

GEASO in Singapore houses some new repairs like Rejuvenation/ Enhanced Rejuvenation, Split Vane/ Fabrication repair and Aft End Liners Replacement to service components such as HPT and LPT Blades, HPT and LPT nozzles, Combustors, Disks, Seals, Shafts and Nozzle Supports.

2.3.6. 2.2.6 Japan

Japan services GE90, CF6 and CFM Rotating parts, Frames and Cases. The repairs they use include EGT enhancement on HPC case finish, Rotating parts build-up dimension and Frames assembly.

2.4. Shop Floor Operations

When an engine arrives at any engine services shop, it goes through main operations as described in the following subsections. Disassembly and Assembly operations take place in the overhaul shops and all other steps may take place at both the overhaul repair back shops or at the component repair shops with specific repair capabilities.

2.4.1. Disassembly

Disassembly is the act of taking apart the engine down to the part level for inspection and servicing.

2.4.2. Clean and Inspect

Clean and Inspect is the process that supports the disposition by applying the appropriate cleaning operations on the component and preparing it for inspection. Inspection is the decisive process that leads to the disposition of the part, and is performed in accordance with the visual and dimensional inspection criteria.

2.4.3. Disposition

Disposition is the process used to record the outcome of the inspection process, which typically results in the part being accepted, rejected or put on hold for an engineer to see. If the rejected part is serviceable, it goes through the appropriate repairs to be used further in the assembly. There is furthermore a list of reason and defect codes that accompany the disposition, elaborating on the condition of the part that was assigned the specific disposition code.

2.4.4. Internal and External Repairs

If the part is serviceable and needs a certain repair or a set of repairs, the part is either sent into the back shop of the overhaul shop (internal repair) or shipped off elsewhere to a component repair shop (external repair) where there is capability to repair that certain component.

2.4.5. Assembly

Assembly is the act of assembling the parts for the certain component.

2.4.6. Installation

Installation is the act of installing all the components to produce the actual engine.

2.5. High Level Flow of the Shop Floor Processes

A customer order issues a Purchase Order, which leads to the engine arriving at an overhaul shop. In the shop, a specific work order for the engine is issued in line with Service Bulletins, if any. The service bulletin is essentially a set of customer preferences that may assume the authority over shop decisions. These may be using a new repair or replacing a scrapped part with a newly designed one. If parts need to get shipped to different component repair shops, hey get sent. The local shop system issues the routers for operations to take place on the shop. Router for disassembly and Clean & Inspect is issued. At the end of inspection, there are four main levels of disposition that may be selected by the mechanic for that part. These are: Scrap/ Buy New; Repair; Pass and Ask Engineer. If a part is neither serviceable nor repairable, it is scrapped and Catalog Sequence Number is retrieved to check for any upgrades or possible replacements. If the disposition selected is “Repair” a repair router is issued for that part. If parts pass the inspection, they are serviceable and are sent to assembly. If it happens at the end of inspection that there is an unusual condition for an evidently unserviceable part, the mechanic puts the part on hold for an engineer to investigate the part. Depending on the outcome of the inspection, an assembly router is issued for the part and the engine is assembled.

2.6. Current Software Systems that Handle the Shop Floor Operations

GE has been using different systems across the shops to support its overhaul and component repair operations. This means that each shop has disparate management tools and various arrangements for manufacturing documents. The drive for change comes from the need for a fully integrated system that will standardize the processes of documenting engine services operations and optimizing the flow of such operations. This new technology will also enable GE to be in line with many of its customers' integrated ERP solutions and allow for continuous business improvement. Some important clients have already implemented SAP: Air France, British Airways, Delta, KLM Engine Services and Lufthansa Technik.

The mission of the paperless shop floor is to eliminate all hardcopy shop documentation by a user friendly electronic format. Apart from reduced documentation cycle time and enhanced data input and management, this new system will also have the benefit of making it easier for shops to comply with FAA regulations when it comes to stamping operations. The system will link the mechanic's training and qualifications to very specific tasks, preventing the mechanic from completing operations he/she is not qualified to perform.

2.7. Manufacturing Execution Systems

Manufacturing Execution Systems (MES) are based on standard software packages. There are three levels of control within manufacturing: the planning level, the execution level and the control level. The planning level is managed by solutions such as material requirements planning and enterprise resource planning and MES takes the output to execute the plan on the shop floor. The overlap between these layers have been improved through software solutions such as SAP, which provide the unified functionality to store, share and use master data and information at all levels.

The MES is primarily a formalization of production methods and procedure into an integrated computer system that presents data in a more useful and systematic form. (McClellan) In most companies a non-integrated variety of systems exist to carry out production. The benefits of integrating these disparate systems include: reduced manufacturing time, reduced data entry time, reduced work in progress, reduced paperwork between shifts, reduced lead times, elimination of lost paperwork, improvement of customer service and improved compliance with regulations issued by the relevant authorities.

MES does not imply a change in manufacturing operations, but rather improves the access to and the quality of information and data related to essential decision-making. As McClellan puts it, "[…] an MES can be proactive, causing events to occur or tasks to be completed according to the plant's operating methods or plan and without human intervention. An example is the automatic movement of a specific item or inventory to a workstation following the part routing and order schedule."

MESA International[1] has identified various areas of production management that would be included in a full MES implementation (McClellan 4-5):

- Resource Allocation and Status: manages resources such as machines, tools, labor skills (includes certification), materials and documents that need to be available to start an operation.
- Operation/ Detail Scheduling: provides sequencing based on priorities, attributes, characteristics and "recipes" associated with specific production units at an operation.
- Document Control- (hopefully there will be very few or NO documents on the floor): controls records and forms that are maintained with the production unit, including work instructions, recipes, drawings, standard procedures, part programs, batch records, engineering change notices (technical revisions, new repairs, SB's), edits "as planned" and "as built" information
- Data Collection: provides a link to collect parametric data
- Labor Management: keeps status of personnel
- Quality Management
- Process Management: monitors production and either automatically corrects or provides decision support to operators
- Maintenance Management
- Product Tracking and Genealogy: (Routers and traveling data sheet to the system) Provides visibility to where work is at all times and its disposition.
- Performance analysis

Core functions that typically come with full MES implementation are:

- Planning System Interface (connection with the planning layer)
- Work Order Management: this function manages work orders, including scheduling for all orders in the system.

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[1] "Manufacturing Enterprise Solutions Association (MESA) International is a worldwide not-for-profit community of manufacturing companies, information technology hardware and software suppliers, system integrators, consulting service providers, analysts, academics and students. The combined purpose is to improve business production operations through optimized application and implementation of information technology and best management practices." www.mesa.org, Viewed 09/15/2007

- Workstation Management: implements the “direction” of the work order plan, workstation scheduling and configuration
- Inventory Tracking and Management
- Material Movement Management
- Data Collection
- Exception Management: ability to respond to unanticipated events that affect the production plan.

Manufacturing environment includes defined routing instead of in-line production as seen with the assembly lines. In defined routing, the workstations are not necessarily ordered in a line. Manufacturing follows process steps outlined in a routing defined by the work requirements. In this structure, the activities are typically initiated on the shop floor itself, without regard for a rigid master factory schedule (National Research Council 92). Work and logistic flow is defined through a routing system. This system can route a partially finished product to the next available workstation that is capable of performing the work required to complete the next step. Each workstation is assigned certain operations it is capable of performing. Intelligent routing system presents acceptable routes, including one determined to be the best according to specified criteria (min cost, max speed, max quality, etc.).

2.8. SAP as an ERP Solution

Enterprise Resource Planning (ERP) is comprised of a set of software applications designed to integrate, manage and streamline business processes. SAP, the leading vendor of ERP solutions, has specific functionality that makes it an attractive option for businesses seeking to minimize the customized coding required to make a software solution work for the business. SAP has a three tier client / server architecture, allowing the data management to be separate from the servers. (Vogel and Kimbell 11-13) There are three layers to this structure: the user interface, the business logic layer and the database. This way, changes can be applied to each layer without having to change the whole system. Companies who opt for SAP not only want to automate standardized core business functions, but also the processes unique to their business. They choose one of the many out of the box industry-specific packages accordingly. Another advantage of SAP is that it enables the design of work and control centers with high accessibility to both data and functionality. Two important characteristics of these centers is their ability to push the relevant information to the user, so that the users do not have to actively seek it. (Vogel and Kimbell 48) The second characteristic is the role-based model that enables the IT administrator to define the set of policies that determine the type of information and functionality a user can access to get the job done for whatever their role is in the company. This is especially useful in the Aviation business shop floor compliance, as certain mechanics are allowed to perform only those operations they are qualified for, as the system does not allow them to mark off operations they were not supposed to complete in the first place. Access to real time data furthermore makes it easier to identify violations and risks quickly. (Vogel and Kimbell 76) With the presence of a centralized database, managing and reporting data is simplified, not to mention uploading compliance lists to reflect new or updated requirements.

For businesses today, some of the tactical reasons for implementing SAP include the need to eliminate the “vertical stove pipes” of data and processes that prevent sharing of this data between the different organizations of a company. There is naturally also an important advantage to SAP in which it replaces the patchwork of legacy systems that double or triple data and process maintenance efforts within the organization. The prospect of leveraging a common ERP platform in line with those of the customers is another advantage to SAP implementation. SAP implementation can save a company millions of dollars if implemented well. In addition, SAP can help automate data entry through radio frequency identification tags (RFID). (Vogel and Kimbell 57) This way, the company can track and retrieve information about a part traveling around on the shop floor, saving time associated with data entry and eliminating human errors that may follow manual data entry for different parts.

2.9. SAP Implementation Background

Given the benefits described in Section 2.8., issues with implementation can arise if the business has poor project management, lack of proper documentation and relies heavily on third party vendors who are hired to customize the SAP solutions for the business. Other impediments to a successful implementation include the lack of cross-functional coordination and ineffective change management. (Kim et. al) Change management consists of grasping and managing the effects of a large scale ERP implementation on the existing business processes. To achieve performance gains, it is critical that a company understand the impact of implementing a software package that calls for the automation of documenting manufacturing processes. If there are different ways to document these processes within different branches of the business, the impact of standardization and automation should be discussed. If there are significant variations in the processes, conflicts of interest should be mitigated by an effective change management strategy.

The implementation of ERP solutions is typically driven by the need to better manage information and make it accessible to the right people. ERP solutions also replace a number of disparate systems to standardize all affected parties’ interaction with the system. Better management of data and information can also lead to better assessment of productivity and helps identify areas that need process improvement. Creating a lean enterprise through utilizing high tech and up-to-date systems has been the vision of the US military aerospace (MRO) industry and seeks to replace the “incremental lean” approach. (Mathaisal) Becoming lean is necessitated through the market demand for swift and efficient manufacturing responsiveness and the need for optimized flow processes. Enterprise transformation through systems engineering can be fulfilled through strategic planning, integration to ensure the conditions necessary for a successful change and lastly, carefully monitored implementation. If there are glitches in any of these stages, implementation may be delayed or even aborted. It is therefore imperative to ensure completion of each stage until the business has fulfilled its vision to create a lean enterprise through ERP implementation. This paper deals with preparing the necessary conditions to ensure integration into the new system. This preparation is realized through the creation of the prototype described in the Results chapter.

2.10. Definition and explanations: Router, Monolithic Router

A Router is a manufacturing document that has a set of instructions for the operations that are to be performed on a certain part on the shop floor. A router contains part-relevant information including work order, quantity and work stations and helps document and track down the operations that are performed on the part during its journey on the shop floor. In the as-is system, a router is generated for each repair that is identified in the inspection process. Each operation listed in the router is stamped off by the approved mechanic, and directed to the next workstation. The router, along with its sub-tier documents such as data collection sheets and the purchase order, travels around with the part.

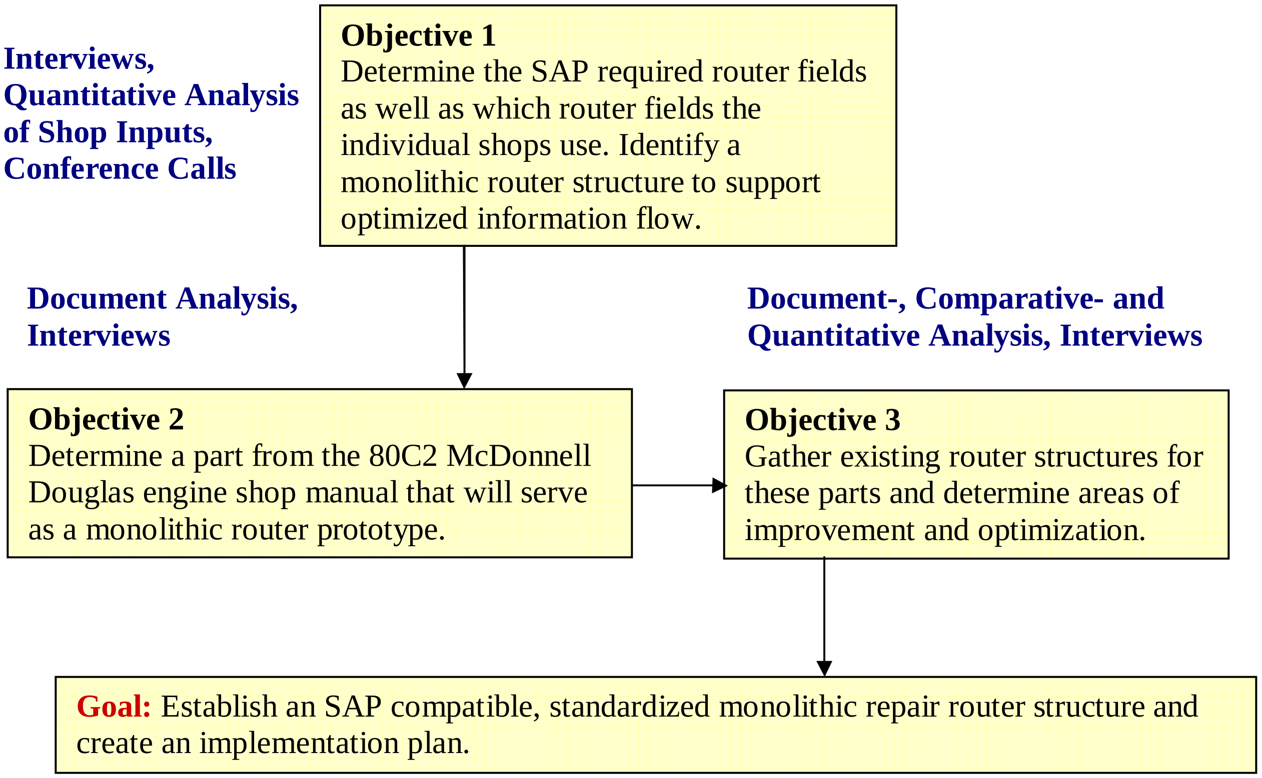
A Monolithic router reduces cycle time and optimizes throughput by combining repairs that have similar operations. Without a monolithic router, a separate router for each repair is issued and there are often identical operations. This implies that the mechanic, as he or she follows the router instructions, will need to perform identical operations repetitively for each separate router. The monolithic router eliminates the inefficiencies associated with the issuance of multiple routers.

