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Removals for Cause: A 35 Year Assessment of LM2500 Engine Removals by the United States Navy

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ABSTRACT

The United States (US) Navy has operated the General Electric LM2500 gas turbine on all its surface combatants for the past 35 years. The LM2500 is utilized as the propulsion engine aboard the US Navy's newest surface combatants including the FFG 7, CG 47 and DDG 51 Class ships. The US Navy owns and operates 400 LM2500 engines. An on-condition maintenance philosophy is employed whereby engines are run-to-failure rather than removed from service upon achieving some operating milestone. This paper assesses the reasons for the removal of the US Navy's LM2500s over their entire service life with a focus on how fleet maintenance capabilities have impacted and affected the cause for engine replacements over time.

NOMENCLATURE

CIP = Component Improvement Program; DFS = Departure From Specification; DIR = Disassembly Inspection Report; DOD = Domestic Object Damage; FOD = Foreign Object Damage; FRCSW = Fleet Readiness Center Southwest; GG = Gas Generator; GTB = Gas Turbine Bulletin; HP = Horsepower; HPT = High Pressure Turbine; IGHP = Isentropic GG Horsepower; I-Level = Intermediate Level; ISO = Isentropic Standard; MTBR = Mean Time Between Removal; NAVSEA = Naval Sea Systems Command; NGG = GG Speed; NSD = Navy Standard Day; NSWC = Naval Surface Warfare Center; OEM = Original Equipment Manufacturer; PBT = Paired Blade Turbine GG, PT = Power Turbine; RFI = Ready For Issue; RMC = Regional Maintenance Center; SFC = Specific Fuel Consumption; SST = Single Shank GG; TMF = Turbine Mid Frame; VSV = Variable Stator Vanes; Wf = Fuel Flow.

BACKGROUND

In the early 1970s, the US Navy chose the General Electric LM2500 gas turbine engine to power its *SPRUANCE* Class destroyers as well as the *OLIVER HAZARD PERRY* Class frigates. The engines received an original power rating of 20,500HP based primarily upon the reduction gear and line shaft transmission limitations. In contrast, similarly configured LM2500s were rated at closer to 30,000HP for industrial power generation applications throughout the US. In 35 years of service, the LM2500 has provided reliable propulsion power, with its service life exceeding original projections of both the manufacturer and the US Navy.

The 2010 MTBR for the LM2500 (fleet wide) is measured with respect to the GG (Compressor, Combustor, HPT and TMF) and PT sections. The GG MTBR is 23,750 hours and the PT MTBR is 27,345 hours. To put those figures in context, when the LM2500 was originally deployed on *SPRUANCE* Class destroyers and *OLIVER HAZARD PERRY* Class frigates, it was envisioned that engine life of 6,000 hours was possible. The US Navy utilized an aggressive in-place borescope program to assess the internal condition of the engine at periodic milestones in order to grant continued unrestricted operations to ships as they achieved and surpassed this original projection. The US Navy leveraged off the military/aero experience from its flight engines to develop a maintenance and support plan for the LM2500 engine. After several years, it became obvious that the aero model need not be implemented in whole for the marine application of the gas turbine since the result of shipboard engine failure did not have the same negative implications as the flight model. Further, since the *SPRUANCE* Class ships had four propulsion engines, the implications of an engine failure marginally impacted the short-term operations of the ship.

Despite the lack of today's engine controller benefits in capturing and characterizing engine operating profiles, a rudimentary understanding was developed in the 1980s of how, over time, the engines were being operated by the ship's crew. Perhaps dramatically different than originally expected, the ship's mission requirements dictated prolonged periods of engine operations at part power points often below 50 percent of rated power. Due to the conservative nature of operating ships in littoral and constricted waterways, ships often ran all four LM2500s in a full plant configuration in order to have immediate responsiveness and maneuvering capability. Even today, with shipboard measuring systems documenting fleet operations, the LM2500 engine spends more than 50 percent of its service life at less than 16,000HP. This experience varies greatly with the aforementioned industrial applications which tend, in general, to operate at greater than 90 percent maximum power rating when on-line. Additionally, the US Navy mission requirements dictated that numerous part power cycles be accumulated on its engines. In contrast to the industrial model of running engines at a flat power point for prolonged periods of time, the US Navy realized numerous throttle command adjustments throughout a given day. On average, the propulsion engines changed speed every four hours of operations, imparting numerous mini cycles to its engines. These frequent transients at relatively low power created a number of unpredicted consequences in component wear leading to engine failures. Eventually, engineering solutions were developed for US Navy operating cycle related failures thereby dramatically extending engine life.

The US Navy made the decision to adopt a run-to-failure engine removal philosophy for the US Navy fleet. Many factors influenced this decision, perhaps chief among them being the difficulty involved in removing the gas turbine engine from the ship. A set of special tooling, identified as removal rails are constructed within the engine's module to support the engine as it is prepared to be removed. The engine is disconnected from its mounting structure and moved along the rails while supported by a set of rollers. The engine moves forward into the module inlet plenum and then transitions vertically into the intake duct while being lifted by a shore side crane. In addition to the special tooling, certified personnel are needed to accomplish this procedure. However, with the US Navy's surface combatants having four LM2500s and being able to meet most mission requirements with one LM2500 out of service, the use of the run-to-failure maintenance philosophy proved to be very practical; greatly reducing engine replacements.

