

Aircraft Maintenance Handbook for Financiers

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Aircraft Maintenance Handbook for Financiers provides an introductory level description of the principles, general practices and economic characteristics associated with aircraft maintenance. The handbook is aimed largely for financiers and students – and, indeed, anyone interested in the underlying concepts of aircraft maintenance.

The handbook begins with an introduction into aircraft maintenance principles; highlighting the building blocks of today's maintenance program and analyzing those concepts that influence maintenance status and valuation. Information is assembled detailing the fundamentals of turbofan design and maintenance concepts; a prerequisite knowledge for all involved in aircraft financing.

An in depth analysis of aircraft maintenance reserves is covered, including identifying those factors that influence maintenance costs and time on-wing performance. For each maintenance event, practical exercises in calculating maintenance reserves is also included.

Principles of Flight-Hour Agreements (FHAs), Part Manufacturer Approval (PMA), and Designated Engineering Representative (DER) repairs are introduced to guide the readers on how these issues impact commercial considerations.

Feedback regarding any viewpoints or discrepancies is highly encouraged. To provide feedback, please e-mail the author at: sackert@aircraftmonitor.com



Section 1

Maintenance Principles

- I. Maintenance Processes
- II. Maintenance Programs
- III. Maintenance Categories
- IV. Maintenance Checks
- V. Maintenance Packaging
- VI. Maintenance Cost Elements
- VII. Maintenance Utility & Status



- ❑ The industry definition of maintenance generally includes those tasks required to restore or maintain an aircraft's systems, components, and structures to an airworthy condition. Maintenance is required for three principal reasons:
 - A. Operational:** To keep the aircraft in a serviceable and reliable condition so as to generate revenue.
 - B. Value Retention:** To maintain the current and future value of the aircraft by minimizing the physical deterioration of the aircraft throughout its life.
 - C. Regulatory Requirements:** The condition and the maintenance of commercial aircraft are regulated by the aviation authorities of the jurisdiction in which the aircraft is registered. Such requirements establish standards for repair, periodic overhauls, and alteration by requiring that the owner or operator establish an airworthiness maintenance and inspection program to be carried out by certified individuals qualified to issue an airworthiness certificate.



I. Maintenance Processes

Aircraft maintenance tasks & events can be categorized by one of the following processes:

- A. Hard-time:** A primary maintenance process under which an item must be removed from service at or before a **scheduled** specified time. Airframe checks and Landing gear overhaul events are example of events that are expressed as hard-time events.
- B. On-Condition (OC):** A maintenance process restricted to components in which determination of continued airworthiness can be made by visual checks, measurements, tests, or other means without a tear-down inspection or overhaul. These “health checks” are to be performed within the time limitations prescribed by an operator’s approved maintenance program.

Each component’s performance tolerances and deterioration limits are generally outlined in the aircraft’s Maintenance Manuals. Additional criteria used in determining eligibility for a component’s on-condition status consist of the ability to inspect a unit for corrosion & structural integrity without disassembly.



II. Maintenance Program

Before certification of a new aircraft, the aircraft manufacturer - the Type Certificate (TC) holder - must prepare and submit for approval to the relevant airworthiness authorities the initial **minimum scheduled maintenance requirements**. These minimum scheduled requirements are outlined in the **Maintenance Review Board Report (MRBR) – Figure 1**.

Following local regulatory authority approval, the MRBR is used as a framework around which each air carrier develops its own individual maintenance program. Although maintenance programs may vary widely, the **initial requirements** for an aircraft will be the same for all.

The tasks detailed in the MRBR cannot be deleted nor can the task content be changed without approval of the MRB Chairman or appropriate national regulatory authority. However, individual task intervals may be escalated based on satisfactory substantiation by the operator, and review and approval by the local regulatory authority.



The tasks detailed in the MRBR:

- Developed by an Industry Steering Committee
- Distributed by Aircraft Manufacturer
- Constitute Minimum Initial Requirements
- Cannot be deleted nor changed

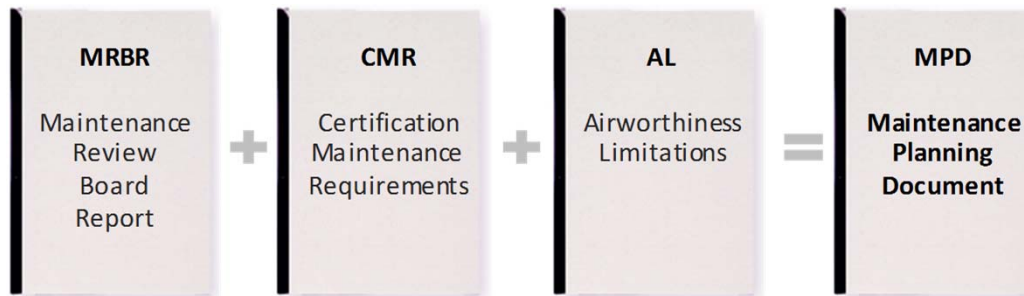
Figure 1. Maintenance Review Board Report (MRBR)



II. Maintenance Program

The MRB Report outlines the initial minimum scheduled maintenance/inspection requirements to be used in the development of an approved continuous airworthiness maintenance program.

As illustrated in **Figure 2**, The **Maintenance Planning Document (MPD)**¹ contains all the MRB requirements plus mandatory scheduled maintenance requirements that may only be changed with the permission of the applicable airworthiness authority. These supplemental inspection tasks are detailed in the aircraft's **Certification Maintenance Requirement (CMR)** and **Airworthiness Limitation (AWL)** documents.



The MPD document provides maintenance planning information necessary for operators to develop a customized maintenance program. The document lists all recommended scheduled maintenance tasks for every aircraft configuration.

Figure 2. Maintenance Planning Document (MPD)

1 - The MPD maintenance tasks, and the rectification of any deficiencies resulting from performance of such tasks, forms the basis for the qualifying scope of work that is used to quantify airframe maintenance reserves.



II. Maintenance Program

- ▶ A **Certification Maintenance Requirement (CMR)** is a required periodic task, established during the design certification of the airplane as an operating limitation of the type certificate. CMRs usually result from a formal, numerical analysis conducted to show compliance with catastrophic and hazardous failure conditions.

A CMR is intended to detect safety significant latent failures that would, in combination with one or more other specific failures or events, result in a hazardous or catastrophic failure condition. Example of a CMR task is performing a detail visual inspection of the elevator tab rods and tab mechanism.

- ▶ **Airworthiness Limitations (AL)** are a regulatory approved means of introducing certain inspections, or maintenance practices, to prevent problems with certain systems. Mandatory replacement times, inspection intervals and related inspection procedures for structural safe-life parts are included in the AL document, and are required by the regulatory authorities as part of the Instructions for Continued Airworthiness. Example of an AL task is performing a detailed inspection of the fuel tank wire bundles to prevent potential wire chafing and arcing to the fuel tank.



II. Maintenance Program

MPD Task intervals are specified in terms of **usage parameters** such as flight hours, cycles, and calendar time. The MPD tasks generally define the following:

- ▶ Task description and intervals at which each component and major assembly should be either inspected, checked, cleaned, lubricated, replenished, adjusted and tested.
- ▶ Intervals of specific structural inspections or sampling program;
- ▶ Intervals at which life-limited / time-controlled parts should be replaced / overhauled;

Many MPD tasks have fixed, **initial** (or threshold) inspection intervals and **repeat** inspection intervals – see **Figure 3**. Often the repeat interval is the same as the initial interval, however there are numerous tasks having repeat intervals that are shorter than the initial interval.

MPD ITEM NUMBER	AMM REFERENCE	P G M	ZONE	ACCESS	INTERVAL		APPLICABILITY		MAN-HOURS	TASK DESCRIPTION
					THRESH	REPEAT	APL	ENG		
53-140-00	51-05-01-210 53-05-03-210	S	121 122 141 142	S1003 NOTE	8 YR 24000 FC NOTE	6 YR 18000 FC NOTE	ALL	ALL	2.00	INTERNAL - GENERAL VISUAL: Forward and Aft Cargo Compartment - Floor Structure Inspect forward and aft cargo compartment floor structure. INTERVAL NOTE: Whichever comes first.

Figure 3. Example Maintenance Planning Document (MPD) Task Intervals



II. Maintenance Program

Most **Scheduled MPD tasks** are assigned into three **program groupings** consisting of: 1.) Systems & Powerplant, 2.) Zonal Inspections, and 3.) Structural Inspections

1. The **Systems & Powerplant Program** include all scheduled on-wing functional and operational maintenance tasks related to the aircraft systems, Auxiliary Power Unit (APU), engine, and components. **System task categories** are detailed below, and **Figure 4** illustrates an example of a system-related task.

LUB = LUBRICATION - Consumable replenishment by lubricating.

SVC = SERVICING - Consumable replenishment by servicing.

OPC = OPERATIONAL CHECK - A failure finding task to determine if an item is fulfilling its intended purposes.

VCK = VISUAL CHECK - A visual failure finding task through observation to determine if an item is fulfilling its intended purpose.