3. Methodology

The goal of this project was to produce a standardized monolithic router structure for use across GE's global overhaul and repair shops after full SAP implementation as well as determine a plan of action for implementation of the said structure. The difficulties of such an effort lay within the variability of the router structures and the utilized fields across the overhaul and component repair shops. The range of engine models that required different router fields also caused this variability.

The objectives were defined carefully in an effort to provide a gradual approach to acquiring the necessary knowledge and resources to solve the business problem of creating the monolithic router structure that will facilitate an improved information flow on the shop floor. Improved information flow implies better tracking, recording and retrieval of information as well as better compliance with the FAA regulations.

The project objectives that were established to meet the goal are shown in Figure 3, and described in greater detail in the following sections.



Interviews, Quantitative Analysis of Shop Inputs, Conference Calls

Objective 1
Determine the SAP required router fields as well as which router fields the individual shops use. Identify a monolithic router structure to support optimized information flow.

Document Analysis, Interviews

Objective 2
Determine a part from the 80C2 McDonnell Douglas engine shop manual that will serve as a monolithic router prototype.

Document-, Comparative- and Quantitative Analysis, Interviews

Objective 3
Gather existing router structures for these parts and determine areas of improvement and optimization.

Goal: Establish an SAP compatible, standardized monolithic repair router structure and create an implementation plan.

Figure 3) Project Objectives and Their Relationship to the Project Goal

3.1. SAP Required Router Data Fields

One of the major objectives was to determine the fields in SAP routers. Because a new design of the monolithic router will need to be SAP compatible, it was crucial to understand the requirements of the software system. Caledonian is the first site to go live with SAP in April 2008, and is actively engaged in the discussions and preparations for a successful implementation. Discussions with the engineering team helped identify the potential main fields for a unified router. The outcome of this discussion was useful in generating a data collection sheet in excel, called the Router Field data sheet. This excel sheet listed out the possible and most prominent fields that may be seen on any given router.

Table 1) Global Liaisons

Global Liaisons	Location
Luiz Araujo	Celma
Arwel Clarke	Wales
Ed Cunningham	Strother
Terri Fortune	Tri-Reman
Zilkamal Mokhtar	Malaysia
Dave Robertson	Caledonian
Bela Rozsalyi	Hungary
Hardy Samuel	GEASO
Steven Sanford	McAllen
Bob Shelton	ACSC
Yufu Yoshikazu	Japan

The global liaisons from each shop, some of which are a part of the project steering committee, will be playing an integral role in future SAP shop implementations. The liaisons who received this Router Field data sheet were provided with clear instructions to mark those fields that were existent on their routers. They were also prompted to provide copies and scans of their current routers and the accompanying shop floor documents so as to complement their excel sheet entries. The completion timeline for this task was deemed appropriate at two weeks. As the data arrived along with the feedback notes, conference calls were scheduled with the liaisons to go over and clarify the results.

After the collection and confirmation phase, all data was aggregated in a single excel file to provide overview. This exercise then helped identify the percentage of SAP compatible fields across 140 routers from 11 global service shops and set the stage for further lower-level evaluation of the fundamental router differences between the shops. ACSC and Caledonian routers were selected for further examination. Quick and efficient access to local data ad traveling documents at these sites influenced the shop choice. The methodology for this crucial evaluation is discussed in the next section.

3.2. 80C2 McDonnell Douglas Part Repair Prototypes

To create a monolithic router structure, it was important to have some structural or rotational part serve as a prototype for the master monolithic router structure. This part had to contain numerous distinct repairs to ensure good coverage of most repair characteristics and related operations found among the parts of the 80C2 McDonnell Douglas engine model as a whole. Identifying this part was made easier through the previous internship experience at GE, which involved establishing and populating the inspection criteria upload fields and generating guidelines for future contractors on uploading this master data. Through familiarity with different inspection methods and the relevant repairs, it soon became clear that the Subject Part A would provide the best example for a master monolithic router structure. This part contains diverse repairs such as repairs of rabbet and pilot diameters, shaft mate faces, disk post seal wire wear, of surface pitting on disk or shaft and of the no. 5 bearing journal diameter. Other listed repairs for this part include removal of silver and silver deposits, blending of critical areas and shot peening, thermal spray repair of pilot diameters and surfaces, Machining and high velocity oxy- fuel inconel 718 as well as the commonly used armpit machining repair. A total of 15 repairs are possible for this disk.

Furthermore, the part was selected through careful consultation of the component repair directory. The component repair directory for the 80C2 line lists out all piece parts of the engine, links them to the relevant pricing, and most importantly tells the user which shops have the capability to repair said part. Apart from listing a good number of repairs, the Subject Part A was also a strategic pick, as it is serviced at the two locations --ACSC and Caledonian- where the team is actively engaged in the discussions surrounding implementation. Daily conference calls with Caledonian, as well as visits to the nearby ACSC CPL1 during the internship phase moreover helped create the right contacts. These local resources proved to be invaluable in obtaining the right documents and information and truly helped take the final steps leading to the Recommendations seen in Chapter 5.

3.3. Evaluation of Existing Router Structures

As mentioned above, the ACSC and Caledonian contacts were key to obtaining the right documentation which facilitated the understanding, analysis and comparison of the existing repair router structures for the Subject Part A. Said documents can be outlined and summarized in the following way:

- ☑ IT Functional Specifications for dispositions,
- ☑ Business Blueprints,
- ☑ Power Point pitches prepared for the Steering Committee,
- ☑ Excel files of the Caledonian monolithic router repairs as well as the ACSC Mix Model Map of operation numbers for all shop parts,
- ☑ Large volumes of Caledonian and ACSC data representing all called repairs for the selected part,
- ☑ Strip-, clean & Inspect- and Repair routers for Subject Part A and various other parts.

To supplement the document analysis, conference calls and Q&A sessions were set up with the contacts on a nearly daily basis. These were crucial in confirming the knowledge derived from document analysis and observations. Observations included direct presence on the ACSC shop floor as well as less interactive participation in daily and weekly business meetings. Table 2 provides a list of the mentioned business contacts and their departments and/ or functions.

Table 2) Q & A Resources

Q&A Session Resources	Department
Karen Campbell	SAP Integration Lead
Alan Fretwell	Caledonian Accessories Operation
Kristin Gantz	Former ACSC Lean Leader
Alan Goforth	ACSC HPT Technical Coordinator
Billy Graham	Caledonian Routers
Courtney Kasselman	Manager Fabrications Cincinnati
Phil King	Global SAP Organization
Mike Laing	GE Engine Services Caledonian Operation
Richard Martini	Cases, Frames and Hot Section, CPL 1
Clint Morley	Project Manager
Joseph Rentrop	Sumps & Seals and Rotating, CPL 1
Dave Robertson	CF6 Platform Engineering
Ronald Winkler	IT Support

The objective of understanding the router structures and what they mean to the shop floor operations was so complex that the methodology created itself for this particular objective. Often times it was unclear how the objective could be achieved up until the completion of one small step, which in turn would lead to another. This iterative process continued until solid results were obtained. The methodology and milestones derived for evaluating existing repair router structures is described below.

1. Determine at which points of the engine service timeline that Disassembly-, Clean & Inspect-, Repair- and Assembly routers are created.

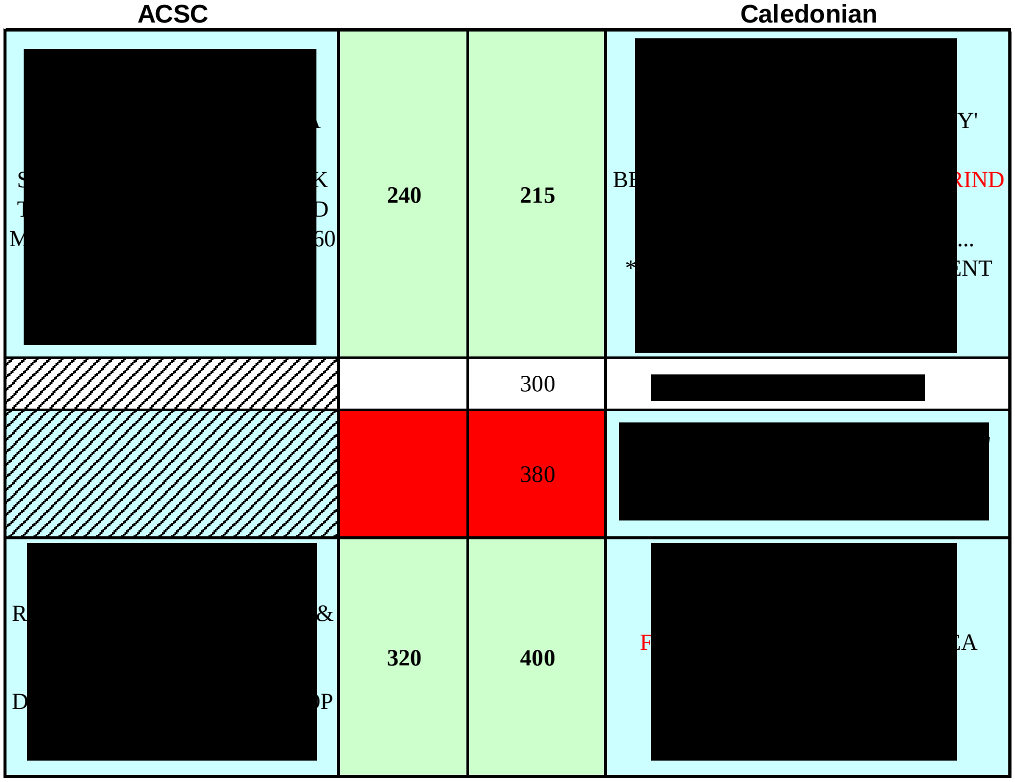
2. Examine an existing repair router to learn how to read and interpret it.

3. Determine how the operation sequence numbers are assigned and what their significance is.

4. Understand what a monolithic repair router means.

5. Investigate the repair router differences between the shops.

To carry out the last step, an exercise of trying to match up the individual operations listed in the ACSC and Cal routers for Repair 11 of the Subject Part A part was carried out, as exemplified in Figure 4.



ACSC			Caledonian
[redacted]	240	215	[redacted]
▨		300	[redacted]
▨	🟥	380	[redacted]
[redacted]	320	400	[redacted]

Figure 4) First Operation Matching Map

As shown in the middle column of the table, the red zone immediately prompted an investigation. Because both of these shops are required to follow the repairs as documented in the engine shop manuals, a missing operation was a definite cue to follow up on this matter. Further investigation showed that this particular operation was represented in the operation planning sheets that are designed to hold the details not included on the routers. This naturally also gave a good idea about the nature of the ACSC and Caledonian routers: ACSC routers provided short and concise summary of the steps to be followed and Caledonian routers went into lower level details and not only listed out each and every operational step but also referenced the background documents (Engine Shop Manual, Standard Practices Manual, Vendor Rework Approval Packages) that they derived their operations from.

3.4. Creating the Monolithic Router Prototype

The process of creating the prototype included two steps: drawing conclusions about the structure of the router and evaluating the work required for its SAP implementation. Comparing routers and understanding the reasons for any existing differences made up the essence of developing the monolithic router structure, as it helped in drawing conclusions about what a monolithic router means for different shops and what the standardized structure will need to look like in the future. The outcome of comparative analyses was also crucial because it helped show the SAP implementation team, especially the Engineering COE, which points they should expect to consider when executing a similar effort on a much larger scale. Understanding how much work is required to implement such a structure on a larger scale required some analysis around how much component repair overlap there is between shops. Because the prototype was created through the comparative analysis of two different router structures for one single rotating part, one can only imagine on how colossal a scale similar work would need to be done. This realization also influenced the recommendations in that the implementation is advised to be done by determining process flows for parts that flow through common cells, instead of trying to standardize routers one by one.

Lastly, the outcomes obtained through comparative analysis and evaluation of existing router structures yield the conclusions and recommendations in this paper, which-- if expressed metaphorically- were meant to cast some light on the dark, winding road of future standardization that is necessitated by SAP implementation.

4. Results and Analysis

This chapter describes the results that were obtained through data and document analyses and highlight how the project objectives were fulfilled. The results outlined in this section provide the foundation for the Recommendations listed in Chapter 5.

4.1. SAP Required Router Fields

The responses acquired from the global shops were collected and organized on an excel sheet to represent the input of each shop. These inputs were representative of a total of 137 different routers used for each engine model at every shop, and provided an accurate estimate of the percentage of the shops that utilize any given field on their routers. Table 3 shows the possible router fields and their occurrences across the global shops.