STATISTICS, LM2500 ENGINE REMOVALS

The focus of this paper assesses the reasons for the removal of the US Navy's LM2500s over their entire service life with a focus on how fleet maintenance capabilities have impacted and affected the cause for engine replacements over time. The US Navy removes the LM2500 engine in two distinct assemblies, the GG and PT sections. Although these two assemblies compose the LM2500 engine, they are often removed as separate and distinct modules with its adjoining half remaining in place aboard ship providing its condition is satisfactory. The US Navy uses two configurations of the LM2500 GG; a SST and a PBT, see Figure 1.

The failure of one of these sections does not necessarily impact the operation or remaining life of the other assembly. Table 1 below, shows the total number of units removed from ships since the first application of the LM2500 gas turbine engine.

Table 1 – Total Number of Removals

Assembly	Removals 1975-2010
Single Shank Gas Generators (SSTs)	78*
Paired Blade Gas Generators (PBTs)	457
Power Turbines (PTs)	309
Total	**844**

*SST Gas Generators were introduced in 1986.
(See Figure 1 for a description of SST and PBT.)

A further breakdown of these engine removals includes the reason for removal from the ship. For clarification, the reason for removal is reported, not by the ship's crew but rather by a shore side component of support personnel who independently investigate the status of a particular engine when a ship requests outside assistance. The shore community is typically civilian degreed engineers, Active Duty Marine Gas Turbine Inspectors, or retired US Navy gas turbine technicians, now working for the shore side maintenance activities. These personnel have extensive expertise in LM2500 engine operation and troubleshooting and thereby have a high confidence factor when recommending engine removal.

In addition, following removal, upon delivery of the engine to the depot overhaul facility for repair, another separate evaluation of the reported rationale for removing the engine is performed by depot personnel. Table 2 lists the definition of terms used in the pie charts in Charts 1 through 3. These pie charts separate engine removals by three distinct periods (1975-1989; 1990-1999; 2000-2010), in order to assess changes in removal philosophy and program impacts.