GVI = INSPECTION - GENERAL VISUAL - A visual examination that will detect obvious unsatisfactory conditions

FNC = FUNCTIONAL CHECK - A quantitative check to determine if one or more functions of an item performs within specified limits.

RST = RESTORATION - Reworking, replacement of parts or cleaning necessary to return an item to a specific standard.

DIS = DISCARD - The removal from service of an item at a specified life limit.

MPD ITEM NUMBER	AMM REFERENCE	C A T	T A S K	INTERVAL		ZONE	ACCESS	APPLICABILITY		MAN- HOURS	TASK DESCRIPTION
				THRESH	REPEAT			APL	ENG		
27-074-00	27-31-00-700	6 9	OPC	15000 FH	15000 FH	211 212	311BL	ALL	ALL	0.10	Operationally check, hydraulic power off, the elevator control surfaces for full range of travel and freedom of movement.
27-075-01	27-31-34-210	9	GVI	7500 FH	7500 FH	334	333BB 333CB	ALL	ALL	0.30	Perform a general visual inspection of the left elevator balance weight installation and elevator tab control mechanism.

Figure 4. Example Systems Tasks



II. Maintenance Program

2. The **Zonal Inspection Program** packages primarily General Visual (GV) inspection tasks into one or more zonal inspections. These inspections check for the general condition and security of attachment of the accessible components, systems and structures items contained in defined zones. This includes checks for deterioration such as chafing of tubing, loose duct supports, wiring damage, cable and pulley wear, brackets, fluid leaks, electrical bonding, general condition of fasteners, inadequate drainage, etc., and general corrosion. The scope and intent of what is to be inspected **is based on what is visible** within the zone with the specified access open. **Figure 5** illustrates an example of a zonal inspection task.

MPD ITEM NUMBER	AMM REFERENCE	ZONE	ACCESS	INTERVAL		APPLICABILITY		MAN- HOURS	TASK DESCRIPTION
				THRESH	REPEAT	APL	ENG		
53-858-00	05-41-02-210	211 212		5500 FC 24 MO NOTE	5500 FC 24 MO NOTE	ALL	ALL	0.50	<i>EXTERNAL - ZONAL (GV):</i> Flight Control Compartment Perform an external zonal inspection (GV) of the flight control compartment - section 41, STA 178 to STA 270. INTERVAL NOTE: Whichever comes first.
53-860-00	05-41-02-210	211 212	NOTE	5500 FC 24 MO NOTE	5500 FC 24 MO NOTE	ALL	ALL	0.33	<i>INTERNAL - ZONAL (GV):</i> Flight Control Compartment Perform an internal zonal inspection (gv) of the flight control compartment - section 41, sta 178 to sta 270. INTERVAL NOTE: Whichever comes first. ACCESS NOTE: Control stand access panels 211A and 212A removal required.

Figure 5. Example Zonal Inspection Tasks



II. Maintenance Program

3. The **Structural Inspection Program** is designed to provide timely detection and repair of structural damage which may occur in the fleet during commercial operations. Detection of corrosion, stress corrosion, minor accidental damage and fatigue cracking by visual and/or Non-Destructive Test (NDT) procedures is considered.

There are three levels of inspections performed. 1.) A **visual examination** is made from within touching distance unless otherwise specified. 2.) An **intensive visual examination** requires direct source of lighting of specific structural areas, systems, installations or assembly's to detect damage, failure or irregularity. 3.) An **intensive examination** of a specific item(s), installation or assembly to detect damage, failure or irregularity. This examination is likely to make extensive use of specialized inspection techniques such as NDT. **Figure 6** illustrates an example of a structural inspection task.

MPD ITEM NUMBER	AMM REFERENCE	P G M	ZONE	ACCESS	INTERVAL		APPLICABILITY		MAN- HOURS	TASK DESCRIPTION
					THRESH	REPEAT	APL	ENG		
57-260-01	51-05-01-210 57-05-03-210	S	551	551BT 551CT 551EB	6 YR 18000 FC NOTE	6 YR 18000 FC NOTE	ALL	ALL	0.75	<i>INTERNAL - GENERAL VISUAL: Left Wing Outboard Rear Spar</i> Inspect aft side of rear spar (chords, webs and stiffeners), including at main landing gear outboard support attachment, and at trunnion attachment. <i>INTERVAL NOTE: Whichever comes first.</i>
57-260-02	51-05-01-210 57-05-03-210	S	651	651BT 651CT 651EB	6 YR 18000 FC NOTE	6 YR 18000 FC NOTE	ALL	ALL	0.75	<i>INTERNAL - GENERAL VISUAL: Right Wing Outboard Rear Spar</i> Inspect aft side of rear spar (chords, webs and stiffeners), including at main landing gear outboard support attachment, and at trunnion attachment. <i>INTERVAL NOTE: Whichever comes first.</i>

Figure 6. Example Structural Inspection Tasks



II. Maintenance Program

Figure 7 illustrates structural areas most susceptible to corrosion, fatigue and cracks. Major accidental damage such as that caused by bird strike or large ground handling equipment is considered readily detectable. Additionally, indications such as fuel leaks, loose fasteners, loss of cabin pressure, etc. are considered readily detectable.

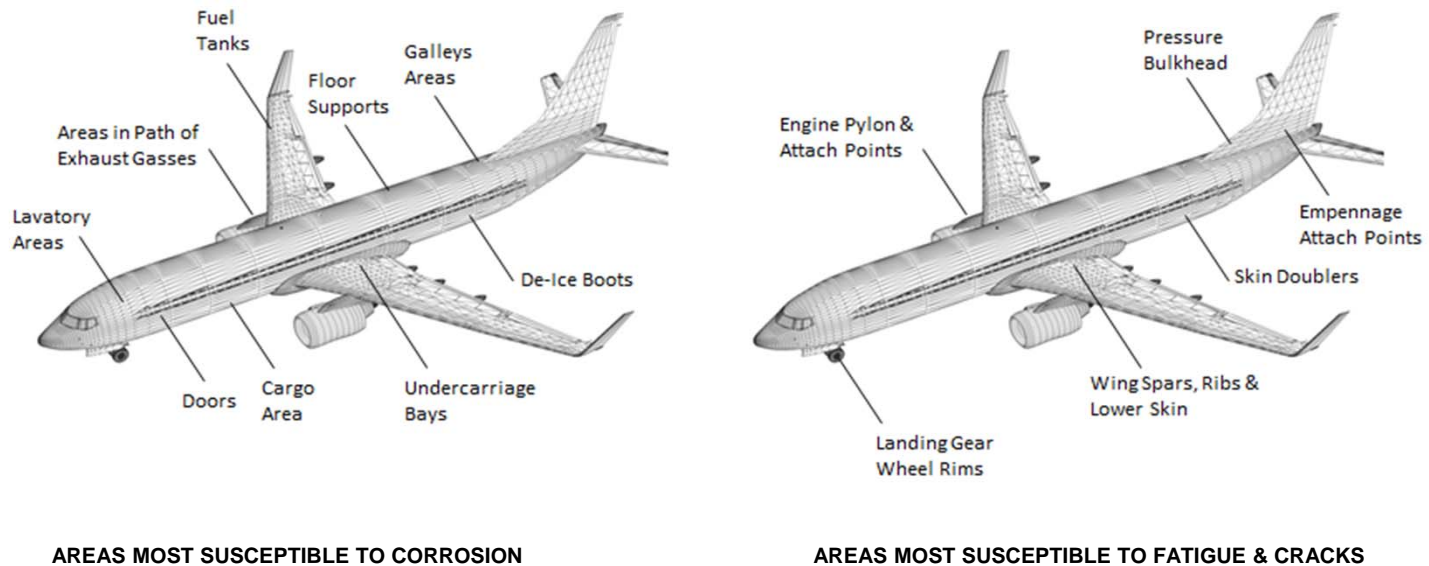


Figure 7. Areas Susceptible to Corrosion, Fatigue, & Cracks



II. Maintenance Program

Figure 8 illustrates the allocation of routine system, zonal, and structural tasks by usage parameters for the Airbus A350-900. The decision on when and how to group/package these tasks will depend on the operators utilization, FH:FC ratio, and other issues such as manpower requirements and spares availability. Depending on the aircraft age and operational profile performance of many of these routine tasks will generate levels of non-routine rectification requirements leading to incremental labor and material costs.

Task Interval	Systems Tasks	Structures Tasks	Zonal Tasks	Total Tasks
Calendar	263	127	125	515
Flight Hour	148	0	0	148
Flight Cycle	9	1	0	10
Flight Hour & Cycle	4	63	0	67
Calendar & FH	23	0	0	23
Calendar & FC	16	1	0	17
Calendar, FH & FC	0	12	0	12
Other	21	0	0	21
Total	484	204	125	813

Figure 8. Summary of A350-900 Routine Maintenance Tasks – A350 MPD, 3rd Revision



II. Maintenance Program

The MPD scheduled maintenance tasks should not be considered as all-inclusive. Each individual airline has final responsibility to decide what to do and when to do it, except for those maintenance requirements identified as "Airworthiness Limitations" (AL) or "Certification Maintenance Requirements" (CMR). Additional requirements in the form of Service Letters, Service Bulletins and Airworthiness Directives are the responsibility of the individual airline to incorporate. Maintenance tasks recommended in engine, APU, and vendor manuals should also be considered. **Figure 9** illustrates the building blocks of an **Operator's Approved Maintenance Program (OAMP)**.