Table 3) Global Data Fields

Router Field	Occurrence	Router Field	Occurrence
ATA Code	86.13 %	**Time Since New**	88.32 %
ESM Family (CF34)	81.75 %	**Part Number**	100 %
ESM Model	90.51 %	**Serial Number**	90.51 %
ESM and Router Revision Number	100 %	**Standard Hours of Operation**	90.51 %
Planner	95.62 %	**Catalog Sequence Number**	32.17 %
Last Update	90.51 %	**Part Position Number**	38.69 %
Inspection sequence	95.62 %	**Component Code**	64.23 %
Mandatory Operation	94.89 %	**IPC Major Module Code**	28.46 %
Work Center	100 %	**IPC Minor Module Code**	28.46 %
Customer	98.54 %	**Part Quantity Traveling with Router**	90.51 %
Unique Router ID Number	95.62 %	**Work Order Bar Code capability**	90.51 %
Cycle Since New	88.32 %	**Step Bar Code Capability**	81.02 %

Among these fields, the highest occurrence is for the ESM and Router Revision numbers, Work Center and Part Number, which is used to identify the part. Illustrated Parts Catalog (IPC) Major and Minor Module codes had a relatively low occurrence, as the information they are used to present is already covered by the ATA code or the Part Number fields. The fields of Cycle Since New and Time Since New were irrelevant if the shop did not service life-limited parts, and hence had no place on the routers. A high percentage of the shops used Work Order Bar Code Capability, which is the main RFID tag that is linked to the work order of that specific router and enables the shop to track the time needed to service the part. A relatively high percentage of the shops also support the Step Barcode Capability, which is an RFID linked to each task in the inspection sequence.

Figure 5 provides a graphic overview of the identified SAP required fields, and their occurrences among the various routers of the global shops. The lowest of these bars is the IIN/ Component Code, which is the code used to link the customer's convention for the part into the router to provide a common language. The variability in the field occurrence comes from the fact that not all shops service life limited parts, and do not always utilize TSN and CSN. The ATA code is also utilized less in comparison to the most commonly occurring ESM model-, Work center- and Part Number fields, as not all engine lines have the same coding system. Hence, these fields are needed in SAP to define the parts on the router, however they may need to be optional or have formatting flexibility to support the various engine models.

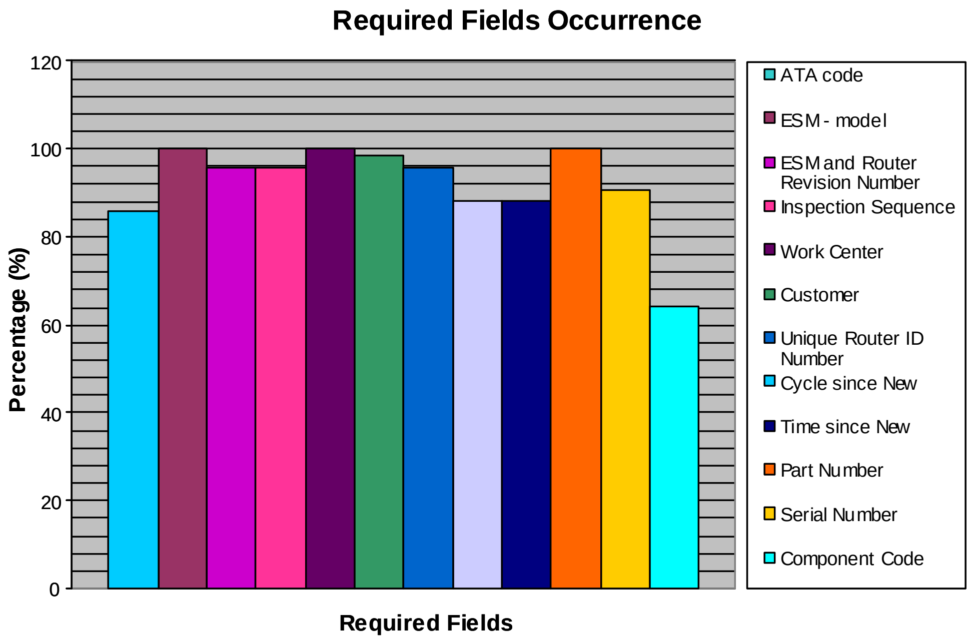


Figure 5) Required Fields Occurrence across Global Shops

The standardized router will have all required fields, however some of these may need be optional, as not every field will be available or needed for non- Life Limited Parts. The fields on the standardized router will therefore include, but are not limited to: Router Number, Router Revision Number and Date, Manual Revision, Customer, Engine Type, Engine Serial Number, Component Code, Part Number, Part Name, Part Serial Number, Part Quantity, Time Since New, Cycle Since New, Time Since Overhaul, Cycle Since Overhaul, Work Order Number, Shop Manual Reference.

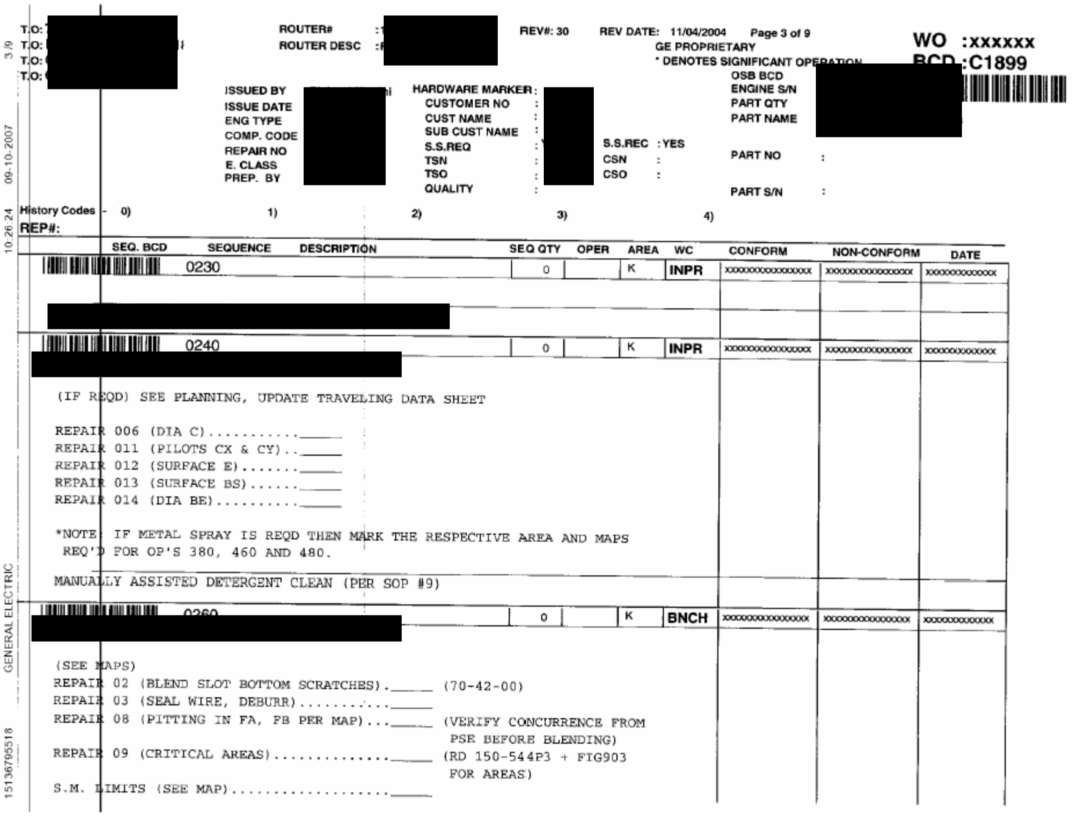
4.2. Analysis of the Existing Repair Router Structures

The results of the ACSC and Caledonian router structure analysis are presented in this section.

4.2.1. ACSC

The CF6-80C2 High Pressure Turbine Disk is one of the parts that ACSC repairs at their Container Place Location. This part was taken as a prototypical model to examine the structure of the repair routers at CPL1. CPL1 uses a master repair router for this part and issues the router with all possible repairs listed under each operation. The mechanics then simply disregard the operations that do not pertain to the repairs that they have called for the part and only follow the operations that list the relevant repair under each step. The operation sequence numbers are arbitrarily listed; however they do follow a strict logical order that regulates the flow of operations. Such logic implies that non-destructive testing (FPI, Eddy Current or Ultrasonic Inspection) comes first, followed by the usual visual and dimensional inspections, followed by machining repairs such as re-contouring and dimensional restoration. The part is then subject to Florescent Penetrant Inspection (FPI), shot peen and thermal spray until it is ready for final approval.

Simple enough, Figure 6 presents a screenshot of the shop floor repair router, which also represents the monolithic repair router that exists in the legacy shop floor execution (SFE) system.



3 /9
09-10-2007
10:26:24
GENERAL ELECTRIC
15136795518

T.O: [redacted]
T.O:
T.O:
T.O:

ROUTER# : [redacted]
ROUTER DESC :

REV#: 30 REV DATE: 11/04/2004 Page 3 of 9
GE PROPRIETARY
* DENOTES SIGNIFICANT OPERATION

WO :xxxxxx
BCD :C1899

ISSUED BY [redacted]
ISSUE DATE
ENG TYPE
COMP. CODE
REPAIR NO
E. CLASS
PREP. BY

HARDWARE MARKER : [redacted]
CUSTOMER NO :
CUST NAME :
SUB CUST NAME :
S.S.REQ :
TSN :
TSO :
QUALITY :

S.S.REC : YES
CSN :
CSO :

OSB BCD [redacted]
ENGINE S/N
PART QTY
PART NAME

PART NO :

PART S/N :

History Codes - 0) 1) 2) 3) 4)
REP#:

SEQ. BCD	SEQUENCE	DESCRIPTION	SEQ QTY	OPER	AREA	WC	CONFORM	NON-CONFORM	DATE
	0230		0		K	INPR	xxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxxx	xxxxxxxxxxxxx
	0240		0		K	INPR	xxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxxx	xxxxxxxxxxxxx
	0260		0		K	BNCH	xxxxxxxxxxxxxxxx	xxxxxxxxxxxxxxxx	xxxxxxxxxxxxx

0230:

[redacted]

0240:

[redacted]

(IF REQD) SEE PLANNING, UPDATE TRAVELING DATA SHEET

REPAIR 006 (DIA C)..........._____
REPAIR 011 (PILOTS CX & CY).._____
REPAIR 012 (SURFACE E)......._____
REPAIR 013 (SURFACE BS)......_____
REPAIR 014 (DIA BE).........._____

*NOTE: IF METAL SPRAY IS REQD THEN MARK THE RESPECTIVE AREA AND MAPS REQ'D FOR OP'S 380, 460 AND 480.

MANUALLY ASSISTED DETERGENT CLEAN (PER SOP #9)

0260:

[redacted]

(SEE MAPS)
REPAIR 02 (BLEND SLOT BOTTOM SCRATCHES)._____ (70-42-00)
REPAIR 03 (SEAL WIRE, DEBURR)..........._____
REPAIR 08 (PITTING IN FA, FB PER MAP)..._____ (VERIFY CONCURRENCE FROM PSE BEFORE BLENDING)
REPAIR 09 (CRITICAL AREAS).............._____ (RD 150-544P3 + FIG903 FOR AREAS)
S.M. LIMITS (SEE MAP)..................._____

Figure 6) ACSC Router Screenshot

The repair codes listed at ACSC for this part, as listed in the GE Standard Catalog are shown in Table 4. These repairs represent not only the codes typically listed in the Engine Shop Manual, but also the Airworthiness Directives (AD) mandated by the FAA, as well as customer authorized Service Bulletins (S/B) that contain recent revisions to the repairs.

Table 4) ACSC Repairs

RW Blend within serviceable Limits	**01 Repair Rabbet Diameters**	**02 Repair scratches on dovetail slot bottoms**
03 Repair disk post seal wire wear	**04 Remove silver corrosion**	**06 Repair brg journal diameter C**
08 Blend surface pitting	**09 Blend critical areas**	**11 Repair diameters CY and or CX**
12 **Repair Surface E**	13 **Repair Surface BS**	**15 Armpit Repair, Honing Repair for rim bolt holes**
AD	**S/B 72-A1026**	**S/B 72-1089**

The repairs that are listed outside of the typical repair code (01 through 15) as listed in the Engine Shop Manual are not represented in the analysis charts, as these may correspond to local differences and would complicate direct comparison of the called repairs among the shops. With only a few exceptions, the data was deemed accurate in representing the repair history. In the end we are left with the following repairs that are called regularly at ACSC: *1, 6, 9, 11, 12, 13, 15* and *"RW"* which is not represented in the analyses due to its generic nature and non-standard coding format. The combinations of repairs that ACSC has called for the Subject Part A in the time span extending from January of 2006 up until September 2007 are shown in Figure 7.