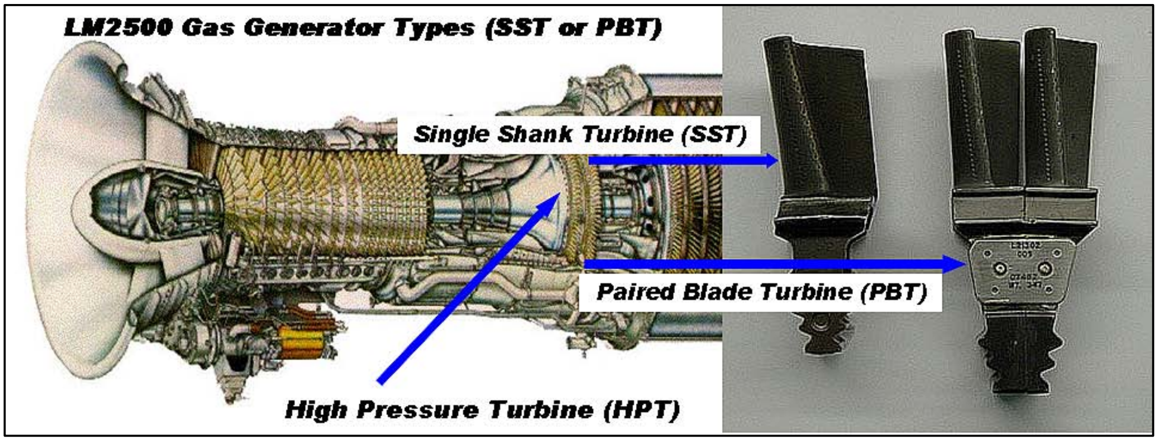


Figure 1 – LM2500 Gas Generator Types

Table 2 - Definition of Terms

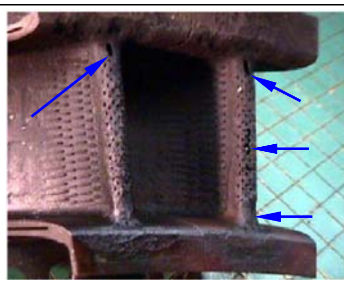
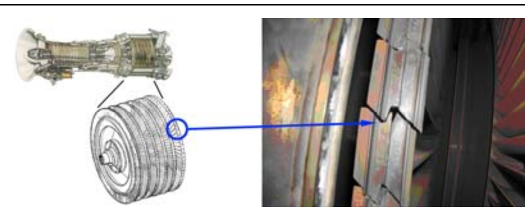
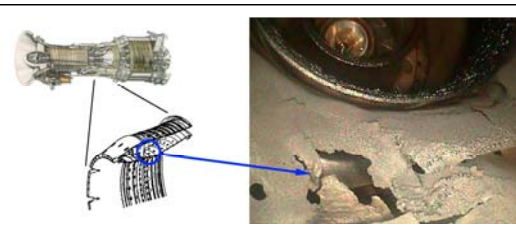
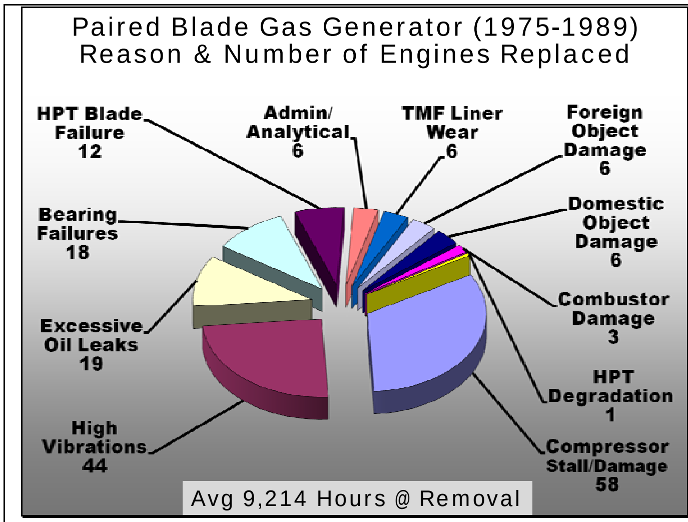
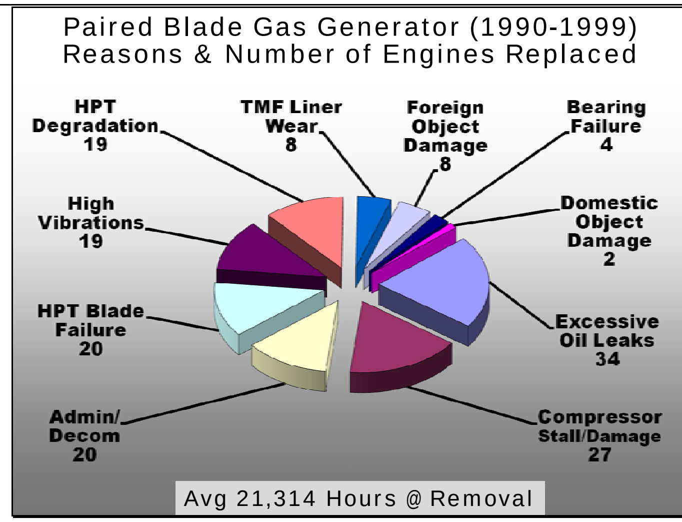
High Pressure Turbine (HPT) Degradation: GGs which have visible coating and/or material degradation and erosion beyond technical manual limits. In many cases, these removals are performed in order to prevent additional collateral downstream damage should the degraded parts become liberated. 	**Bearing Failure:** GGs or PTs which have bearing material and debris found in the engine's lube oil sump strainers/filters. 
Administrative Removal: GGs or PTs removed from service although it has not failed in service. Removed because the ship has been decommissioned or the GG or PT has been removed as a fleet leader to perform an analytical assessment at a particular milestone.	
Compressor Stall/Damage: GGs which have realized physical damage as a result of an engine stall, normally a high-speed stall during transient operations. Although the US Navy has the capability to remove the top half of the compressor case of the engine aboard ship and replace discrepant components within the engine, damage is too severe to permit shipboard remedies.	
High Vibrations: GGs or PTs which demonstrate vibration levels above 3.5 mils at steady state conditions. Engines are removed when the shore side gas turbine community has determined that trim balancing of the engine aboard ship is no longer practical.	
Variable Stator Vane Inoperable: GGs with variable vane systems which cannot be cycled or slewed through their range due to excessive corrosion and binding in the compressor casing bores which cannot be repaired aboard ship.	
Turbine Midframe Liner Wear: GGs with clocking or shifting of an internal liner which causes damage to thermocouple probes and gas path components.	
Vane Rail Wear: During routine inspections of the PT, at a given hours point, excessive wear is noted by an inspector on the vane rails which exceeds US Navy service limits.	
Airfoil Damage: Different from collateral damage, individual airfoils show impact or fracture damage which exceeds established field limits.	
DOD: Parts within the GG or PT become liberated from their attachment point causing damage.	
FOD: Material that has been ingested into the GG causing internal damage which cannot be repaired aboard ship.	
Excessive Oil Leaks: GG or PTs which have a large quantity of oil leaking beyond the US Navy service criteria. In most cases, the oil leak path is within the bearing cavities precluding shipboard corrective action.	
Combustor Damage: GGs which have significant amount of material burned or missing within the combustor beyond US Navy service limits. Damage is often confined to the combustor dome location.	
Excessive Interlock Wear: PTs during routine inspections which show excessive interlock wear beyond service limits.	

Chart 1 – PBT Engine Removal Pie Charts





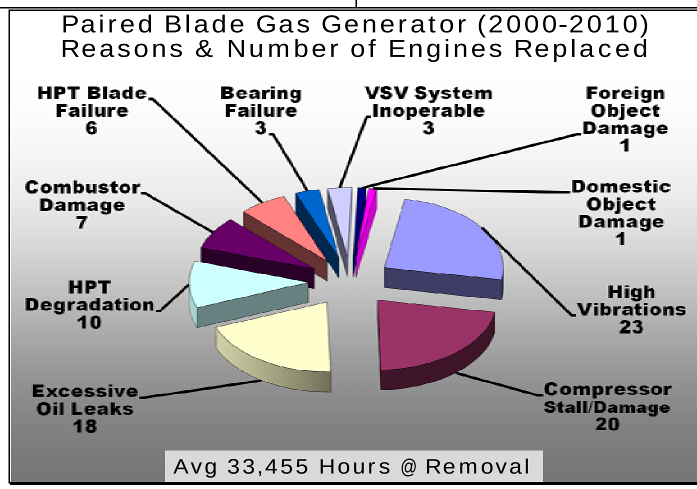
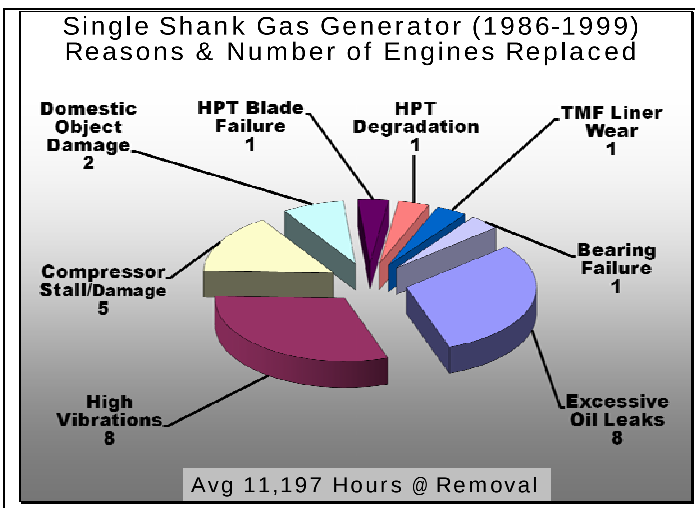