- ▶ Maintenance Planning Document (MPD)
- ▶ Vendor & Maintenance Manuals
- ▶ Service Bulletins & Service Letter
- ▶ Airworthiness Directives
- ▶ EASA/FAA and local regulatory requirements
- ▶ Airline Tasks
 - Engine health-monitoring requirements;

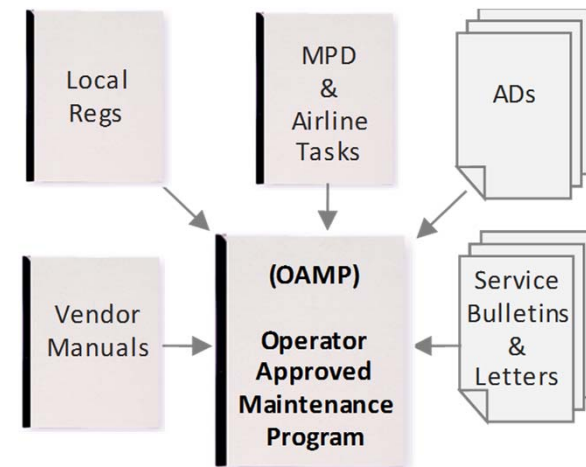


Figure 9. Example Maintenance Planning Document (MPD) Task Intervals



II. Maintenance Program

The **Approved Maintenance Program (AMP)** outlines an air carrier's **routine, scheduled maintenance tasks** required to provide instructions for continued airworthiness. Each scheduled task in turn will need to be converted to procedures that will be used by airline mechanics to fulfill the intended requirement. The manual containing these procedures is defined as the **Aircraft Maintenance Manual (AMM)** – see **Figure 10**.

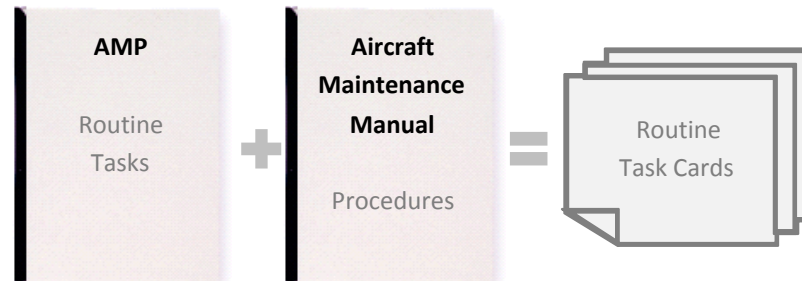


Figure 10. Maintenance Documents Used to Generate Routine Tasks Cards

During the course of normal operation an aircraft will require **unscheduled, non-routine maintenance** to make repairs of discrepancies, or to remove and restore defective components. A need for unscheduled maintenance may result from scheduled maintenance tasks, pilot reports, or unforeseen events, such as hard or overweight landings, tail strikes, ground damage, lightning strikes, or an engine over-temperature.



II. Maintenance Program

As illustrated in **Figure 11**, the **documents required to address non-routine maintenance** are generally composed of: a.) Aircraft Maintenance Manual (AMM), b.) Structural Repair Manual (SRM), c.) Wiring Diagram Manual (WDM), d.) System Schematic Manual (SSM), e.) Fault Reporting and Fault Isolation Manuals (FRM & FIM), f.) Illustrated Parts Catalog (IPC), and the Dispatch Deviation Guide (DDG).

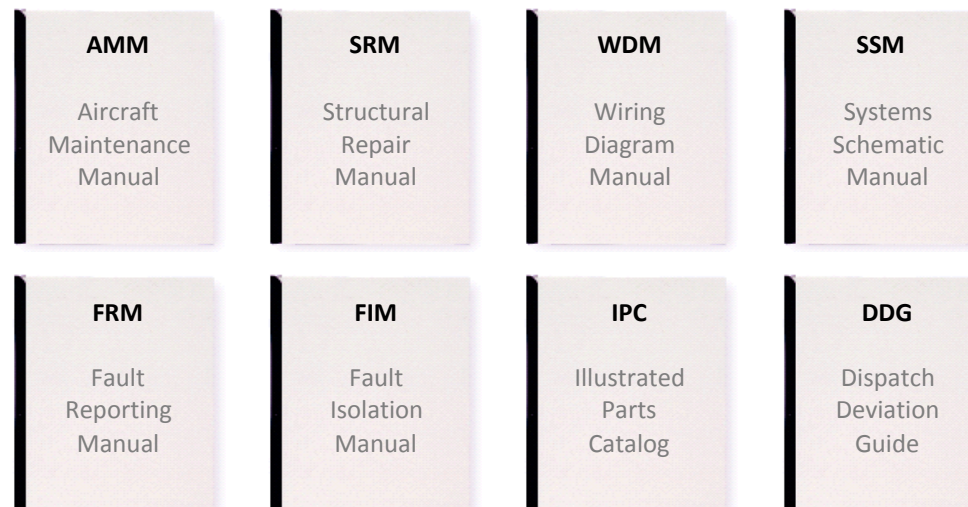


Figure 11. Maintenance Documents Used to Support Non-Routine Activities



II. Maintenance Program

A **bridging program** is established to align the maintenance program of an existing operator with that of the new operator. When an aircraft transitions from one program to another, the time in service, calendar times, or cycles of operation accumulated under the previous program must be applied in determining task due times under the new program. The bridging process will normally consider the following factors as a precursor to determining the appropriate task requirements:

- ▶ Program differences;
- ▶ Age of the aircraft: calendar, total flight hours & flight cycles;
- ▶ Configuration differences;
- ▶ Next due heavy maintenance check;
- ▶ Aircraft utilization;
- ▶ Airworthiness Directive/Service Bulletin Status;
- ▶ Applicable regulatory authority requirements



III. Maintenance Categories

The perspective of maintenance at the event level helps airline's decide whether tasks should be performed in-house or outsourced. Maintenance events are categorized under line & base maintenance, and shop maintenance – **Figure 12**.

- ▶ **Line maintenance** events includes routine servicing, troubleshooting, and maintenance corrective actions required for airplane dispatch. Line maintenance generally includes transit/daily checks and "A" Checks;
- ▶ **Base maintenance** events comprises in-depth inspections known as system checks and structural checks, and often includes substantial rectification of non-routine tasks; Base maintenance generally includes "C" Checks and structural checks;
- ▶ **Shop maintenance** is the maintenance of components, including engines, after they have been removed from the aircraft. Examples of shop tasks are restoration of engines and overhaul of landing gears.

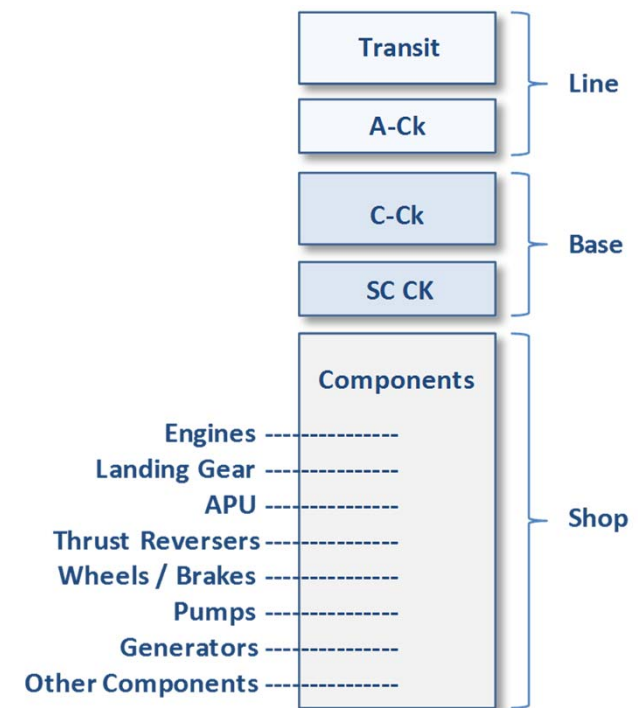


Figure 12. Maintenance Event Categories



IV. Maintenance Checks

All tasks defined through the maintenance development process will ultimately need to be allocated into **scheduled work packages**. Maintenance packages range from daily walk-arounds, to service checks performed at line maintenance station, to major checks performed at maintenance bases.

Scheduled maintenance tasks with similar intervals may be grouped in blocks and accomplished in large packages, or done incrementally in a phased program. The group of tasks are called letter checks, most often defined as “A”, “C”, & “D-Checks”. The following describes each letter check in more detail.