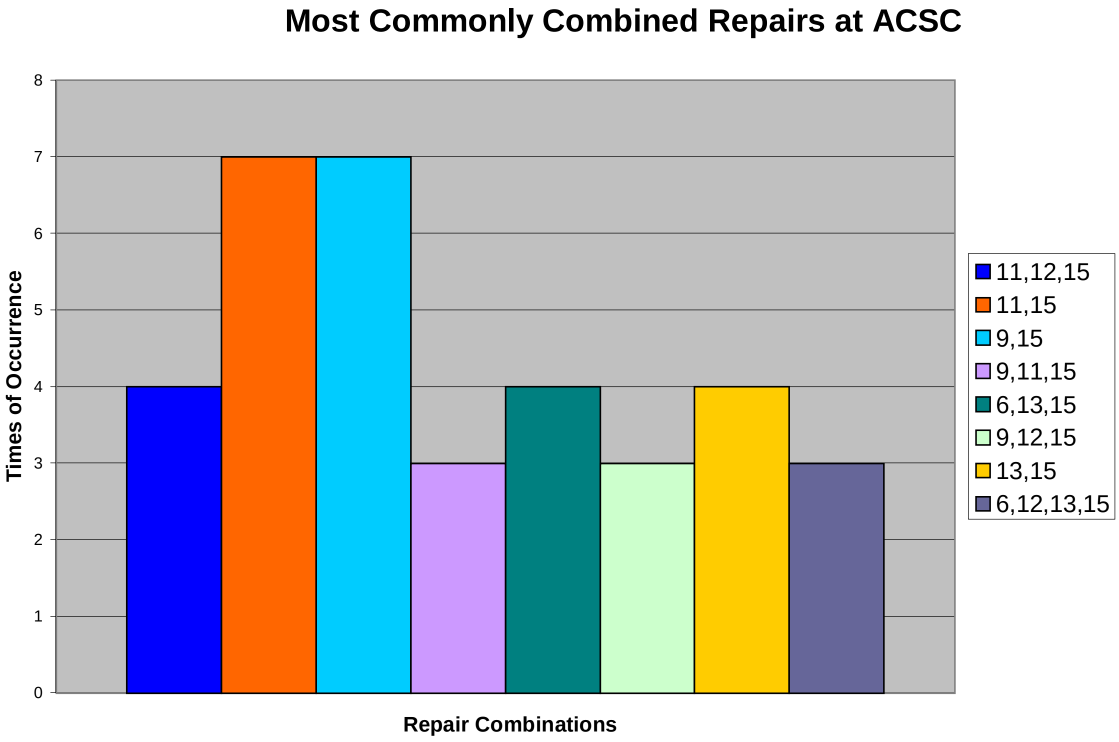


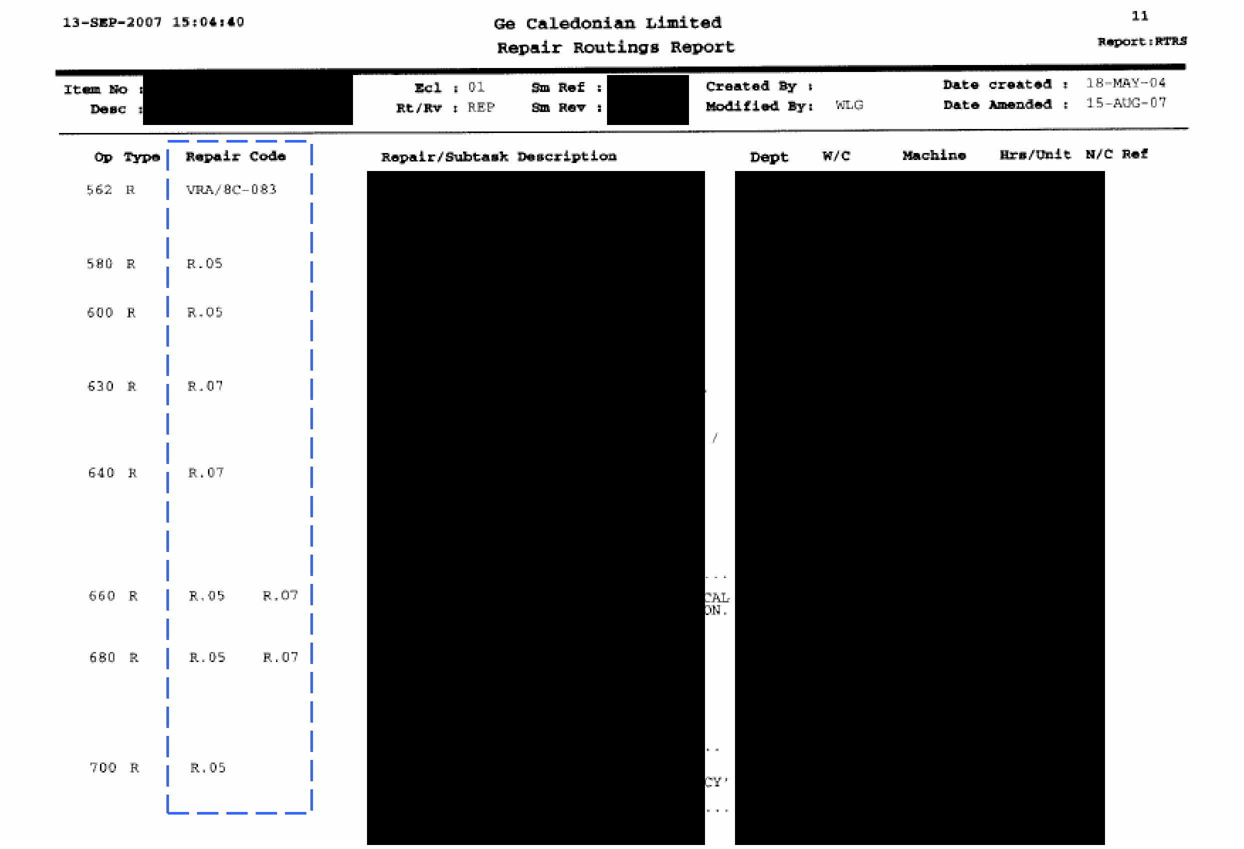
Figure 7) ACSC Repair Combinations

Out of a total of 249 repairs, 40 different combinations were identified. The chart represents combinations of repairs that were called at least three times. The unique combinations *9, 15* and *11, 15* were called most frequently at 7 times each and were detected at a total of 20 and 25 times respectively within other combinations (such as 1, **11**, **15** and 1, 6, **9, 15**).

4.2.2. Caledonian

The CF6-80C2 High Pressure Turbine Disk is one of the parts that GE Caledonian repairs. Unlike the static monolithic repair router at ACSC, the Caledonian shop uses a dynamic monolithic repair structure in their Cal 21 legacy shop floor execution system. The repair engineers at Caledonian have already sequenced and optimized all repair operations performed on this part, so that the monolithic structure contains all possible repair procedures. Caledonian does not need to issue the whole monolithic router as their legacy system is set up to strand together the operations that belong to the pertinent repairs chosen at the end of the inspection disposition phase. This means that the system pulls out the operations listed for each repair in the sequencing order that has been pre-programmed into the system and simply strands them together for the new router. The monolithic operation sequencing follows no categorical order apart from the intuitive logic followed by ACSC; and has been optimized over the years through iterative heuristic experimentation. It could be said that the shop has created its own optimum in following and setting up these operations over a certain span of time through experience and past six sigma projects. This local optimum is one of the stumbling blocks in creating one standardized, “vanilla” monolithic repair router; an issue that will be discussed in detail in the next section.

Figure 8 shows a single page excerpt from the 21 page- long monolithic repair router for the Subject Part A. The Operations are linked to multiple repairs where applicable. The repair codes are outlined on the screenshot to highlight multiplicity of these codes for common operations.



13-SEP-2007 15:04:40

Ge Caledonian Limited

Repair Routings Report

11

Report:RTRS

Item No : [redacted]
Desc :

Ecl : 01 **Sm Ref :** [redacted]
Rt/Rv : REP **Sm Rev :**

Created By :
Modified By: WLG

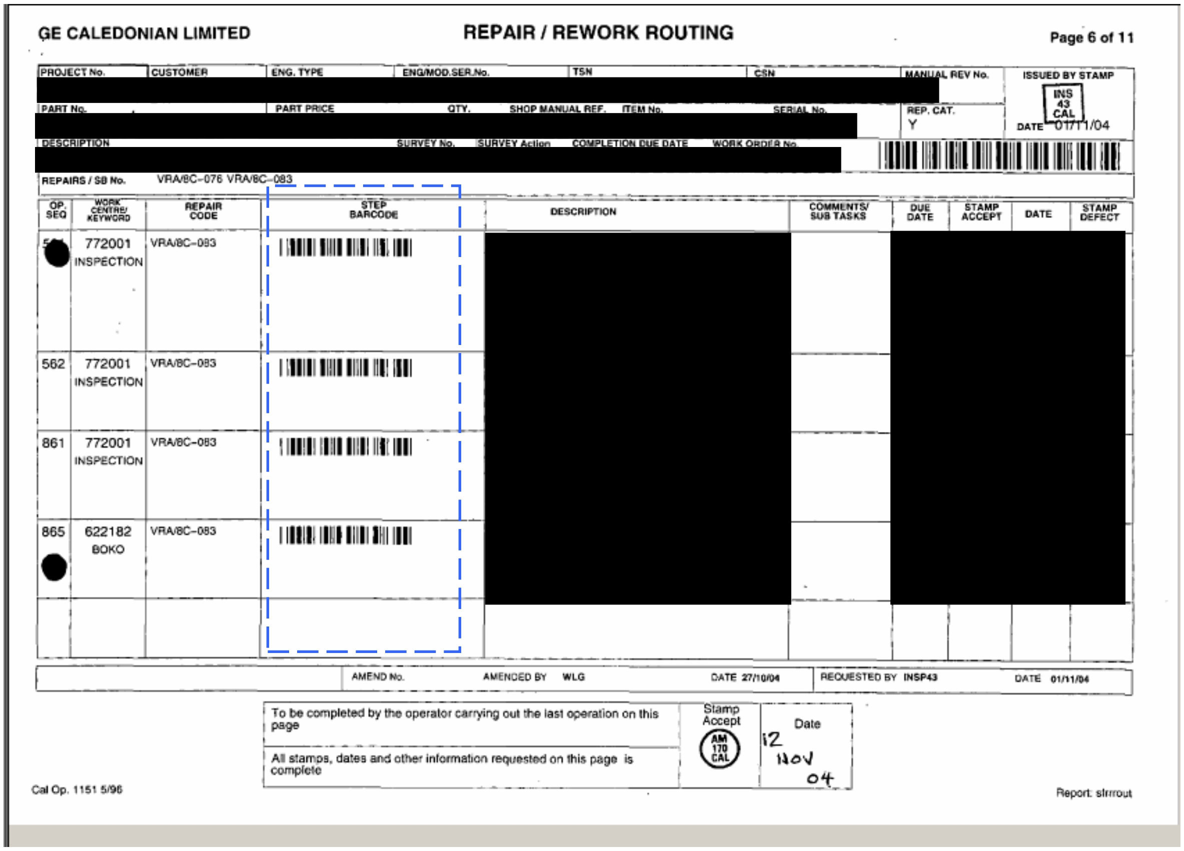
Date created : 18-MAY-04
Date Amended : 15-AUG-07

Op	Type	Repair Code	Repair/Subtask Description	Dept	W/C	Machine	Hrs/Unit	N/C Ref
562	R	VRA/8C-083	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	
580	R	R.05	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	
600	R	R.05	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	
630	R	R.07	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	
640	R	R.07	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	
660	R	R.05 R.07	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	
680	R	R.05 R.07	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	
700	R	R.05	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	

Figure 8) Caledonian Router Screenshot

After the necessary repairs for an inspected part have been selected, the mechanic enters this information into the system to generate the relevant repair router. This router determines the repair work scope of the part. This router is different than the monolithic router in that it contains interactive fields for stamping off operations and barcode scanning (outlined).

The workscoped router is shown in Figure 9:



GE CALEDONIAN LIMITED **REPAIR / REWORK ROUTING** Page 6 of 11

PROJECT No. | CUSTOMER | ENG. TYPE | ENG/MOD.SER.No. | TSN | CSN: [redacted]

MANUAL REV No.

ISSUED BY STAMP: INS 43 CAL

PART No. | PART PRICE | QTY. | SHOP MANUAL REF. | ITEM No. | SERIAL No.: [redacted]

REP. CAT. Y

DATE 01/11/04

DESCRIPTION | SURVEY No. | SURVEY Action | COMPLETION DUE DATE | WORK ORDER No.: [redacted]

REPAIRS / SB No. VRA/8C-076 VRA/8C-083

OP. SEQ	WORK CENTRE/ KEYWORD	REPAIR CODE	STEP BARCODE	DESCRIPTION	COMMENTS/ SUB TASKS	DUE DATE	STAMP ACCEPT	DATE	STAMP DEFECT
[illegible]	772001 INSPECTION	VRA/8C-083		[redacted]		[redacted]			
562	772001 INSPECTION	VRA/8C-083		[redacted]		[redacted]			
861	772001 INSPECTION	VRA/8C-083		[redacted]		[redacted]			
865	622182 BOKO	VRA/8C-083		[redacted]		[redacted]			

AMEND No. AMENDED BY WLG DATE 27/10/04 REQUESTED BY INSP43 DATE 01/11/04

	Stamp Accept	Date
To be completed by the operator carrying out the last operation on this page	AM 170 CAL	12 NOV 04
All stamps, dates and other information requested on this page is complete		

Cal Op. 1151 5/96

Report: slrrrout

Figure 9) Caledonian Workscoped Router Screenshot

The data obtained from Caledonian clearly points to the few repairs that are called regularly: *6, 9, 13, 15* as well as "Blend". Apart from the standard repair codes discussed in the ACSC section, Caledonian has the repair codes shown in Table 5-- the ACSC code is underlined and listed next to its Caledonian counterpart for clarity: BLEND stands for the generic blending operation and is represented by "RW" on the ACSC routers. PART.R.013 stands for "Partial Repair 13" to indicate the missing plasma operation in Caledonian. This code is equivalent to Repair 13 at ACSC.

Table 5) Caledonian Repairs

BLEND RW: within serviceable Limits	**VRA/8C-077 Repair 09: Blend critical areas**	**VRA/8C-076 Repair 15: Armpit Repair**
VRA/8C-083 SB 72-1089: Re-contour Dovetail Slot Bottom Aft Corner	**PART.R.013 Repair 13: Repair Surface BS**	**SB.72-1145 & SB.72-1217**

Last but not least, the "VRA" stands for "Vendor Rework Approval" and is represented by a unique, Caledonian generated code. The VRA is a document that Caledonian is mandated to follow by the Evendale Headquarters for repair substantiation. The Caledonian shop, for whichever VRA they are following, cannot deviate from the operations listed in this package and has to send in physical evidence collected through random sampling of the repaired parts that it is complying exactly with the standards set by both GE and the FAA. This collection of samples and testing is also evident in the operation steps seen on the Caledonian routers as a local attribute. An excerpt from a VRA can be examined in *Appendix D*.

The combinations of repairs that Caledonian has called for the Subject Part A in the time span extending from January of 2006 up until September 2007 are shown in Figure 10.