Chart 2 – SST Engine Removal Pie Charts



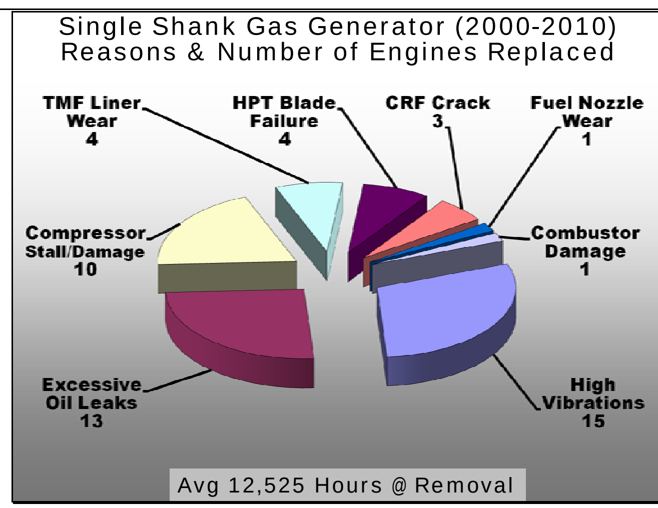
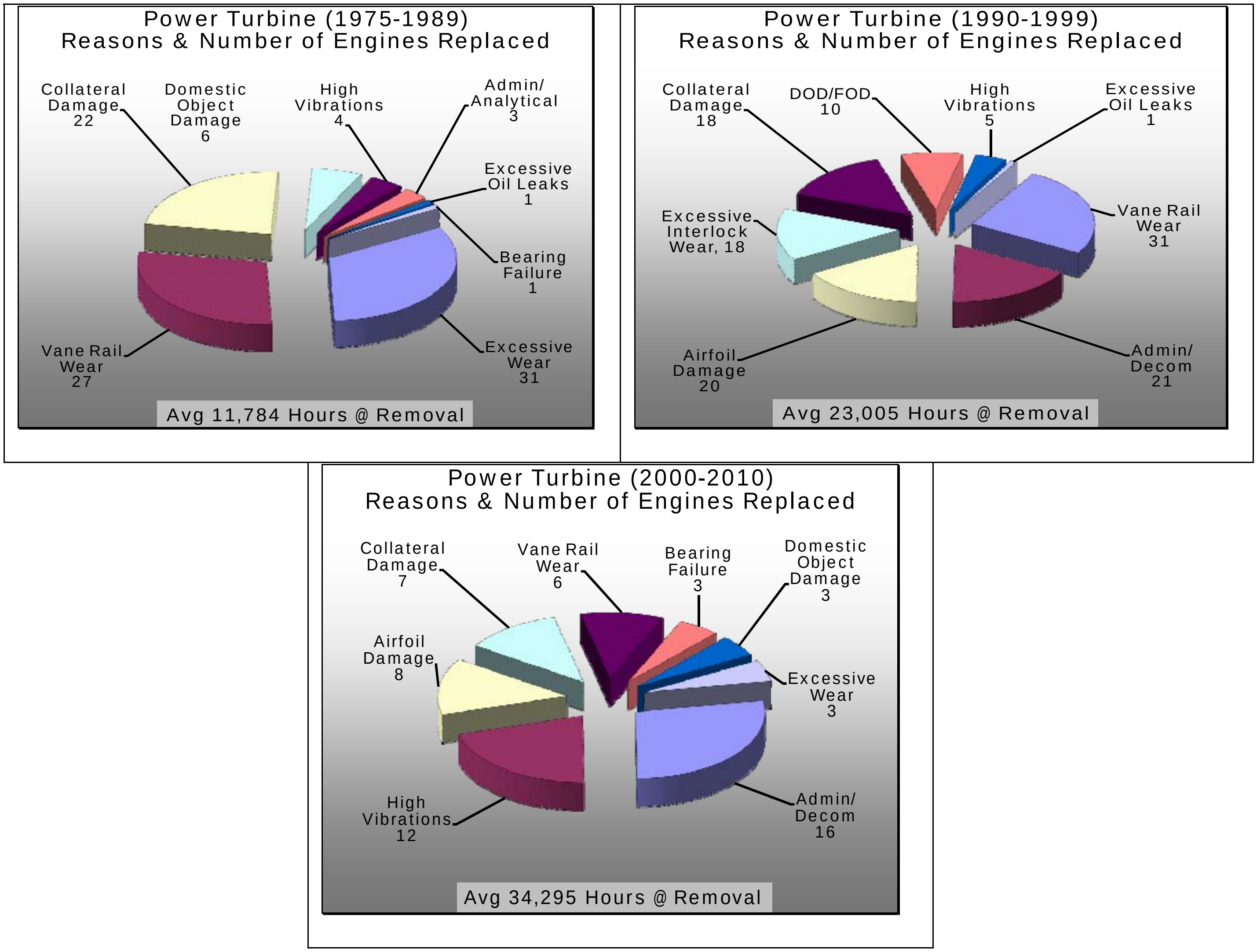