- ▶ **“A-Checks”** are generally consists of a general inspection of the interior/exterior of the airplane with selected areas opened. The A-check is typically performed biweekly to monthly. Examples of A-check tasks are checking and servicing oil, filter replacement, lubrication, operational checks, and inspections.
- ▶ **“C-Checks”** are typically scheduled every 18 - 36 months depending on the operator, airplane type, and average utilization. Many of the tasks assigned to C-Checks come from the Systems & Powerplant Program. Examples of C-Check tasks include functional and operational systems checks, cleaning and servicing, attendance to minor structural inspections and Service Bulletin requirements.



IV. Maintenance Checks

- ▶ “D-Checks” or **Heavy Structural Inspections (HSI)**, are scheduled every 6-12 years, depending on the airplane type and average utilization, and taken out of service for several weeks. The bulk of tasks assigned to the HSI come from the Zonal & Structural Inspection Program. During a heavy structural inspection the exterior paint is often stripped and large parts of the outer paneling are removed, uncovering the airframe, supporting structure and wings for inspection of most structurally significant items. In addition many of the aircraft’s internal components are functionally checked, repaired/overhauled, or exchanged. Often the completion of a heavy structural inspection is referred to as a completion of a maintenance cycle. **Figure 13** illustrates the scheduling of maintenance checks for the A350-900.

Check	Mx Event Category	Intervals	Main Tasks	Total Tasks
A-Check	Line	1,200 FH	Systems Tasks	Multiple
C1	Base	36 Month	1C / 36 Mo	33
C2	Base	72 Month	1C / 36 Mo + 2C / 72 Mo	176
C3	Base	108 Month	1C / 36 Mo	33
C4 / 12-Year HSI	Base	144 Month	1C / 36 Mo + 2C / 72 Mo + 4C / 144 Mo	379

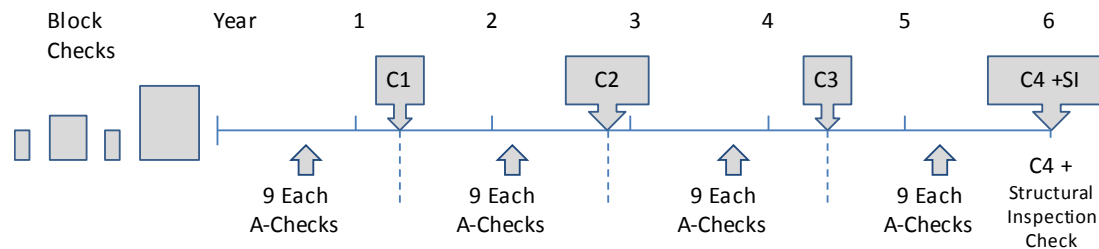
Figure 13. Example A350-900 Maintenance Check Scheduling – A350 MPD, 3rd Revision



V. Maintenance Packaging

The **block check** packaging method - **Figure 14** - is focused on the principle of grouping tasks which require frequent repetition under a letter check. This method produces a small number of large work packages having the disadvantage of relatively long maintenance ground time.

Each letter check generally incorporates all the work covered by preceding checks, plus the tasks assigned at that letter-check interval. Thus each letter check often requires an increasing amount of man-power, technical skills, and specialized equipment.



Block Check Advantages

- Simplifies planning & scheduling of work packages
- Accomplishment of modifications
- Rectifications of non-routines
- More efficient sequencing of long jobs

Block Check Disadvantages

- Sporadic manpower requirements
- Longer ground time

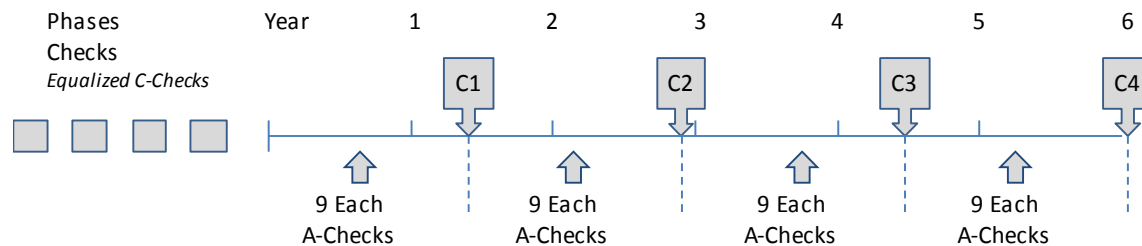
Figure 14. Example Block Maintenance Check Packaging



V. Maintenance Packaging

The **phased check** – sometimes referred to as equalized or segmented check - apportions tasks to smaller packages that may be accomplished more frequently than the packages in a block check – see **Figure 15**. An operator, for example, may phase or segment, portions of its heavy maintenance tasks equally over the appropriate number of C-Checks.

Typically, the objective of a phase check is to even out the maintenance workload over time and shorten the length of each period of down-time. Peaks and valleys in man-power requirements are minimized by moving tasks from one check package to another. The overall result of an equalized maintenance program is that the total number of scheduled maintenance down-time can be reduced over an aircraft's maintenance cycle.



Phase Check Advantages

- Reduced ground time
- Increased airplane availability
- Reduces sporadic manpower
- Flexibility of grouping tasks

Phase Check Disadvantages

- Increases production planning & scheduling
- Limited time for accomplishment of major modifications
- Limited time to identify & rectify non-routines maintenance.

Figure 15. Example Phase Maintenance Check Packaging



VI. Maintenance Cost Elements

Aircraft maintenance costs can be categorized into various elements. Understanding how each cost element relates to an aircraft's operation helps in making fair comparisons between competing aircraft, and between equivalent aircraft operating at different flight profiles. Popular maintenance cost elements consist of: a.) labor and material costs, b.) routine and non-routine costs c.) calendar-based costs, and d.) flight-cycle and flight-hour costs

- a) **Labor & Material Costs** – labor and material costs help compare the impact of an aircraft's design, its maintenance program, and its reliability. Labor and material is the basic level at which maintenance costs data is collected and analyzed.
- b) **Routine & Non-routine Costs** – **Routine maintenance** costs are comprised of the labor & material costs associated with performing the scheduled maintenance tasks outlined in the airline's approved maintenance program. **Non-routine maintenance** is required to make unscheduled repairs of discrepancies, or to remove and restore defective components. Labor and material costs associated with non-routine work are the primary drivers of increasing maintenance costs as an aircraft ages.
- c) **Calendar-based costs** are those costs that do not vary according to aircraft usage. These costs are typically determined as annual costs and allocated on an hourly basis to the aircraft according to the number of hours the aircraft is flown. Generally, the largest calendar-based cost are those affiliated with heavy structural checks and landing gear overhauls.



VI. Maintenance Cost Elements

- d) **Flight-cycle and Flight-hour Costs (Figure 16)** - **Flight-cycle costs** are the fixed maintenance costs associated with an aircraft trip - where one cycle equals one trip, and are independent of flight length flown; for example engine Life-Limited Parts (LLPs) have costs that are charged a “per-flight-cycle” basis. **Flight-hour costs** are the variable maintenance costs proportional to the flight length flown; for example engine performance restoration costs are charged on a “per flight-hour” basis. The same aircraft operating at different average flight lengths will require different levels of maintenance due to flight-cycle and flight-hour effects

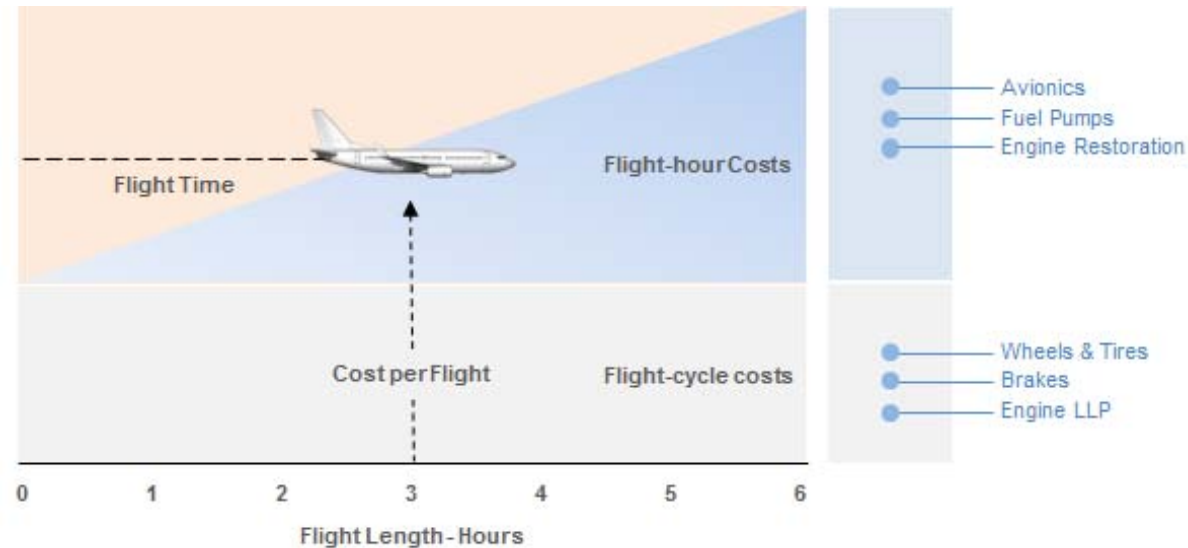


Figure 16. Flight-cycle and Flight-hour Costs



VII. Maintenance Utility & Status

A maintenance event's utility profile follows a **conventional saw-tooth maintenance cycle** as illustrated in **Figure 17**. Maintenance value declines with time on-wing, however, depending on the nature of the maintenance event, the value may or may not fully amortize to zero nor does it fully re-capitalized to 100% of its maintenance value (i.e. the workscope will often only partially restore the value lost.)