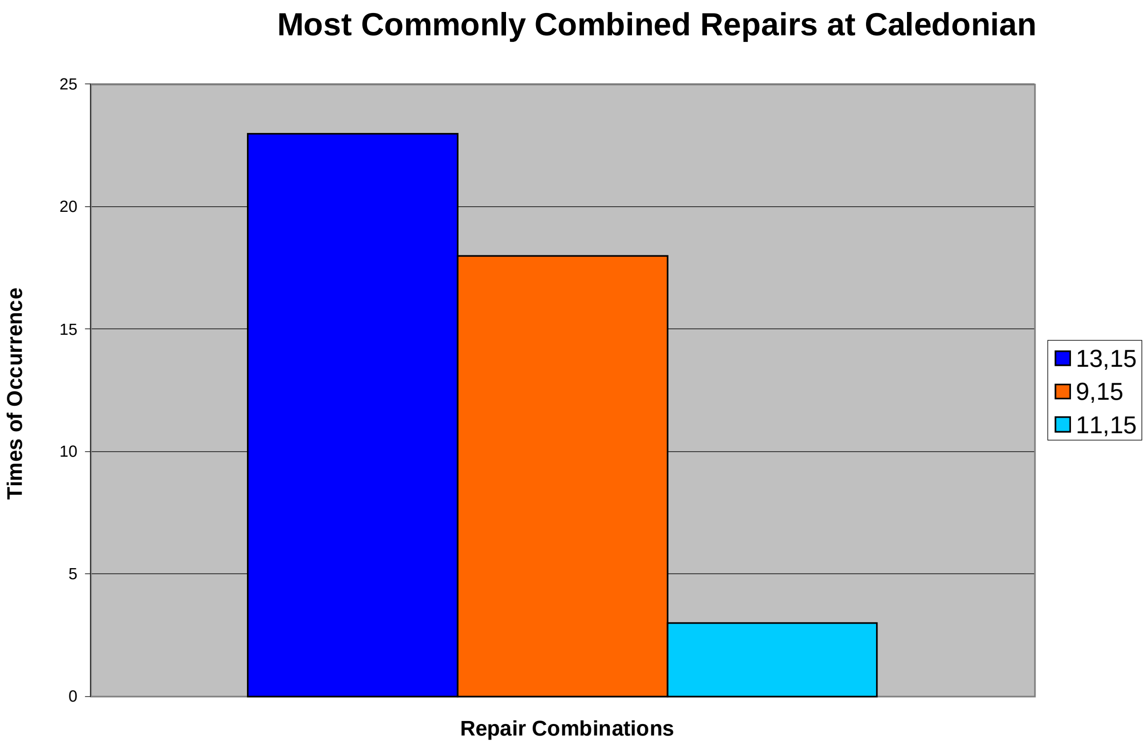


Figure 10) Caledonian Repair Combinations

Because Caledonian provided a larger amount of data, a random sampling of 40 shop repair orders out of the possible 126 was taken to estimate the frequency of repair combinations. Out of these 40 shop orders, the combinations *13, 15* and *9, 15* were called most frequently at a total of 23 and 18 times respectively (*i.e. 23 of 40 orders contained repairs 13, 15 and 18 of 40 orders contained repairs 9, 15*). The above chart hence represents the total number of times these two combinations were called. Furthermore, there were a total of 19 distinct combinations within the 40 shop orders; 11 of which called the unique combination 13, 15 and 4 of which called the unique combination 9, 15 (unique meaning not as a part of any other combination).

4.2.3. ACSC and Caledonian Repair Routers: Commonalities versus Local Differences

The ACSC CPL1 and Caledonian repair router characteristics have been discussed separately in the previous two sections. This section is intended to give the reader a better understanding of the differences between these local documents and procedures. These differences can be grouped under two headings by their significance: as primary and secondary. Primary differences are shop specific and exemplify the type of issues that are likely to emerge in the global implementation of standardized repair routers among the shops. The secondary differences are listed as more common issues of lesser significance.

Primary Differences

1. Coding differences that reflect local compliance:

ACSC repairs are coded to mirror the engine shop manual repair codes, whereas the Caledonian routers have locally generated Vendor Rework Approval codes that supersede the ESM repairs. The VRA ensures repair substantiation and provides no flexibility to deviate from it, even if the said deviation is simply a re-sequencing of operations.

2. Local operation differences:

There are local procedures at every shop, to which ACSC or Caledonian are no exception. The local procedures are also expressed in different formats. The best example for this is the ACSC “manually assisted detergent clean” and the Caledonian “Metalas Clean”. The Metalas Cleaning procedure is machine operated and is always listed out as a separate operation on the Caledonian routers with its own operation sequence number. The ACSC routers, on the other hand, have this cleaning operation listed as a footnote to other operations and hence do not assign a separate operation sequence number to it.

3. Level of detail and the accompanying background documents:

At ACSC, planning documents are a crucial complement to the routers. ACSC routers represent a summarized overview of the main steps required, and do not list each and every step that must be completed to execute the operations. For example, the sequence of operations on the ACSC routers go from Machining to FPI, apparently missing an etch operation. The etch operation, however is listed as part of the FPI planning sheet and constitutes one of the steps that need to be taken to complete the FPI inspection. Hence, the mechanic who is performing the said operations on the shop floor is forced to go back and reference the operation and planning sheets to retrieve the details.

Caledonian routers, on the one hand, are very detailed in listing out the operational steps individually, down to the level of machine set up and preparation and even include dimensional information. They strictly follow and reference the Vendor Rework Approval packages, standard practices or the engine shop manual paragraph by paragraph where applicable. There is a great level of detail in these routers, which makes them longer and seemingly eliminates the need to reference the background documents to a great extent. (Although mechanics and technicians are required to reference these documents each time as documents may have undergone revisions.)

The conciseness of the ACSC routers is in fact the product of following lean principles. With the guidance of their former lean leader, ACSC has reconstructed and internally standardized their routers to reflect the flow of processes for similar parts. This process was initiated through an operation matching effort (similar to the one in the below table) for all parts that flow through any single cell (flow families). The process will be descried more in detail in *Section 4.3.*

This primary difference is examined here and documented exhaustively in Appendix A. The table listed in Appendix A combines the most commonly combined operations at both ACSC and Caledonian, namely the combined Repairs 9 and 15. All operations were extracted from the master repair routers that these sites provided and ordered in the exact sequence that the master router implies. This one-on-one comparison clearly illustrates the previously stated differences. Merely pulling the operational steps out of the master routers was not sufficient in matching up the operations, so that all of the accompanying planning sheets and VRAs were examined to produce the most accurate analysis possible. Hence the reason for repeating the operation sequences on the ACSC part: these steps match up the Caledonian operations as elaborated in their respective operation planning sheets and do not have separate operation sequence numbers.

Some major points that spring out from this comparison are the change of order between operations *230* (Machine VTL) and *260* (Bench/ Blend) at ACSC (highlighted in red). These two operations do not match up with the Caledonian operations in the expected 230→ 260 order, and instead reverse it as 260→ 230. This phenomenon can be explained by tracking these operations back to the repairs listed in the engine shop manual. The engine shop manual provides flexibility for the order in which some operations are performed. Therefore, if the shop decides to alter the order of such operations in line with their capabilities and the local operation flow optimum (this would also be dependant on current plant layout); they are allowed to do so. Another underlying reason for such changes is the current technology in the shops.

Another important point is the duplicated operations listed on the Caledonian router. These are highlighted in blue and are located near the end of the table. This is an evident inefficiency characterized by the exact same operation listed as two separate operations with slightly different wording (and with separate operation sequence codes) on the workscoped monolithic router. Please refer to Appendix A for the detailed comparison.

Secondary Differences

4. Variety of repairs:

ACSC has a larger scope of repairs than Caledonian. ACSC is a component repair shop and Caledonian has the capability of doing only certain repairs at its “back shop”. The pie charts in Figure 11 illustrate not only the commonly combined repairs, but also serve to demonstrate the differences in repair variety.

5. Operation sequence codes:

Operation sequence codes vary greatly within shops and apart from following an increasing numerical order, do not present any coding value for actual operations. ACSC has undergone some changes to standardize their operation codes, however the operation codes still vary greatly between shops.

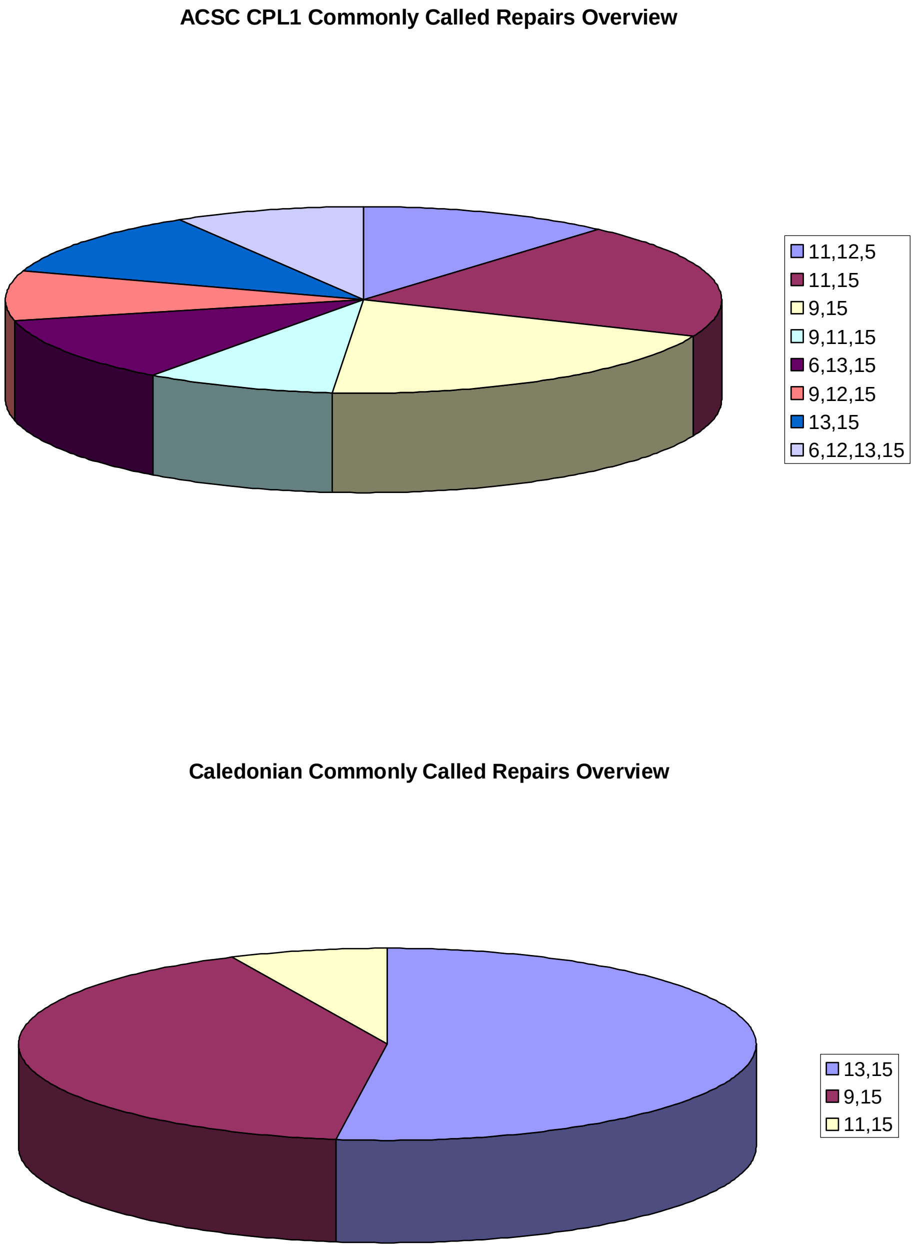


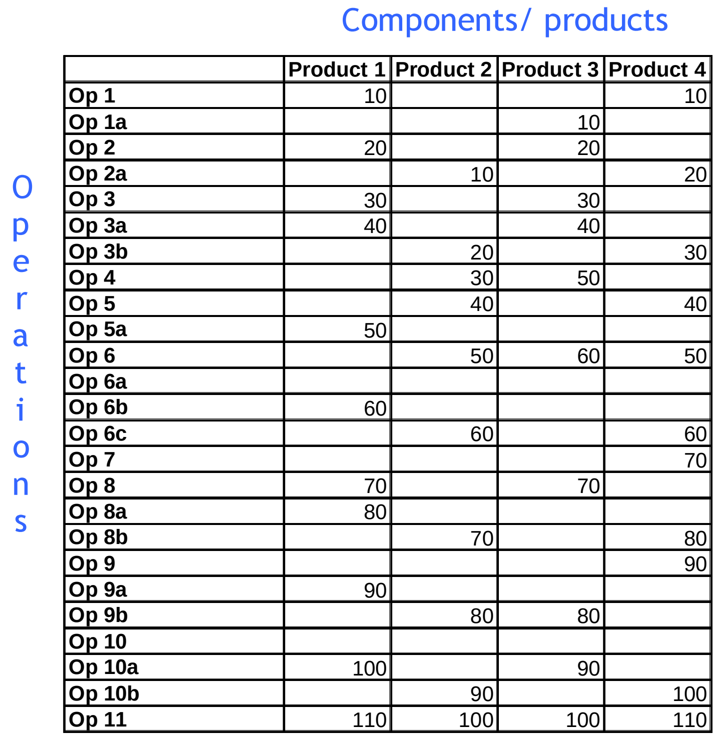
Figure 11) ACSC and Caledonian Frequent Repair Combinations

4.3. Prototype of the To Be Monolithic Router Structures

The challenge of standardizing a router characterizes itself more as a need to streamline the operations that it contains rather than finding a standardized SAP format. Even when there is a master repair router structure behind the legacy SFE system, the verbiage and the duplicity of operations continues to be an issue. In the Caledonian example, the system has the capability of pulling out called repairs from the somewhat streamlined master repair router, however similar or identical operations appear repetitively on the workscoped routers. Notes and cautions as well as detailed set up and tooling information are also listed and have been assigned sequence codes. In proposing a global monolithic router structure, it is essential to clean up the router content and normalize the flow of operations for the repairs of part families.

Standardizing part flow requires grouping, combining and possibly re-sequencing similar operations listed in the numerous repair routers issued for similar components. This exercise requires the whole team of representatives who have the authority and expertise to speak for a group of such parts (Rotating parts, Cases, Sumps, Seals, Disks, etc.) to get together and discuss the best option for a standardized flow. This exercise yields the critical path that must be followed by similar part repairs and helps identify common operations.

Excerpts from the ACSC lean training documents help solidify this concept; as shown in Figure 12.