Chart 3 – PT Removal Pie Charts



DEPOT REPAIR PROCESS

The US Navy repairs its LM2500 gas turbine engines at the FRCSW depot at North Island, San Diego, CA. This FRCSW LM2500 repair facility was established in 1980 to accomplish the US Navy's overhauls. Significant infrastructure investments have been made over the years to develop and maintain its tooling, test cell and shop floor capability. A complete description of the US Navy's engine workscope and repair requirements was detailed in a separate ASME-IGTI paper (ASME GT2004-53456, Resultant Benefits of Standardized Overhaul Packages for LM2500 Propulsion Gas Turbine Engines in US Navy Applications, Driscoll & Picozzi) [1]. In short, engines are inducted into the US Navy repair line quarterly under a predefined workscope designed to produce an overhauled engine which can meet the US Navy's desired life cycle and configuration. This workscope, which is updated annually, is not an attempt to produce a "zero time" engine, but rather one developed over a number a years to address known degradation modes for the engine deployed in the US Navy operating profile.

In the 1980-1999 timeframe, customized engine repairs were performed on US Navy LM2500 GGs and PTs based upon their total operating time at induction as well as the failure mode realized on a given asset. Engines with less than 10,000 hours at the time of removal were subject to a streamlined repair, while those engines which had accumulated in excess of 10,000 hours had a more detailed, complex repair scheme invoked. Because the failure of individual engines and the resultant repair requirements differed greatly, a normalized depot repair flow was difficult to establish. Instead, engines could migrate around the depot shop floor randomly, often awaiting part support and work definitization in order to proceed. As a result, the turnaround time and potential throughput at the depot varied greatly, often tied to the scope of repair.

The application of individual repair assessments also impacted forecasting and cost of repairs. Data shared between the aviation and surface navy communities showed that components and modules unaffected by targeted repairs often had drastically reduced secondary life when evaluated in the field or on second pass depot induction. These findings helped convince the US Navy to establish a standardized repair for incoming assets as either PBT, SSTs, or PTs. See Figure 2 for an illustration of the LM2500 GG standardized workscope.

In conjunction with the defined work package, a firm fixed price agreement is negotiated annually so that US Navy budget practices can be effectively utilized to ensure adequate spare assets are available to sustain fleet operations worldwide. When the standardized repair was first introduced, the FRCSW depot management anticipated an increase in man-hour labor to support the requirement, however, perhaps counterintuitively; the result has been a reduction in processing cost as time spent evaluating components for repair has been eliminated. This new process has produced a "manufacturing-like" series of actions which break down engine modules and components without scrutinizing their condition. These modules are then rebuilt to the US Navy repair standard and compiled into sections of the engine. Rotors are balanced and then assembled with their adjoining frames to constitute the repaired GG or PT. In conjunction with this process, the ability to forecast material requirements has been greatly enhanced, permitting long lead procurements at discounted pricing. Since 100 percent replacement factors for critical components has been defined, proactive material readiness programs have been developed to reduce downtime associated with outstanding material requirements.