Example of events that are fully re-capitalized following maintenance are airframe heavy structural checks and landing gear overhauls. Events that are partially re-capitalized following maintenance are engine performance restorations and APU overhauls; both of these equipment are composed of individual modules, each of which are assigned designated levels of shop work based on accumulated time and cycles.

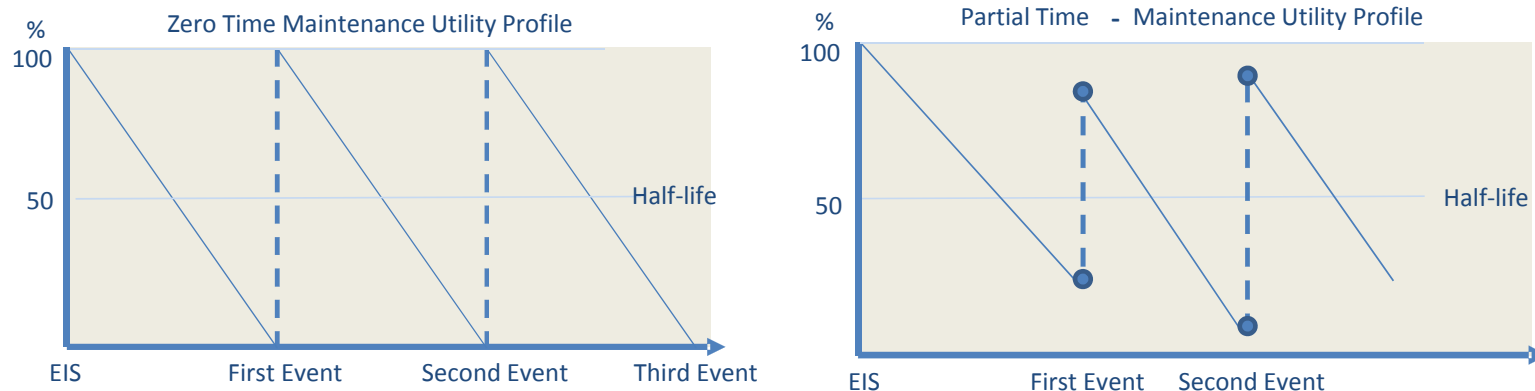


Figure 17. Example Maintenance Utility Profiles



VII. Maintenance Utility & Status

Most operating leases provide that the lessee is liable for the ongoing costs related to maintaining an aircraft to required regulatory standards. Depending on the credit-worthiness of the Lessee, the payment of maintenance reserves will provide the Lessor with additional protection mechanism if an event of default should occur. Therefore, in the event an aircraft is forcibly repossessed following a default by the airline, the aircraft may require some outstanding high-cost maintenance work before it is in a condition to be re-leased or sold to another airline. As illustrated in **Figure 18**, an investor's primary risk in relation to maintenance is the lessee's failure to pay for those high-cost maintenance events that they consume.

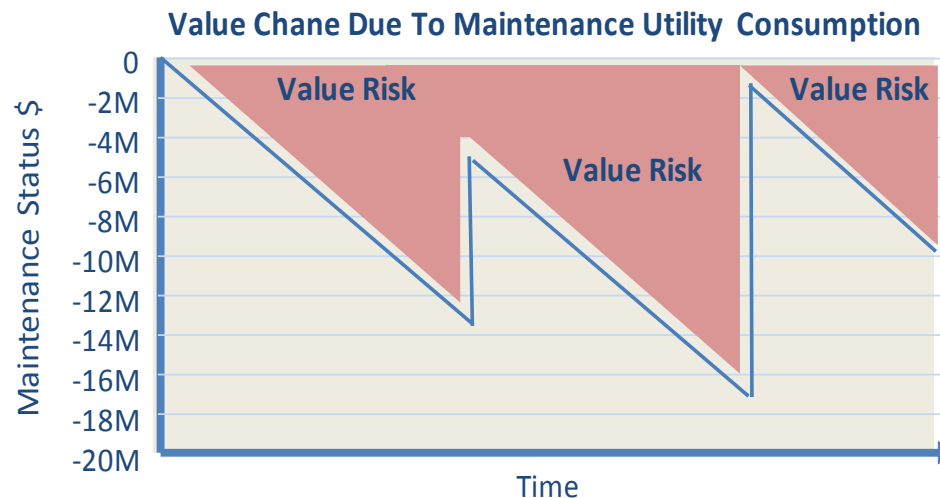


Figure 18. Maintenance Utility Value Risk



VII. Maintenance Utility & Status

Maintenance status is used to assess, in whole or part, the **value of maintenance utility remaining**. An aircraft's maintenance status can be quantified by analyzing data related to its maintenance condition at a specific point in time. The key to quantifying maintenance status lies in making accurate assessments as to: 1.) Where each major maintenance event is relative to their last and next shop visit, and 2.) What percentage of its next shop visit cost is remaining.

Depending on the aircraft type and age, maintenance status can represent a significant proportion of an it's overall market value. Where appraisers are responsible for quantifying the market value of an aircraft, they use, as a baseline reference, two industry-standard terms to represent an aircraft's maintenance status. These terms consist of **full-life** and **half-life**.

- ▶ The **full-life** status implies that each major maintenance event has just been fully restored or overhauled to zero-time condition; the airframe is zero-timed from its heavy check, the landing gear is zero-timed from an overhaul, the engines are fresh from a performance-restoration shop visit, and all engine Life Limited Parts (LLPs) have zero-life used.
- ▶ The **half-life** status assumes that the airframe, engines, landing gear and all major components are half-way between major overhauls and that any life-limited part has used up half of its certified life. Half-life status does not indicate that the aircraft is half-way through its useful life.



VII. Maintenance Utility & Status

Half-life enables a comparison to be made between values of aircraft of different types and ages using a common denominator. An aircraft's half-life adjustment value can be quantified using the following equation:

$$\text{Adjustment from Half-Life} = (\text{Mx Event \% Life Remaining} - 50\%) * (\text{Mx Event Cost})$$

The following **example** illustrates the adjustment from half-life calculation for an A320 six-year structural check:

- ▶ 6-Year Structural Interval = 72 Mo
- ▶ Average Cost of Event = \$840,000
- ▶ Event Life Consumed = 60 Mo
- ▶ Event Life Remaining = 12 Mo
- ▶ % Life Remaining = $12/72 = 16.67\%$

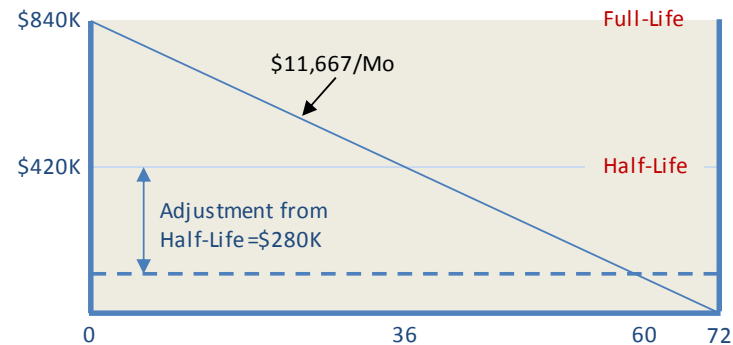


Figure 19. Adjustment from Half-Life : A320 6Y CK

$$\text{Adjustment from Half-Life} = (16.67\% - 50\%) * \$840,000 = (\$280,000)$$



VII. Maintenance Utility & Status

Generally, an appraiser attempts to attach a value resulting from differences in maintenance status between the hypothetical average aircraft and the aircraft they are appraising. For new, or nearly new aircraft, where the maintenance status is half-life or better, the maintenance value adjustment tends to be negligible.

As an aircraft ages, maintenance begins to account for a higher proportion of the aircraft's total value; over time, escalating non-routine maintenance tasks require incremental labor to address unscheduled repairs and discrepancies, or to remove and restore defective components. Additionally, higher material costs are expected to be incurred given that costly components begin to reach a state of "beyond economic repair", and many piece-parts are scrapped and replaced.

After an aircraft reaches a certain age the main differentiator between specific aircraft of the same vintage will often be the value in their maintenance status. Thus the position in the maintenance cycle is a source of value difference between aircraft of the same type and vintage, and consequently it is useful to quantify in monetary terms the value of maintenance status.



VII. Maintenance Utility & Status

Figure 20 illustrates an example calculation summarizing the maintenance adjustment from half-life for a 2011 build A320.