Components/ products

Operations

	Product 1	Product 2	Product 3	Product 4
Op 1	10			10
Op 1a			10	
Op 2	20		20	
Op 2a		10		20
Op 3	30		30	
Op 3a	40		40	
Op 3b		20		30
Op 4		30	50	
Op 5		40		40
Op 5a	50			
Op 6		50	60	50
Op 6a				
Op 6b	60			
Op 6c		60		60
Op 7				70
Op 8	70		70	
Op 8a	80			
Op 8b		70		80
Op 9				90
Op 9a	90			
Op 9b		80	80	
Op 10				
Op 10a	100		90	
Op 10b		90		100
Op 11	110	100	100	110

Figure 12) Mixed Model Map First Step

Figure 12 shows all possible repair operations listed for a hypothetical group of similar products. Ordering the operations in preparation for the next step may be an iterative process, and it is useful to start ordering by first determining a couple common operations for all products and using those as reference points to order the operations that come before and after.

The next step is to look at nomenclature and sequence of events. Variety in wording often makes similar or identical operations seem different and leads to duplication. Sequence of orders should also be standardized as much as possible, keeping in mind all regulations. The following list provides examples of how identical operations can be expressed in different ways:

- I.P Machine = Prep for metal spray = In-Process Machine = Machine
- Identify Part Number = Incoming Review of Hardware
- Grit Blast = Media Blast = Prep for Final
- Incoming Inspection = Dimensional Inspection/Quote Part
- Weld Surf A = Weld
- Metal Spray = Thermal Spray = HVOF
- Machine Metal Spray = Finish Machine = VTL

The best description should be picked for each operation to standardize its usage. The optimal sequence of operations can then similarly be determined through discussions to produce a result akin to that shown in Figure 13. In comparing this to the first image, it is evident that the process flow for this part has been optimally defined. The clutter has been eliminated by using a common nomenclature and a single operation number for each distinct operation, creating a much cleaner outlook on the process.

Components/ products

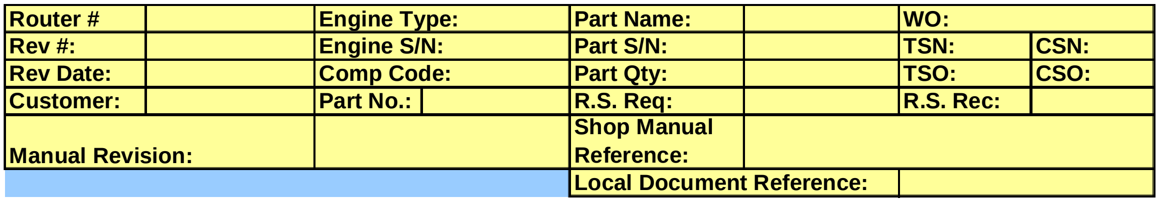
Operations

	New Operation Number	Product 1	Product 2	Product 3	Product 4
Op 1	**10**	10	X	10	10
Op 2	**20**	20	10	20	20
Op 3	**30**	30	40	30	40
Op 4	**40**	40	20/30	40/50	30
Op 5	**50**	50	50		50
Op 6	**60**	60	60	60	60
Op 7	**70**	70			70
Op 8	**80**	80	70	70	80
Op 9	**90**	90	80	80	90
Op 10	**100**	100	90	90	100
Op 11	**110**	110	100	100	110

Figure 13) Mix Model Map Second Step

The proposed standard master router structure for the Subject Part A can be seen in Appendix B. The formatting is intended to imitate the SAP screen.

The router fields in the header have been identified through SAP requirements as well as shop inputs and requests as discussed in *Section 4.1*. The router fields are: Router Number, Router Revision Number and Date, Manual Revision, Customer, Engine Type, Engine Serial Number, Component Code, Part Number, Part Name, Part Serial Number, Part Quantity, Repair Substantiation Required, Repair Substantiation Recorded, Time Since New, Cycle Since New, Time Since Overhaul, Cycle Since Overhaul, Work Order Number, Shop Manual Reference and Local Document Reference. These fields can be seen in Figure 14.



Router #		**Engine Type:**		**Part Name:**		**WO:**	
Rev #:		**Engine S/N:**		**Part S/N:**		**TSN:**	**CSN:**
Rev Date:		**Comp Code:**		**Part Qty:**		**TSO:**	**CSO:**
Customer:		**Part No.:**		**R.S. Req:**		**R.S. Rec:**	
Manual Revision:				**Shop Manual Reference:**			
				Local Document Reference:			

Figure 14) Header for Prototype Monolithic Router

The repairs in this structure were grouped around the main operations that determine the flow of the part through the shop. By doing this instead of spelling out each repair step and trying to combine those in order, repetitious operations were eliminated (as they can only be listed once). Looking at the router also finally gives the observer a clear idea of what the process flow is for that part. The order greatly resembles the flow of the ACSC routers; however some operations were separated to make the router more applicable to other shops (FPI is now Etch and FPI separately). Because this is not the ultimate repair router structure for the Subject Part A, shops would also need to discuss the naming conventions for the operations and perhaps generalize the terms. Column 2 in Appendix B shows how the repair codes will be standardized to replace the locally generated codes. The Operation description serves to elaborate on the repair details when necessary. This could be a note pointing to which area of the component this operation is being applied to, such as Column 3 in Appendix B: “Repair 6 DIA C”, “Repair 9 BRG B”, etc. The details of these operations will need to be backed up by local procedures or compliance documents. There is a field in the header to provide link to these local documents and the upload of these documents could also be automated to automatically populate the “…” note fields listed next to the Repairs. This common structure allows for the necessary flexibility around accommodating local procedures and documents like the previously mentioned VRA and Planning sheets. The shops will be responsible for uploading these documents onto their local servers to link to the standardized router. The goal here is to think in terms of the process flow and not by individual repairs. Once the process flow has been determined, the repairs can be grouped around those and can still be called out at the end of the disposition phase.

4.4. Prototype Design Reflections

What is engineering design? The Accreditation Board for Engineering and Technology defines the engineering design as “the process of devising a system, component or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation.” The prototype presented in this project meets this criteria by incorporating the design steps of establishing objectives and a systematic methodology to construct a router design.

Why is this design? It was important to design a prototype to solidify the findings that helped envision the monolithic repair router. This router will be system generated and will not be issued on paper in the future. It was therefore helpful to represent the new visual characteristics of these routers by generating a format and color scheme that imitates the UI of SAP screens. Similar designs will further need to be generated to train and prepare the shops for SAP interfacing. This design also represented good IT interface design practices through reducing text length and providing a good match between how the information is presented and how the user is expected to perform the operations described on the screen. (Hart) When there was shared information, in this case the name of the operation, this became a header for that field followed by the applicable repairs. This eliminates clutter and confusion around the repetition of repair numbers as well as similar operations and streamlines the process flow to be followed. Color coded radio buttons show which operation is currently being completed. When this button is green, the user is informed that the operation is still being performed, and knows to record conformance information to be able to move on to the next operation.

Constraints: Only two master repair routers from ACSC and Caledonian were closely examined for the Subject Part A, as opposed to three with Japan. This was mainly due to having established contacts at these sites, with whom conference calls and in-person meetings could be set up fairly quickly and effortlessly. The availability of the contacts was important to handle the time limitations of completing this project. Limited shop floor experience and observation also somewhat confined the level of accuracy that is represented in the prototype process flow. This process flow may not be completely feasible for Caledonian, as the observations that led to its creation were made mainly on the ACSC CPL1 shop floor.

Implementation/ Testing of Design: Testing of this design will need to be carried out in the SAP technical sandbox first. The repair workscope automation will need to be linked to the disposition screens in SAP. The system will then need to be set up so that it only demonstrates the operations that are linked to the repair workscope and populates the initially blank detail sections from the previously identified local procedures. There will also be a link to the local server that contains shop specific documents for referral. Once the functionality meets the specified requirements, the design can be implemented outside of the sandbox, in the actual system.

Action Items: Listed below are the proposed action items and dates to carry out the design in short term.

Task	Date	Owner	Status
Create Initial Prototype	10/05/2007	Hilal Tetik	**Completed**
Create Timeline for Shops	**10/11/2007**	Hilal Tetik, Engineering COE	**In Progress**
Finalize Prototype	**10/19/2007**	Engineering COE, Cal Team	**On Hold**
Receive Shop Input for Standardization/ Present Pitch	**10/24/2007**	Engineering COE	**On Hold**
Tell shops to identify part families (Cal & Celma) and collect routers	**10/24/2007**	Engineering COE	**On Hold**
Start Mapping Operations	**11/19/2007**	Caledonian, Celma	**On Hold**
Initial Prototype Design Test in SAP	**11/19/2007**	Engineering COE, Ron Winkler, Cal Team (may involve outside vendor)	**On Hold**

Figure 15) Action Items

4.5. Standardized Global Router Vision Synopsis

The ACSC and Caledonian comparison in *Section 4.2.3* highlights some of the main differences between shops that stand in the way of an effortless transition to standardized routers. This furthermore shows us that the fundamental differences between component repair and overhaul shops need to be taken into consideration when proposing standardized routers.

Overhaul Shops' main focus of Disassembly and Assembly operations are static and characterize a more linear flow of operations. It is therefore easier to standardize and optimize routing documents for these clear-cut tasks. They also typically have a different scope of repairs that they are capable of doing in their repair back shops.

Component Repair Shops have less predictability in terms of organizing their operations. Even with the presence of a master template for operations flow; the exact operation sequence is determined after post-disposition workscoping (as some repairs may not call for certain operations). The repairs may flow differently, but they have common operations, which should be identified to group these repairs.

There are additional differences across shops that go beyond their internal operations. Different countries are regulated by different authorities; such as the FAA in the United States and the European Aviation Safety Agency in European countries. These authorities sometimes have different methods or different criteria of governing quality. In line with these regulations, there may be different local procedures or requirements. Nevertheless, assuming there are shop structure similarities, the proposed template can be implemented if shops can negotiate. The shop implementation timeline is shown in Figure 16.

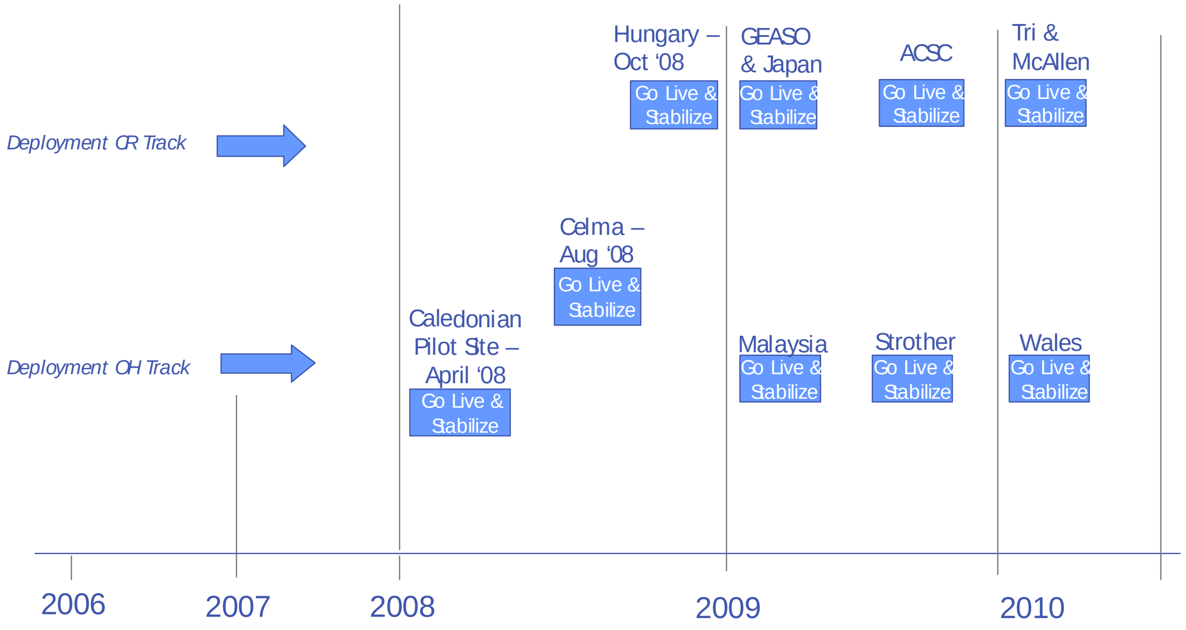


Figure 16) Implementation Timeline

By this timeline, Caledonian and Celma should be the first two shops to start the standardization efforts and set an example for other shops to follow. They have a number of common components that they repair, and can start the operation mapping process for part families. To move a step ahead of the timeline, it would also be wise to engage Hungary in the process for mapping familiarization and standardization support. Overhaul shops like Malaysia, Strother and Wales can learn from the routing standardization that Caledonian and Celma went through previously (mainly for disassembly and assembly routers). GEASO, Japan and ACSC also have a fair amount of commonality around component repair capability, and should coordinate their efforts together. These shops may need to start the process relatively early than their Go-Live dates and at approximately the same time with each other. The recommended time for this would be late 2008. This will allow them to coordinate with and receive implementation feedback from Hungary, the first Component Repair shop to go live.

To get an idea of how much component repair overlap there is between shops, consider the following example: For the 80C2 engine model, there are 199 unique components, 122 of which get repaired at multiple sites. There are a total of 304 global routers for these components. As discussed in *Section 4.3*, the best way to standardize routers is to group them around similar parts and processes (i.e. “case process routers”, “sump process routers”) instead of trying to standardize one component router at a time. With that in mind, Figure 17 shows the reader how much overlap there is between shops and what level of collaboration is necessitated through this commonality. The numbers in the overlapping fields represent the components that get repaired at the pertinent shops. For instance, there are 7 different 80C2 components that get repaired at both Caledonian and Celma. (The largest one-on-one overlap for this engine model is between ACSC and Caledonian with 32 different components.) These shops would then need to see what characterizes these components to group them accordingly (i.e. rotating or structural), determine the underlying flow and then propose a master router structure for each group. To see a detailed overview of the components that are repaired at multiple sites, please refer to *Appendix E*.