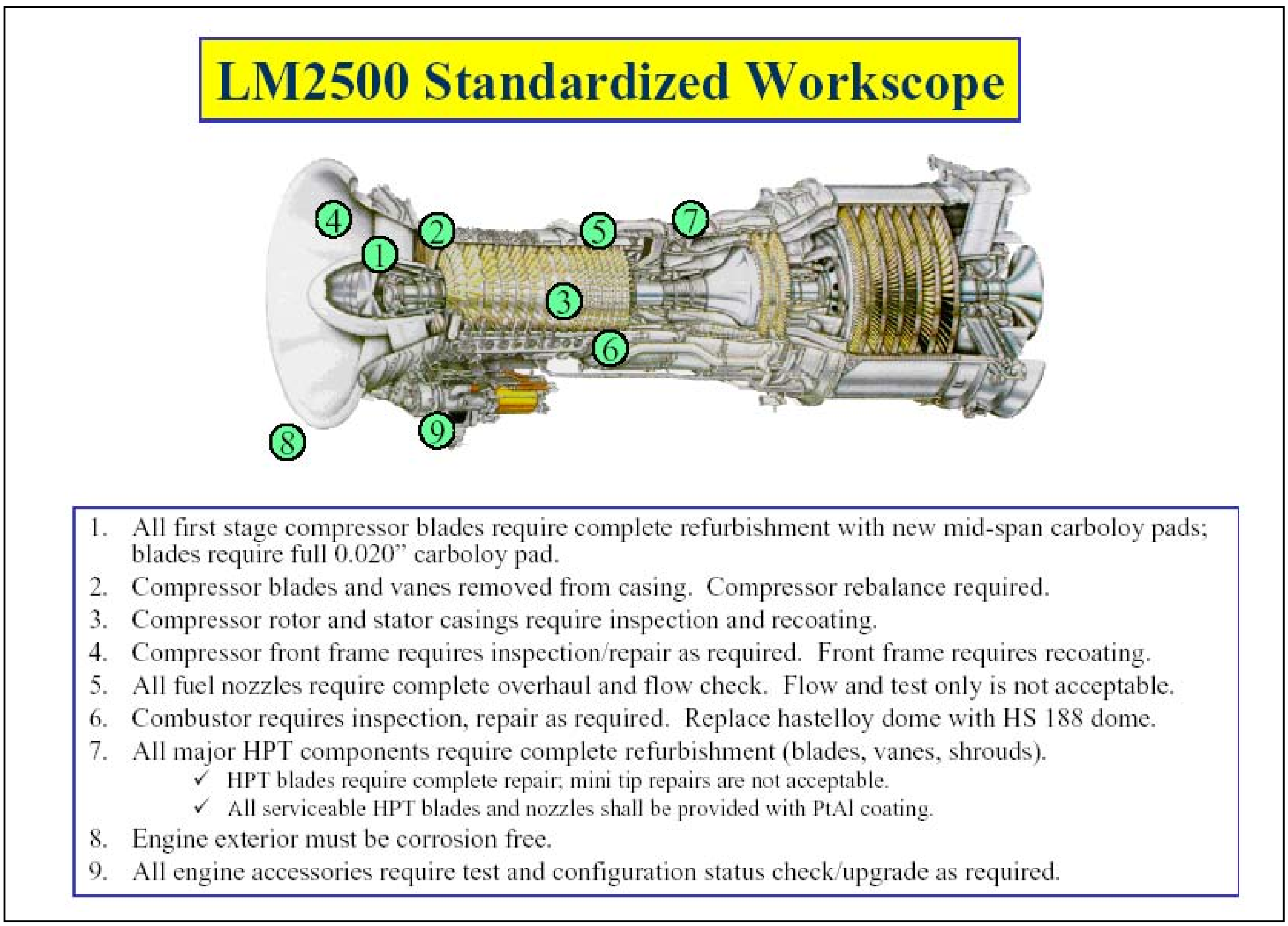


Figure 2 – LM2500 Standardized Workscope

The US Navy's stated goals with its standardized repair workscope are as follows:

1. Attain a high percentage of engine certification during the first pass through the test cell.
2. Produce engines low in vibration signature (below OEM specification).
3. Produce engines with firing within temperature margin at ship's alarm set points.
4. Meet stated turnaround time for RFI asset production.
5. Produce defined configuration for fleet implementation.

It should be noted that the US Navy does not specifically address fuel economy as one of its stated goals, although this item is of particular interest over the past several years. With the rising price of marine diesel fuel, it will likely be added to the other metrics as a means for assessing the workscope at the FRCSW depot facility.

DISASSEMBLY INSPECTION REPORTS

At the inception of its LM2500 depot overhaul program, the US Navy understood the importance of assessing the condition of engines entering the depot repair process. Originally, it was believed this assessment was needed to characterize the condition of various engine components and their degradation rates in order to potentially define a fixed milestone (operating hours point) at which engines should be removed from the ship for repair, similar to the aero industries "time on wing" approach.

Interestingly, the US Navy determined that even at progressive milestones identified in conjunction with the engine manufacturer, the condition of the fleet leader engines was quite good and did not merit removal from service. These findings at 6,000, 8,000 and 10,000 hour marks, enabled the US Navy to move away from a operating hours criteria to a more condition based approach whereby engines were removed only for need, where shipboard repair capability (I- Level) was not sufficient to resolve operational problems.

Over time, the DIRs became the means for developing fleet inspection criteria which addressed specific engine failure modes unique to the marine operating profile. Two gas turbine inspection points were developed specifically based upon DIR findings in order to assess engine conditions aboard ship as a predictor of possible engine failure. Carboloy Pad Inspection, GTB No. 22, resulted from several compressor blade failures in the 1980s which resulted in tremendous domestic object damage to LM2500 compressors. In effect, the pads in the midspan of the first stage compressor blades were wearing at an accelerated rate to the point where pad material was completely worn away, permitting metal-to-metal contact of adjacent titanium blade midspans which led directly to blade failure from stress risers.

Failure of the first stage compressor blades caused significant collateral damage throughout the downstream portions of the engine, in some cases damaging compressor, HPT and PT airfoils. Using the DIRs as a measuring stick, the US Navy was able to identify an appropriate inspection point where field personnel could assess the remaining carbolloy pad thickness and forecast when it had reached a critical point.

The US Navy consequently developed a first stage blade replacement procedure, which, upon opening of the compressor casing, allowed replacement of the compressor blades with new carbolloy pads, reducing and/or eliminating the first stage blade failure mode realized in the fleet. Today, these blades are routinely replaced by I-Level activities at 10,000 hour intervals. Engine removals for first stage compressor blade failures have not occurred in the past decade. This issue is unique to the US Navy's operating profile, highlighting the need for owner evaluations during shop visits vice reliance on the OEM for inspection protocols.

A second gas turbine inspection point was established to assess the condition of the LM2500 PTs. PT Internal Inspection, GTB No. 12, resulted from several PT failures for vane rail wear and loss of blade pre-load. Through the use of DIRs for the PTs entering the depot repair shop, the US Navy was able to determine a first inspection point for evaluating the PT internal condition. The inspection criteria specifically calls for measuring the wear within the PT with its casing propped open and restoring blade preload when excessive wear is indicated. In this fashion, a potential failure for the PT is reduced, permitting additional operating hours in place until a subsequent re-inspection is required to facilitate additional condition assessment. In conjunction with the OEM, the US Navy has developed numerous repair techniques for the PT aboard ship. While vane rail wear has not been eliminated as a PT failure mode, GTB No. 12 inspections have enabled the MTBR for the PT to exceed 27,000 hours, well beyond the most optimistic predictions when the LM2500 was first fielded aboard ship.