AIRCRAFT STATUS												Status as of : 21-Nov-17		
Aircraft :		Airframe :		Engine Pos 1 :		Engine Pos 2 :		APU :						
Model:	A320-200	TSN :	22,328	TSN :	22,328	TSN :	22,328	TSN :	4,000					
DoM:	29-Sep-11	CSN :	10,634	CSN :	10,634	CSN :	10,634	CSN :	5,000					
Engine:	V2527-A5 S1	Mo FH :	302	TSLSV	N/A	TSLSV	N/A	TSLSV	N/A					
APU:	GTCP-131-9A	Mo FC :	144	CSLSV	N/A	CSLSV	N/A	CSLSV	N/A					

MAINTENANCE ADJUSTMENT FROM HALF-LIFE													
Mx Equipment	Mx Event	Maintenance Intervals			Date Last Mx Event	Maintenance Intervals		Mx Cost \$	Maintenance Value (\$)		Life Remaining		Half-Life Adjust (\$)
		Mo	FH	FC		Consumed	Remain		Consumed	Remain	% Total	% Half-Life	
Airframe	6-Year SI	72			07-Jul-17	5	67	\$ 875,000	\$ 60,764	\$ 814,236	93.1%	43.1%	\$ 376,736
Airframe	12-Year SI	144			N/A	77	67	\$ 925,000	\$ 494,618	\$ 430,382	46.5%	-3.5%	\$ (32,118)
Ldg Gear	Overhaul				N/A								
	Nose	120		20,000	N/A	74	46	\$ 160,000	\$ 98,667	\$ 61,333	38.3%	-11.7%	\$ (18,667)
	Main	120		20,000	N/A	74	46	\$ 320,000	\$ 197,333	\$ 122,667	38.3%	-11.7%	\$ (37,333)
APU ¹	Overhaul		8,000		N/A	4,000	4,000	\$ 350,000	\$ 175,000	\$ 175,000	50.0%	0.0%	\$ -
Eng Pos 1	Perf Rest		27,000	13,000	N/A	22,328	4,672	\$ 3,300,000	\$ 2,728,978	\$ 571,022	17.3%	-32.7%	\$ (1,078,978)
Eng Pos 1	LLP Rpl			20,000	N/A	10,634	9,366	\$ 3,842,519	\$ 2,043,067	\$ 1,799,452	46.8%	-3.2%	\$ (121,808)
Eng Pos 2	Perf Rest		27,000	13,000	N/A	22,328	4,672	\$ 3,300,000	\$ 2,728,978	\$ 571,022	17.3%	-32.7%	\$ (1,078,978)
Eng Pos 2	LLP Rpl			20,000	N/A	10,634	9,366	\$ 3,842,519	\$ 2,043,067	\$ 1,799,452	46.8%	-3.2%	\$ (121,808)
								\$ 16,915,038	\$ 10,570,472	\$ 6,344,566			\$ (2,112,953)

Figure 20. Example Maintenance Adjustment from Half-Life Calculation



Section 2

Turbofan Design Concepts

- I. Turbofan Architecture
- II. Turbofan Modules
- III. Bypass Ratio
- IV. Life-Limited Parts (LLPs)
- V. Quick Exchange (QEC) Kit



- ❑ All of the jet engines used in currently manufactured commercial jet aircraft are turbofans. They are used commercially mainly because they are highly fuel efficient and relatively quiet in operation.
- ❑ A turbofan is a type of aircraft engine consisting of a ducted fan which is powered by a gas turbine. A portion of the air that passes through the fan enters the compressor stages in the core of the engine where it is further compressed and processed through the engine cycle.
- ❑ However, the majority of the air passes through the outer diameter of the is bypassed around the core of the engine. The air accelerated by the fan in a turbofan engine contributes significantly to the thrust produced by the engine. In large engines, such as the engines that power the B777, B787, A330, & A350, etc., as much as eighty percent of the thrust delivered by the engine is developed by the fan.



A modern turbofan engine often operates **25,000 hours** between major overhauls; equivalent to **13,500,000 miles** or flying to the moon and back over **27 times**.

I. Turbofan Architecture

Conventional “direct drive” turbofan engine architecture embodies either a twin-shaft or three-shaft design – see **Figure 21**. In a twin-shaft configuration the Fan & Low Pressure Compressor (LPC) is driven by the Low Pressure Turbine (LPT), and the High Pressure Compressor (HPC) is driven by the High Pressure Turbine (HPT). A three-shaft turbofan includes an additional, Intermediate Pressure Compressor (IPC) and turbine (IPT) section.

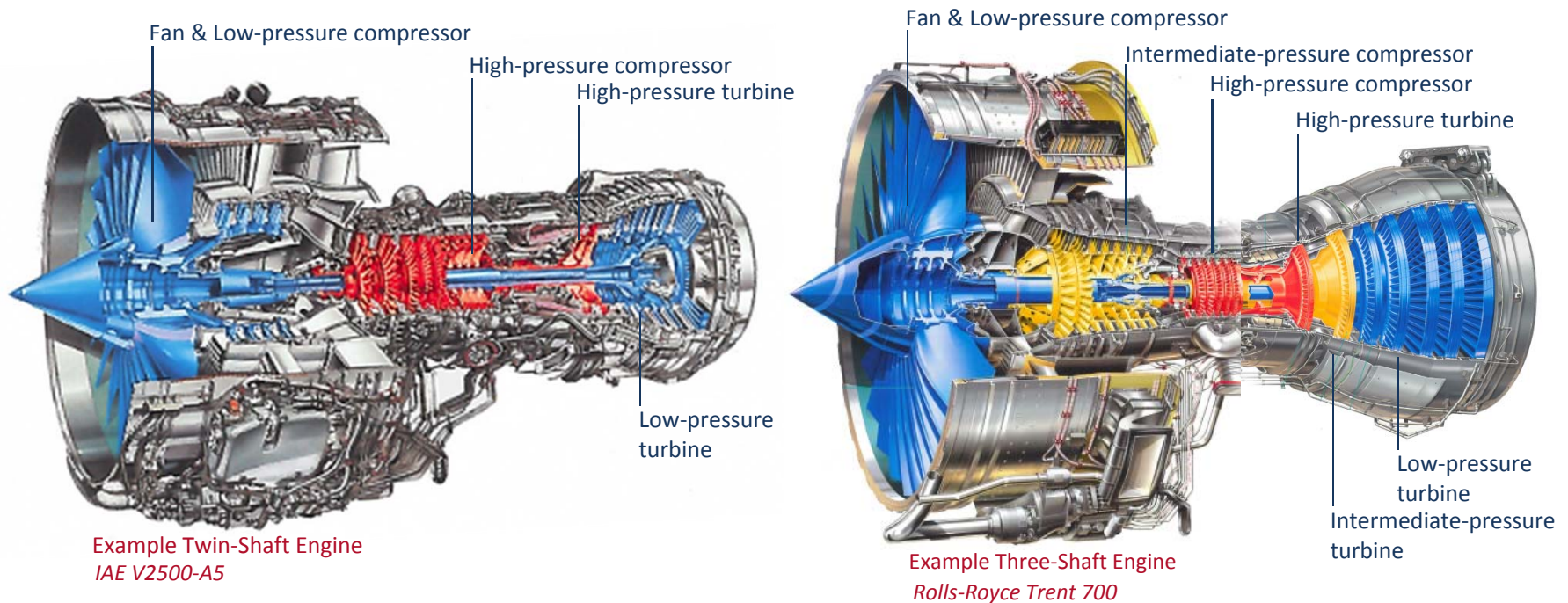


Figure 21. Twin and Three Shaft Turbofan Architecture

II. Turbofan Modules

As illustrated in **Figure 23**, engines are designed as a series of modules for ease of assembly & subsequent maintenance. Each module has its individual identity, service history and designated levels of work. The **Core Modules (Hot Section)** of an engine consist of the HPC, Combustor & HPT, and are generally restored at each shop visit.