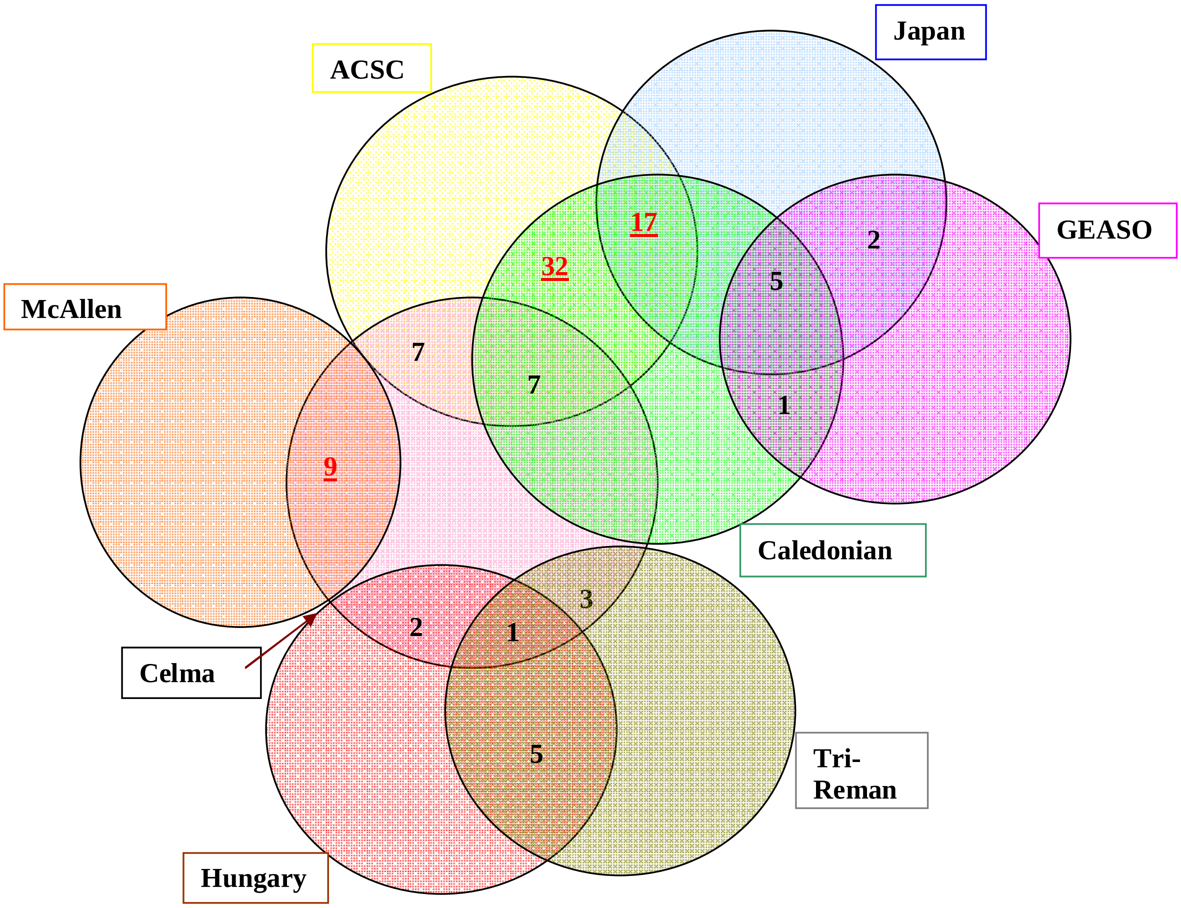


Figure 17) 80C2 Global Component Repair Overlap

5. Conclusions and Recommendations

The goal of this project was to establish an SAP compatible, standardized monolithic repair router structure and create recommendations that would help fulfill the paperless shop vision. In order to realize this goal, extensive data collection and analysis was conducted in line with the objectives.

Including the use of router fields worldwide and the comparison of existing repair router structures for a single rotating part, the results of the analyses led to some important realizations which shaped the recommendations in this section. Some of the significant findings were the main differences between what both ACSC and Caledonian call “master repair routers”. The variation in Repair coding was also surprising, as exemplified by ACSC using the same nomenclature for Repair 009 as the Engine Shop Manual, in contrast to Cal using the locally generated code for its repair substantiation document, VRA/8C-077. Another example was Caledonian and ACSC calling the same operation by different names. (E.g. ACSC used “Blend” while Caledonian used “RW” for the same operation.) The mapping analysis in this paper replaced these disparate codes with more conventional forms. Basic standardization of such coding conventions will similarly need to precede any efforts to standardize the flow of operations on the next level. Based on this analysis, a prototype monolithic repair router for a sample part was created, as shown in Appendix B. This router uses commonly defined operation numbers based on the flow of part families, rather than organizing routers by repairs. Common wording also eliminates redundancies. Finally, links to locally stored documents allow customization.

Creating a standardized global repair router is undoubtedly an intricate task that requires collaborated effort from all affected shops. When confronted with the concept of a central structure owning and managing a standardized routing document, shops justifiably expressed concern about the efficacy and success of such an attempt. In addition to that, extensive data analysis and consideration of personal inputs-- as presented in the Results section- clearly showed what local variations should be anticipated when going forward with this plan. There is indisputably the need for a well-defined methodology and a cost-benefit analysis that will justify the standardization efforts to ensure shop collaboration. That being said, shops will need to realize that standardization will be a result of their partnership and collaboration with the centralized Engineering COE structure as well as with each other. The following methodology was developed to support the standardization process:

1. *Mapping Operations:* Router operations need to get mapped internally first to enable a clean global comparison. Global operations will then need to get mapped against one another. The mapping example in *Section 4.2.3.* of this paper was used strictly to identify the differences between ACSC and Cal and does not represent the internal standardization process. Internal mapping needs to be realized through identifying part families, collecting repair routers for these part families (for example for 5 components that are in the same family, one would have 5 routers) and listing out the operations included in these routers. Once they

have been compiled in one place, one can start to look at these operations to eliminate multiple instances and recombine if need be.

2. *Collaboration:* Once a shop has an internally standardized representation of how each of their part families flow through the repair operations, they can “map” their proposed flow of operations against other shops. This will then enable these process engineers to gain an awareness of local differences that will lead to a more productive discussion among shops. The representatives from the shops who are involved in repairing similar parts will then need to meet on GE’s Web- or Teleconference based platforms to negotiate the optimal way to restructure and standardize their flow of operations. The collaboration timeline, as discussed in the Results section, is dependant on the actual implementation dates and could be spread out as follows: Caledonian and Celma with each other/ Caledonian and Celma with Hungary/ Caledonian with Malaysia, Strother and Wales/ GEASO, Japan and ACSC with each other and with Hungary.

3. *Accommodating Local Deviations:* Once the optimal flow of operations has been identified, there will still be need for flexibility on the standardized routing documents to allow for local deviations. These differences can be caused by variations in tooling, technology, certifications, capabilities and localized procedures. These details will be kept in the local servers, to which the routers will be linked. Shops can also customize the contents of the routers to a certain extent by adding notes or comments to the description section.

The key to success with creating and establishing the standardized router structure will be to first get shops’ support and give them the initial local responsibility to optimize their own routers. In the next steps, it will be crucial to follow up with the shops and ensure that all implementation milestones are complied with. Standardization will urge the business to find the best practices within, and eliminate inefficiencies related to verbiage in the routers. Standardizing the router will also help identify an optimized flow of operations for repair part families and this flow may reduce hand offs between singular steps by enforcing flow through cells that are defined by the main operational steps. Even when this process seems lengthy and challenging, the lean thinking it represents will set the business on track for growth.

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Appendices

Appendix A: ACSC and Caledonian Repairs 9, 15 Match-up

ACSC CPL1	Repair Code	Operation Sequence Number		Repair Code	Caledonian
			60	9	[redacted]
[redacted]	All	140	65	9	[redacted]
[redacted]	All	170	70	9	[redacted]
[redacted]	9	260	75	9	[redacted]
[redacted]	9	260	80	9	[redacted]
[redacted]	9	260	81	9	[redacted]
[redacted]	9	260	82	9	[redacted]
[redacted]	9	260	87	9	[redacted]
[redacted]	9	260	90	9	[redacted]
[redacted]	9	260	94	9	[redacted]
[redacted]	9	260	98	9	[redacted]

Appendix A (Continued)

[redacted]	9	260 (Referral note to S/M limits included under this repair)	164	15	[redacted]
[redacted]	15	230	168	15	[redacted]
[redacted]	15	230	174	15	[redacted]
[redacted]	15	230	177	15	[redacted]
[redacted]	15	230	180	15	[redacted]
[redacted]	15	230	182	15	[redacted]
[redacted]	15	230	184	15	[redacted]
[redacted]	15	230	190	15	[redacted]
[redacted]	15	230	198	15	[redacted]
[redacted]	15	230	202	15	[redacted]
[redacted]	15	230	205	15	[redacted]

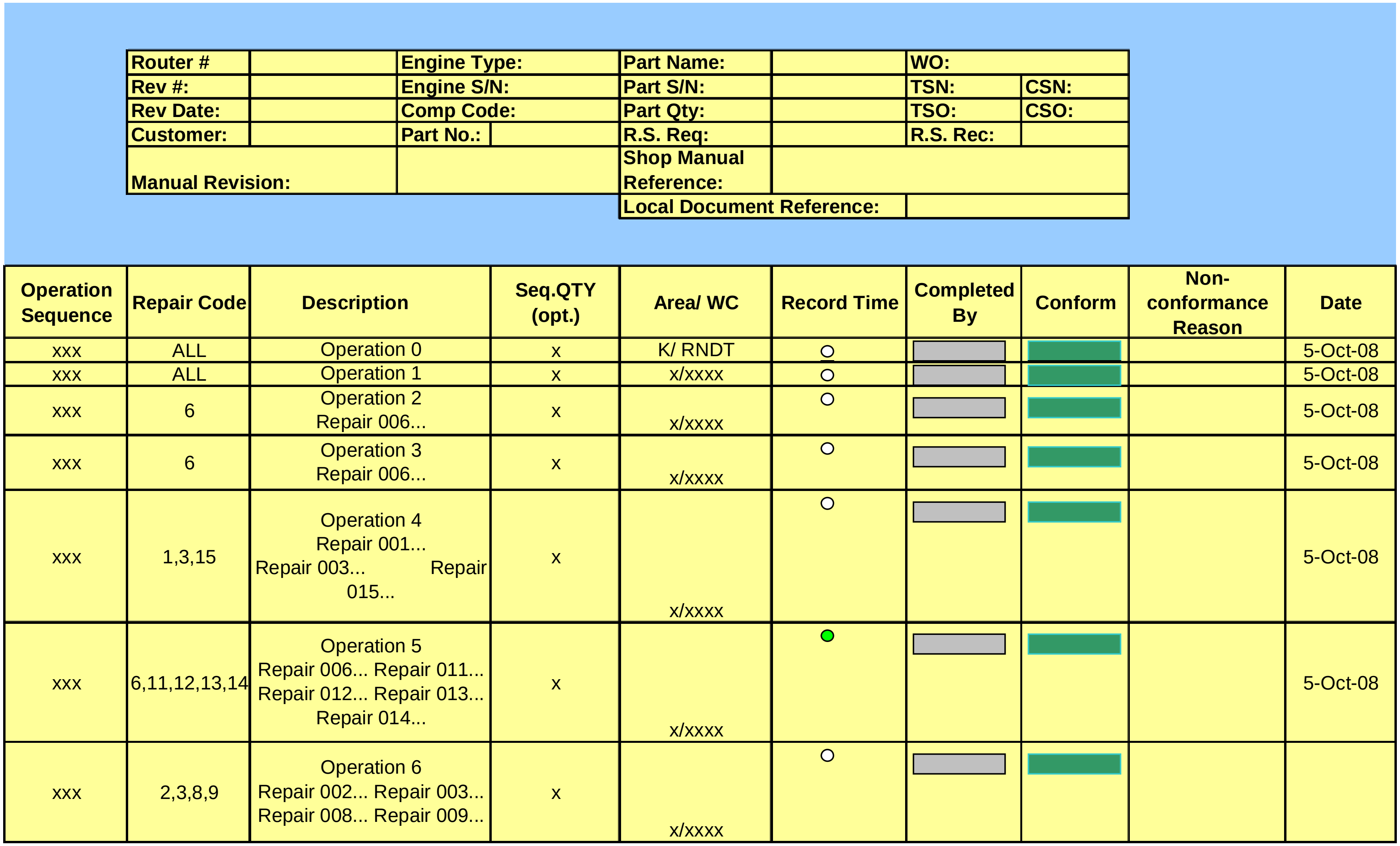
Appendix A (Continued)

[redacted]	▨	▨	207	15	[redacted]
[redacted]	15	230	210	15	[redacted]
[redacted]	15	230	290	9	[redacted]
[redacted]	▨	▨	292	9	[redacted]
[redacted]	9, 15	320	294	9	[redacted]
[redacted]	▨	▨	300	15	[redacted]
[redacted]	9, 15	320	380	15	[redacted]
[redacted]	9, 15	320	384	9	[redacted]
[redacted]	9, 15	320	400	15	[redacted]
[redacted]	9, 15	320	415	9	[redacted]
[redacted]	▨	▨	444	15	[redacted]
[redacted]	9, 15	380	460	15	[redacted]
[redacted]	9, 15	380	462	9	[redacted]
[redacted]	▨	▨	465	15	[redacted]
[redacted]	9, 15	380	470	15	[redacted]

Appendix A (Continued)

[redacted]	9, 15	380	475	15	[redacted]
[redacted]	9, 15	380	485	9	[redacted]
[redacted]	▨	▨	500	9	[redacted]
[redacted]	All	540	1400	9, 15	[redacted]
[redacted]	All	560	1420	9, 15	[redacted]

Appendix B: Proposed Standard Monolithic Repair Router- in SAP Screen Format



Router #		**Engine Type:**		**Part Name:**		**WO:**	
Rev #:		**Engine S/N:**		**Part S/N:**		**TSN:**	**CSN:**
Rev Date:		**Comp Code:**		**Part Qty:**		**TSO:**	**CSO:**
Customer:		**Part No.:**		**R.S. Req:**		**R.S. Rec:**	
Manual Revision:				**Shop Manual Reference:**			
				Local Document Reference:			