In addition to field inspection criteria, the DIRs have helped support the development of other field repairs meant to extend shipboard life for the LM2500 engine. The US Navy has developed in-place, shipboard GG TMF replacement procedures resulting in a substantial cost reduction for the US Navy by avoiding having to replace the GG and use a RFI replacement asset. DIRs have also assisted the fleet in becoming aware of and properly diagnosing fuel nozzle tip wear due to combustor liner clocking, which, in the past may have resulted in GG replacement. DIRs enabled the US Navy to identify the visual characteristics associated with high vibration engines, including broken clamps, loose piping connections as well as internal component wear. These findings enabled the US Navy to develop a field trim balance capability whereby, when engines are deemed to be vibrating sufficiently, weights are added to the compressor rotor to dampen the vibration signature and permit sustained engine operations. The DIRs confirmed the vibration profile most common to the marine application of the LM2500 which permitted a balance computer program to be developed to define the moment and vector for optimal rotor balancing. See Figure 3 for the LM2500 vibration severity levels.

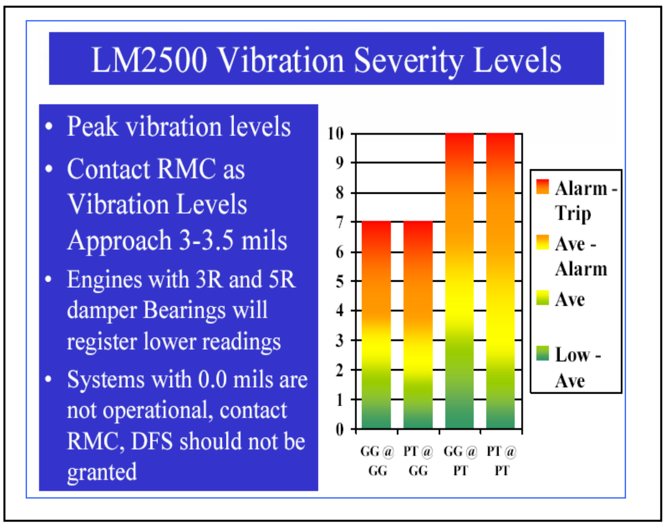


Figure 3 – LM2500 Vibration Severity Levels

Perhaps most importantly, the DIRs enable the US Navy to correlate data across any engine and platform to refine its standardized repair scope. For example, repeated DIR findings detailed wear to an internal oil tube within the HPT rotor on SSTs. This wear was consistent on engines with vibration related causes for removal as well as ones removed for other rationale. This enabled the US Navy to add these components to its workscope for close inspection and made its re-use in the repaired units permissible only when it met new part inspection criteria.

In addition, the DIRs helped confirm the need to replace engine bearings during the repair cycle. Repeated assessment of engine bearings documented conditions which would negatively impact repaired engine life and a cost benefit assessment was performed. Today, DIRs are developed for all incoming engines and circulated around the engineering community and shared with the engine manufacturer as a means for further honing the US Navy's planned repairs. The importance of these reports and this process cannot be over-stressed.

POST OVERHAUL PERFORMANCE TESTING

The US Navy engines are operated through a standardized performance test upon completion of their repairs. The performance test operating profile has been slightly modified over the years to test the repaired engine to ensure it will meet projected life expectancy once it is installed aboard ship. The repair cost for an LM2500 GG is 30 percent of the cost of a new production unit. As such, the asset can be repaired several times over its ultimate life and still provide a solid return on investment compared to replacing with new. The repair cost for the PT is 33 percent of the new production unit. Repaired engines undergo the same field assessment inspections as a new production unit; no additional or early inspection points are required for these assets. The US Navy assumes a repaired unit will meet the same MTBR life as a production engine. The actual realized life for a depot repaired engine is 66 percent of the production engine life. This number represents the life achieved by all engines repaired at the US Navy depot. It is projected, that engines with the standardized workscope implemented will have greater than 90 percent of the production engine life. Although the engines are not "zero timed" during the repair cycle, they are required to meet the same test requirements as production units acquired from the OEM with the addition of an acceleration test within a specified time limit and power requirement. The US Navy test requirements include HP output and defined vibration limits.

Figure 4 shows the mathematical formulas for converting ISO condition parameters to NSD values. The NSD for the LM2500 gas turbine means a rating achieved at 100 degrees F vice the more typical 59 degree F used in ISO calculations. The NSD is used as a means of assuring that a given ship and engine will meet all performance requirements including maximum power output wherever the US Navy operates throughout the world. The intent of the NSD requirement is to ensure that while ships perform missions in high ambient temperature climates, full ship power and maneuverability will be available to the war fighter, regardless of ambient conditions.