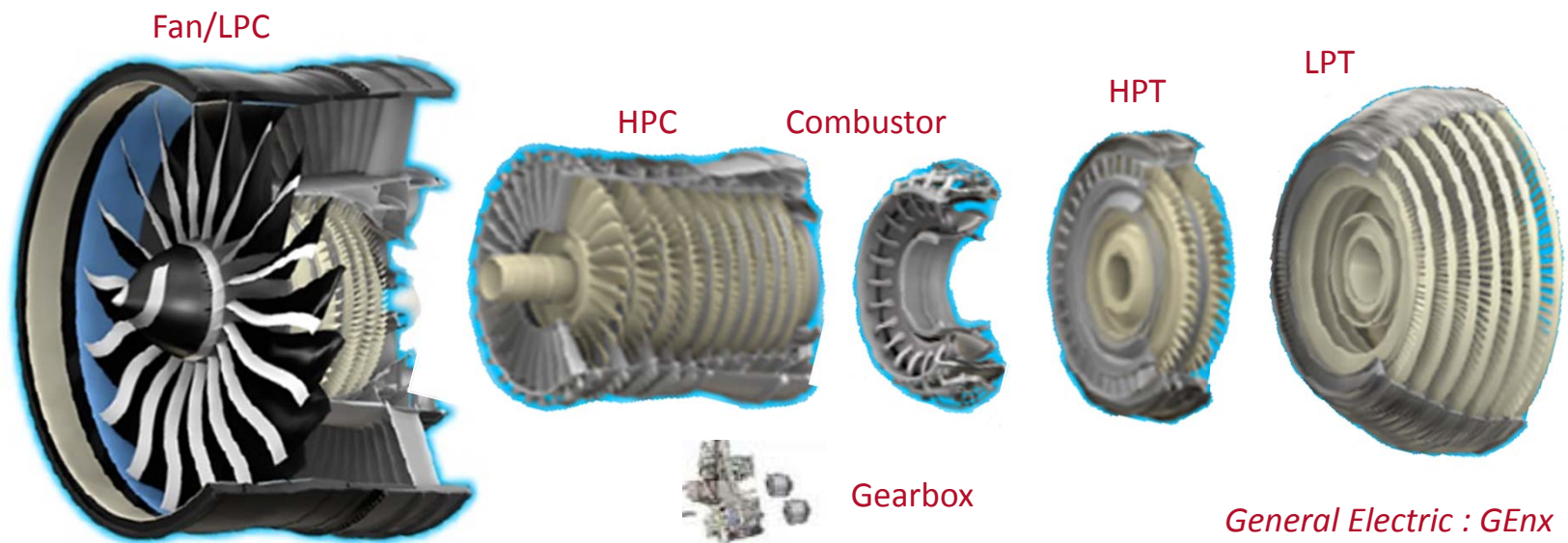


Figure 23. Conventional Twin-Shaft Turbofan Module Breakdown

II. Turbofan Modules

- 1. Fan/Low Pressure Compressor (LPC) Figure 24 –** The Fan is simply a specialized type of a compressor and usually contains one stage. The Fan is responsible for producing the majority of a typical turbofan's thrust.

The LPC receives a burst of air from the Fan and begins to compress it through alternating stages of rotor blades and stator vanes.

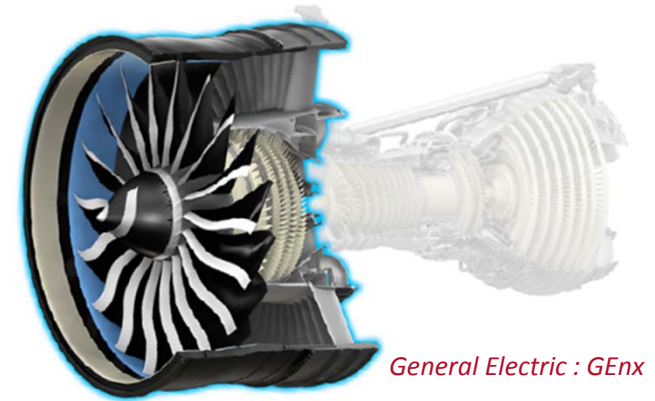


Figure 24. Fan/LPC Module

- 2. High Pressure Compressor (HPC) Figure 25 -** The HPC module is made up of a series of rotor and stator assemblies whose main function is to further raise the pressure of the air supplied to the combustor. It is the later stages of a HPC where the airflow is at considerable higher temperatures and pressures, which explains why these blades and vanes are made of more temperature resisting titanium and nickel alloys.

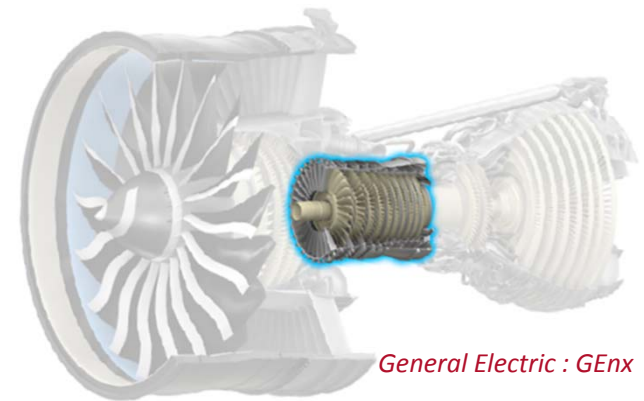


Figure 25. HPC Module

II. Turbofan Modules

3. Combustor Figure 26 - In the combustion system, fuel is burnt with the air received from the compressor modules, sending hot gas downstream to the High Pressure Turbine (HPT). It consists of a combustion chamber, a fuel injector, an igniter and nozzle guide vanes. Most of today's modern turbofan engines employ an annular combustion system.

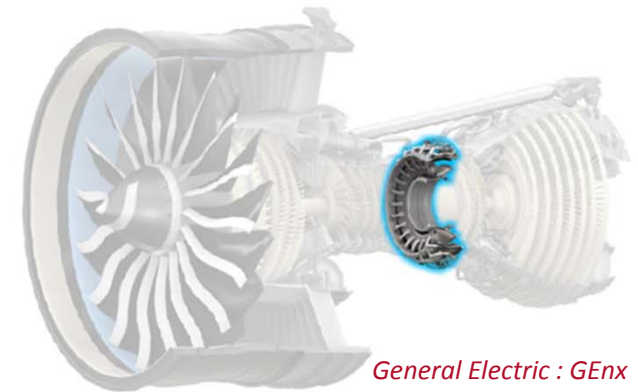


Figure 26. Combustor Module

4. High Pressure Turbine (HPT) Figure 27 - The HPT module is made up of the HPT rotor and nozzle guide vane assemblies, which act to extract the combustion thermal energy for driving the High Pressure Compressor (HPC) and the accessory gearbox. Both combustor and HPT are exposed to the maximum temperatures that occur in the engine

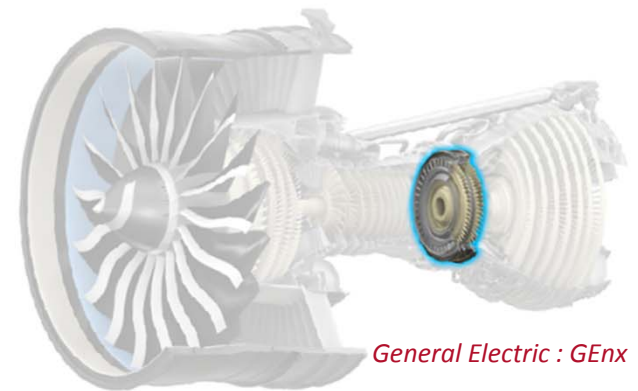


Figure 27. HPT Module

II. Turbofan Modules

- 5. Low Pressure Turbine (LPT) Figure 28** – The LPT is an assembly of disks with turbine blades that are attached to the low pressure shaft, nozzle guide vanes and a rear frame. The LPT extracts the remaining combustion thermal energy to drive the Fan and Low-Pressure Compressor rotor assembly.

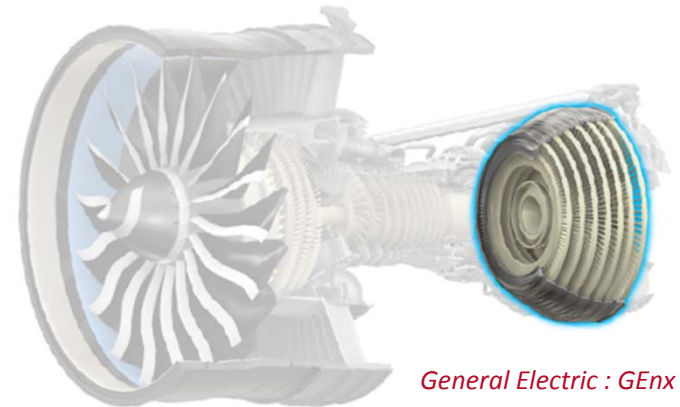


Figure 28. LPT Module

- 6. Accessory Drive (Gearbox)** - The accessory drive section is usually attached to the engine core or fan case. The accessory drive transfers mechanical energy from the engine to drive the basic engine & aircraft accessories (e.g. generators and hydraulic pumps) mounted to the accessory gearbox.