Operation Sequence	Repair Code	Description	Seq.QTY (opt.)	Area/ WC	Record Time	Completed By	Conform	Non-conformance Reason	Date
xxx	ALL	Operation 0	x	K/ RNDT	○	▭	🟩		5-Oct-08
xxx	ALL	Operation 1	x	x/xxxx	○	▭	🟩		5-Oct-08
xxx	6	Operation 2 Repair 006...	x	x/xxxx	○	▭	🟩		5-Oct-08
xxx	6	Operation 3 Repair 006...	x	x/xxxx	○	▭	🟩		5-Oct-08
xxx	1,3,15	Operation 4 Repair 001... Repair 003... Repair 015...	x	x/xxxx	○	▭	🟩		5-Oct-08
xxx	6,11,12,13,14	Operation 5 Repair 006... Repair 011... Repair 012... Repair 013... Repair 014...	x	x/xxxx	●	▭	🟩		5-Oct-08
xxx	2,3,8,9	Operation 6 Repair 002... Repair 003... Repair 008... Repair 009...	x	x/xxxx	○	▭	🟩		

Appendix B (Continued)

xxx	1,2,3,6,8,9,11,12,13,14,15, Blend	Operation 7 Repair 001... Repair 002... Repair 003... Repair 006... Repair 008... Repair 009... Repair 011... Repair 012... Repair 013... Repair 014... Repair 015... Blend...	x	x/xxxx	○	▭	🟩		
xxx	1,2,3,6,8,9,11,12,13,14,15, Blend	Operation 8 Repair 001... Repair 002... Repair 003... Repair 006... Repair 008... Repair 009... Repair 011... Repair 012... Repair 013... Repair 014... Repair 015... Blend...	x	x/xxxx	○	▭	🟩		
xxx	1,2,3,6,8,9,11,12,13,14,15	Operation 9 Repair 001... Repair 002... Repair 003... Repair 006... Repair 008... Repair 009... Repair 011... Repair 012... Repair 013... Repair 014... Repair 015...	x	x/xxxx	○	▭	🟩		
xxx	ALL	Operation 10	x	x/xxxx	○	▭	🟩		
xxx	ALL	Operation 11	x	x/xxxx	○	▭	🟩		
xxx	ALL	Operation 12	x	x/xxxx	○	▭	🟩		
xxx	ALL	Operation 13	x	x/xxxx	○	▭	🟩		
xxx	ALL	Operation 14	x	x/xxxx	○	▭	🟩		

Appendix B (Continued)

xxx	1,3,6,11,12,13,14	Operation 15 Repair 001... Repair 003... Repair 006... Repair 011... Repair 012... Repair 013... Repair 014...	x	x/xxxx	○	▭	🟩		
xxx	3, 6, 11, 12, 13, 14	Operation 16 Repair 003... Repair 006... Repair 011... Repair 012... Repair 013... Repair 014...	x	x/xxxx	○	▭	🟩		
xxx	1	Operation 17 Repair 001...		x/xxxx	○	▭	🟩		
xxx	1,3	Operation 18 Repair 001... Repair 003...	x	x/xxxx	○	▭	🟩		
xxx	ALL	Operation 19	x	x/xxxx	○	▭	🟩		
xxx	ALL	Operation 20	x	x/xxxx	○	▭	🟩		
xxx	ALL	Operation 21	x	x/xxxx	○	▭	🟩		

Appendix C: ACSC Operation Planning Sheet

ACSC MANUFACTURING OPERATION SHEET

PART NO.: [redacted]
PART NAME:
OPER NO : 230
REV. NO.: F
OPER. NAME: [redacted]
PPR NO.: [redacted]
SHEET

1) Part numbers: [redacted]

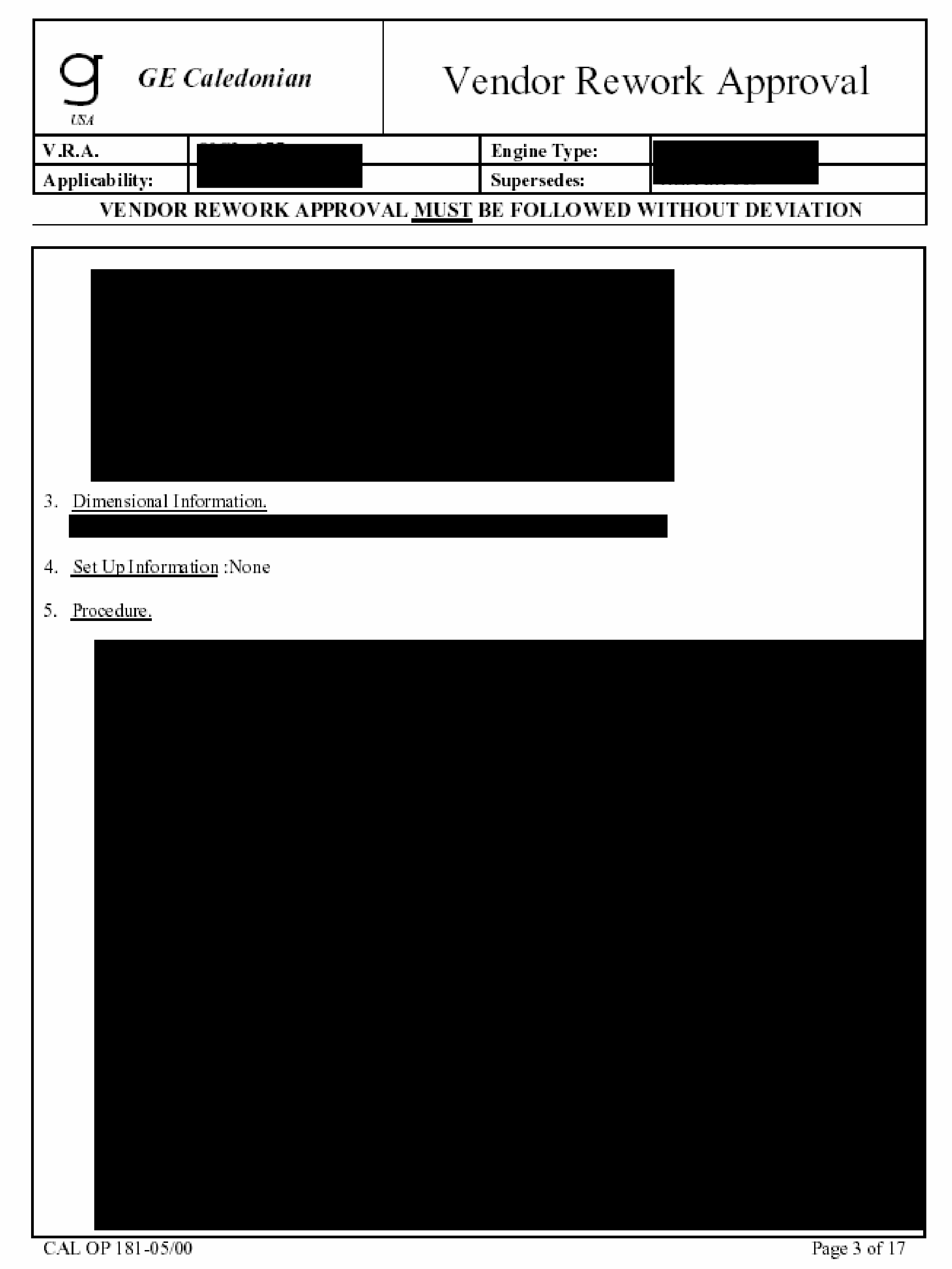
2) Tooling: [redacted]

3) CNC program: [redacted]

4) Set up procedure: [redacted]

5) Machining procedure: [redacted]

Appendix D: Caledonian Vendor Rework Approval



GE Caledonian USA

Vendor Rework Approval

V.R.A.	[redacted]	**Engine Type:**	[redacted]
Applicability:	[redacted]	**Supersedes:**	[redacted]

VENDOR REWORK APPROVAL MUST BE FOLLOWED WITHOUT DEVIATION

[redacted]

3. Dimensional Information.

[redacted]

4. Set Up Information :None

5. Procedure.

[redacted]

Appendix E: Overview of 80C2 Components at Shops

Component	ACSC	Caledonian	Japan	GEASO	Celma	Hungary	Tri-Reman	McAllen
Fan Frame	x	x						
Mount Yoke	x	x						
Fan Disk Stg 1	x	x	x					
No. 1 Brg Rotating Air/ Oil Seal		x		x				
Fan Fwd Shaft	x	x						
Fan Rotor Stgs 2-5 Spool	x	x	x		x			
Spinner Cone	x		x		x	x		
Fan Case	x	x			x			
No. 1 Brg HSG	x	x						
Stg 5 Booster Case	x	x	x			x		
No. 3 BRG Damper HSG	x				x			
Stationary Seal	x				x			
No.1 Brg Stationary Air/ Oil Seal	x				x			
Outlet Guide Vane					x	x		x
Center Vent Airtube	x	x						
Fan Stator Vane- Stg 1	x				x			
Sts 2-4 Booster Case	x	x	x			x		
Stg 1 Stator Vane Assy	x				x			
Booster Vane- Stg 2	x	x						
Booster Vane- Stg 3	x	x						
Booster Vane- Stg 4	x	x						
Booster Vane- Stg 5	x	x						
Mid Liner Segments	x	x			x	x		
Fan Coupling Nut	x	x						
OGV Inner Support	x					x		
Inner Liner Segments	x				x	x		
Fwd Liner Segment	x	x			x	x		
No. 3 Brg Stationary Air/ Oil Seal	x	x						
Fan Blade Key					x	x		
Fan Blade Retainers	x				x	x		
Fan Blade Spacer					x	x		
No. 3R Spanner Nut	x	x						
HPCR Stg 1 Disk			x	x	x			
HPCR Stg 2 Disk			x	x				
HPCR Spool Shaft Stgs 3-9	x	x	x					
HPCR Stg 10 Disk	x	x	x					
HPCR Spool Shaft Stgs 11-14	x	x	x					
HPCR Spool Shaft Stgs 10-14	x	x	x					
No. 4R Brg Rotating CDP Seal	x	x	x					
No. 4R Brg Rotating Vent Seal		x	x	x				
Compressor Rotor Bumper Brg	x	x						
Stg 1 Vane Shroud	x	x						
Stg 2 Vane Shroud	x	x						

Appendix E (Continued)

HPC Casing	x		x		x			
Compressor Stator Actuation Ring Segment	x					x		
HPCR No. 4 Bearing Air/Oil Seal			x	x				
Actuator Level	x	x						
HPC Spline Adapter	x	x						
No. 4 Brg Inner Spanner Nut	x	x			x			
Brg Retainer	x	x			x			
CRF		x	x		x			
Stationary CDP Air Seal					x		x	
No. 4 Brg Stationary Air/ Oil Seal	x						x	
No. 4B Brg Vent Seal					x		x	
Mid-Sump Seal	x	x			x			
CRF Aft Sump HSG	x	x						
CRF Fwd Sump HSG	x	x			x			
No. 5R Brg HSG	x	x						
Closures	x	x			x			
HPT Stg 1 Nozzle Vane				x	x			
HPT Stg 1 Nozzle Support	x	x		x				
HPT Stg 1 Shroud	x				x			
HPT Stg 1 Shroud (NS)	x				x			
Stage 2 HPT Shroud	x				x			
HPT Stg 2 Shroud Support	x				x			x
HPT Stg 1 Shroud Support					x			x
HPTR Stg 1 Disk/ Fwd Shaft	x	x	x					
HPTR Stg 2 Disk	x	x	x					
Impeller Spacer	x	x						
HPTR Stg 1 Blade Retainer	x	x						
HPTR Stg 2 Blade Retainer	x	x						
HPTR Thermal Shield	x	x	x					
Diffuser Fwd Seal	x		x		x			
Diffuser Aft Seal			x	x	x			
HPTR Diffuser Ring		x	x	x				
HPTR Aft Inner Seal			x	x	x			
HPT Stg 1 Blade	x			x	x			
Impeller Cover	x	x	x					
Nr. 5R Spacer	x	x						
HPT Stg 2 Blade				x	x			
Impingement Ring- Stg 2	x	x			x			
Hanger Support	x	x						
No. 5 Brg Spanner Nut	x	x			x			
HPTR Heat Shield	x	x	x					
HPT Shroud Retainer	x	x						

Appendix E (Continued)

LPT Case	x	x	x					
LPT Pressure Balance Seal	x	x						
LPT Nozzles- Stg 1					x			x
LPT Nozzles- Stg 3					x			x
LPT Nozzles- Stg 4					x			x
LPT Nozzles- Stg 5					x			x
LPT Shroud- Stg 1						x	x	x
LPT Shroud- Stg 2						x	x	
LPT Shroud- Stg 3						x	x	
LPT Shroud- Stg 4						x	x	
LPT Stator Interstage Seal- Stg 2					x	x	x	x
LPT Stator Interstage Seal- Stg 3					x	x	x	
LPT Stator Interstage Seal- Stg 4								
LPT Shroud- Stg 5						x	x	
LPT Stator Interstage Seal- Stg 5					x	x	x	x
LPT Rotor Interstage Seal- Stg 2		x	x	x				
LPT Rotor Interstage Seal- Stg 3		x	x	x				
LPT Rotor Interstage Seal- Stg 4			x	x				
LPT Rotor Interstage Seal- Stg 5			x	x				
LPT Blade- Stg 1					x			x
LPT Blade- Stg 2					x			x
LPT Blade- Stg 3					x			x
LPT Blade- Stg 4					x			x
LPTR Disk- Stg 1		x	x	x				
LPTR Disk- Stg 2	x	x	x					
LPTR Disk- Stg 3	x	x	x					
LPTR Disk- Stg 4	x	x	x					
LPTR Disk- Stg 5	x	x	x					
LPT PB Inner Rotating Seal					x		x	
LPTR Shaft/ Torque Cone	x	x	x					
LPT Rotating Air/ Oil Seal				x	x			
LPT Blade- Stg 5					x			x
Coupling Nut, LPT Rotor	x	x						
Spanner Nut No.6 Brg	x	x						
No. 6 Brg Stationary Air Seal	x	x						
TRF	x	x	x		x			
No. 6 Brg Sump HSG	x	x						