ISO Conditions	$\delta = \frac{P_2}{14.696}$	NSD Conditions
$\theta_{ISO} = \frac{T_2}{(459.67+59)}$	Theta	$\theta_{NSD} = \frac{T_2}{(459.67+100)}$
$NGG_{ISO} = \frac{NGG}{\sqrt{\theta_{ISO}}}$	Gas Generator Speed	$NGG_{NSD} = \frac{NGG}{\sqrt{\theta_{NSD}}}$
$IGHP_{ISO} = \frac{IGHP}{\left(1*\delta*(\theta_{ISO})^{0.52}\right)}$	Isentropic GG Horsepower	$IGHP_{NSD} = \frac{IGHP}{\left(1*\delta*(\theta_{NSD})^{0.52}\right)}$
$W_{2-ISO} = \frac{W_2*\sqrt{\theta_{ISO}}}{\delta}$	Compressor Airflow	$W_{2-NSD} = \frac{W_2*\sqrt{\theta_{NSD}}}{\delta}$
$SFC_{ISO} = \frac{W_{FM-ISO}}{IGHP_{ISO}}$	Specific Fuel Consumption	$SFC_{NSD} = \frac{W_{FM-NSD}}{IGHP_{NSD}}$
$T_{54-ISO} = \frac{T_{54}}{\left(ACFT5*HCFT5*(\theta_{ISO})^{0.98}\right)}$	Power Turbine Inlet Temperature	*ACFT5 and HVFT5 for NSD cannot be determined since they are based on constants and correction factors and those are unknown for NSD conditions*
$W_{FM-ISO} = \frac{W_{FM}*LHV}{\left(18400*ACFWF*HCFWF*\delta*(\theta_{ISO})^{0.65}\right)}$	Fuel Flow	*ACFWF and HCFWF for NSD cannot be determined since they are based on constants and correction factors and those are unknown for NSD conditions*

Figure 4 – Mathematic Formulas for Converting ISO Condition Parameters to NSD Values

CONCLUSIONS

- Analytical removals of sample LM2500 gas turbine engines at early milestones in the program helped the US Navy better understand the degradation rate of the engine internal components. By confirming that engine components were in good condition at 6,000, 10,000 and other operating hour milestones, the US Navy's gas turbine engineering community was able to comfortably become more liberal in assessing conditions aboard ship which translated directly to engine life four to five times greater than initially projected.
- The US Navy has used DIRs to help define its field inspection and corrective repair capabilities to address known conditions. The assessments made in these reports directly resulted in GTBs 12/22 and 24 which are the recurring inspections by which the US Navy assesses the condition of any given engine. In addition, the DIRs helped identify the need for additional development of I-Level maintenance personnel and tooling capability to address characteristic problems which could be corrected aboard ship.
- Despite the increase in engine population, average age of the fleet and operating tempo, the US Navy has removed fewer PBT GGs and PTs in the past decade than either of the previous two decades. This is at least partially driven by the US Navy becoming more familiar with conditions which may merit recurring inspections onboard ship vice removal, permitting dramatically increasing life expectancy for these engines. It is projected that this same familiarization has been developed on the SST and may support a reduction in SST removals over the next decade.
- Numerous reasons for removal in the early days of the program have been reduced or eliminated altogether by the CIP, which targeted high failure components for investigation. For example, early in the program, LM2500 bearings were a high failure item; the CIP has greatly improved bearings so now engines are rarely removed from service. In addition, HPT degradation has largely been eliminated as a reason for removal as numerous hot section rainbow rotor tests and subsequent metallurgical evaluations have led to a good understanding of the component's life in the current US Navy mission profile.
- Various reasons for removal have been reduced or eliminated by the increased capability to perform I-Level

repairs aboard ship. As an example, the US Navy in conjunction with the OEM, developed a trim balance capability to address engine vibration aboard ship; this has greatly reduced the number of engines removed for high vibrations.

- It is expected engine users will see a change in the reasons for removal as the average age of engines increases. Making adjustments in users' maintenance practices, by analyzing the changes for removals, can have a direct impact on extending engine service life.
- The US Navy was able to introduce a number of component refurbishment programs after the depot assessments showed those components to be degraded but adequate for repair vice replacement with new hardware. Repairs in general cost only a fraction of the new component cost.
- Just as the US Navy has realized economies of scale and reduced life cycle cost over 35 years by analyzing reasons for removals using DIRs to assess engine and component failures and increasing waterfront I-Level capabilities, other engine users may also achieve the same benefits.

USER/OWNER CONSIDERATIONS

- Engine users may wish to retain hardware which is considered unrepairable during depot visits. These components may offer tremendous insights into degradation rates and may prove to be repairable over time. These parts may also offer cost savings compared to replacement with new.
- Engine users may wish to implement their own version of the US Navy DIRs as a tool for understanding the impact of the operating profile on engine life. These reports may help extend the ultimate life of engines providing cost avoidance opportunities.
- US Navy highly recommends that engine users and owners become closely involved in the development and implementation of their standardized workscope when engines undergo depot repairs/overhauls.
- Being actively involved in the overhaul cycle helps ensure the technical philosophy and goals of the workscope are being met by the overhaul facility, thereby resulting in a quality overhauled end product.

THE WAY AHEAD

It has been proven over the years that the US Navy has been extremely successful in increasing the MTBR for their fleet of LM2500 gas turbine engines. This increase can be attributed to numerous factors, including their run to failure philosophy. In addition, with the use of the DIRs, the US Navy has been able to refine both their field inspection criteria and standardized repair workscope, which has dramatically reduced the number of engine removals.

In the future, the US Navy hopes to achieve the following goals:

- To utilize the field inspection practices it currently uses on the PBT GGs and PTs, to decrease the number of shipboard removals of SST GGs.
- To add fuel economy metrics to their standardized repair workscope, as a means to better determine the overall health of the repaired engine.
- To continually improve the DIR practice, as a means to refine the standardize repair workscope package, to improve field inspection criteria and to develop new field repair procedures with the goal to extend the LM2500 shipboard life.
- To continue to deploy the digital controller upgrade to the CG-47 and DDG-51 class ships. This upgrade allows the US Navy to better understand the LM2500 engine operating profile and apply this knowledge to engine inspection and repair practices.

ACKNOWLEDGMENTS

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