III. Bypass Ratio

As illustrated in **Figure 29**, an engine's bypass ratio is the ratio of the air that goes around the engine to the air that goes through the core. In high bypass engines, most of the total thrust (anywhere from 60% - 80%) of high bypass turbofan engines is produced by the bypass air accelerated in the fan stage, whereas the engine core primarily acts as gas generator providing the power to drive the turbines

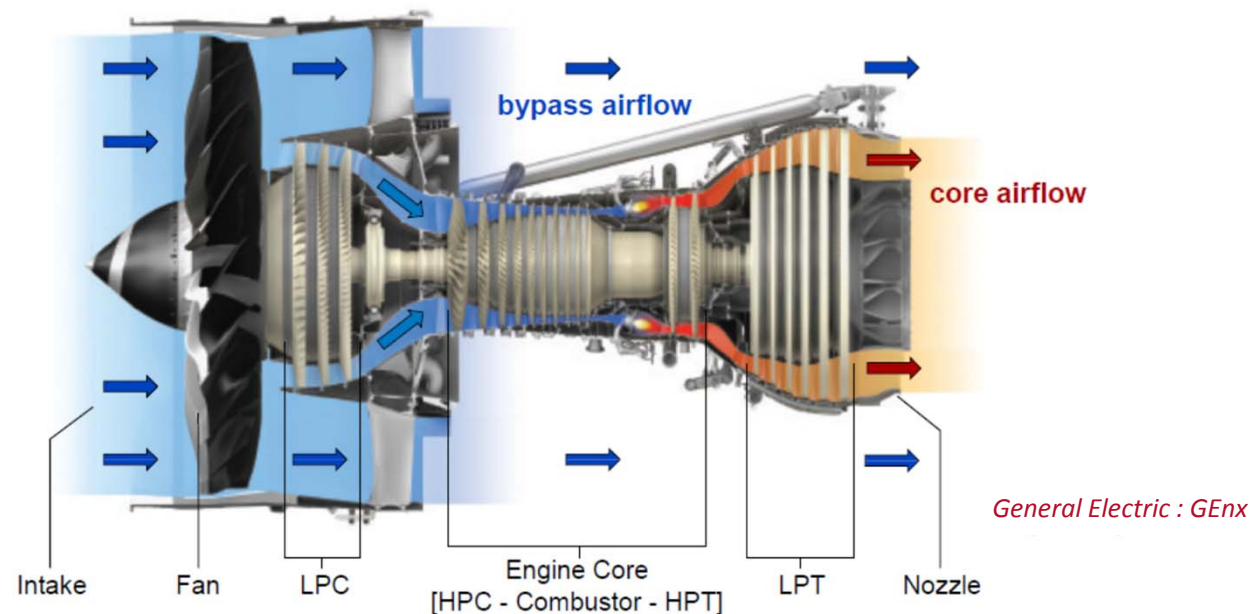


Figure 29. Engine Bypass Ratio



IV. Life-Limited Parts

Within engine are certain major rotating structural parts that cannot be contained if they fail and whose primary failure is likely to result in a hazardous damage to the engine. As a result, such parts are governed by the number of flight cycles operated. These parts are known as **Life-Limited Parts (LLP)** and their life limitations are defined by the OEM in **Chapter 5 of each engine's shop/overhaul manual**. LLPs generally consist of disks, seals, spools, and shafts. LLPs are discarded once their useful lives are reached. Once an engine's accumulated flight cycles approaches the shortest LLP life limit, the part(s) have to be removed.

In most cases, the declared lives of LLPs are between 15,000 - 30,000 cycles, and a complete set will represent a high proportion (greater than 20%) of the overall cost of an engine. If the engine is operated over a long-range network, LLPs may never need to be replaced over the life of the engine. Over short-range routes however, LLPs may need to be replaced two or three times and, consequently, contribute a relatively high cost.

IV. Life-Limited Parts – Example CFM56-3C LLPs

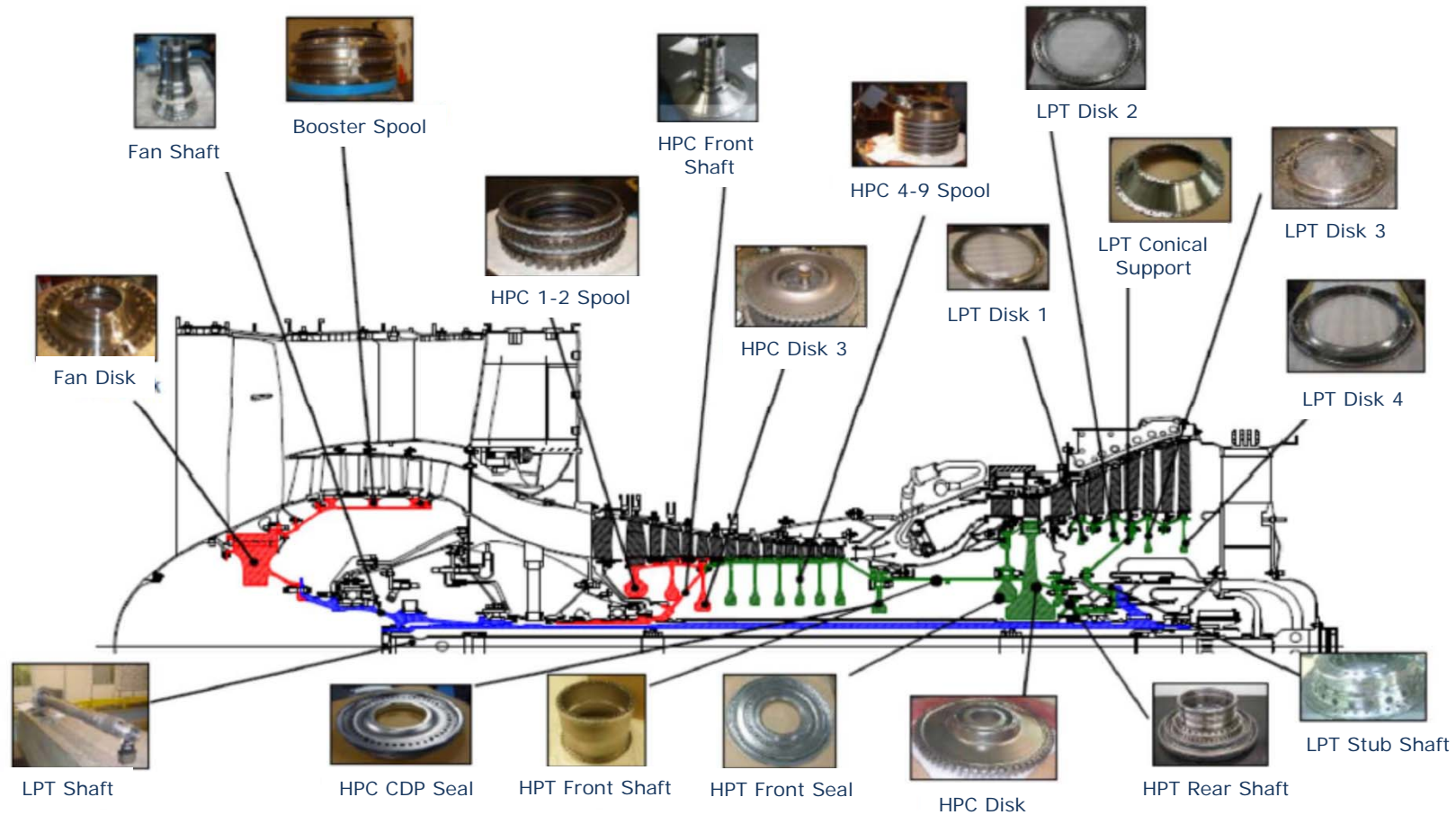


Figure 30. Example Engine Life-Limited Parts Installed on CFM56-3C



IV. Life-Limited Parts

Certain LLPs can have shorter lives imposed on them by airworthiness directives (ADs) or other technical issues such as a decrease in fatigue characteristics or strength capability. Additionally, some engine manufacturers certify ultimate (or target) lives of LLPs at the time they certify an engine model. Other manufacturers certify the lives of LLPs as experience is accumulated. In these scenarios ultimate lives are reached after one or several life extensions.

A number of engine models also contain **static LLPs**. Although these parts are not classified to be critical rotating parts they do fall under the category of parts whose failure could create a hazard to the aircraft. Such parts often consist of shrouds and frames.

V. Quick Engine Exchange (QEC) Kit

The Engine in the form that is Ready-For-Installation (RFI) on an aircraft, is generally called a Powerplant. It consists of Bare Engine + QEC (Quick Engine Change) Kit. The Quick Engine Change (QEC) kit is a collection of components and accessories that are installed on a bare engine. Commonly installed QEC Components include: Starters & Starter Values, Hydraulic Pumps, Integrated Drive Generators(IDG), Anti-icing Valves and Ducts.



Section 3

Turbofan Maintenance Concepts

- I. Trend Monitoring
- II. Exhaust Gas Temperature (EGT)
- III. EGT Margin (EGTM)
- IV. Removal Causes
- V. Shop Visit Rate (SVR)
- VI. Shop Visit Process
- VII. Workscoping Planning
- VIII. Borescope Inspection
- IX. Commercial Considerations



- ❑ Turbofan maintenance cost represents the highest percentage of an aircraft's direct maintenance cost, carrying with it the risk of unexpected high expenses. Therefore, an understanding of the various concepts in turbofan maintenance is important to grasp the factors that drive engine removals and shop visit cost.
- ❑ Turbofan maintenance is an on-condition process, and in the case of turbofan engines the determination of continued airworthiness is largely determined through trend monitoring analysis. Trend monitoring algorithms look at successive snapshots of observations to help the fleet manager analyzing the wear trend of the engine.
- ❑ The design of today's turbofan engines follows a modular concept. This modular design essentially dictates how engine maintenance is managed. Each of the modules has its own identity, service history and specific inspection schedules. During a shop visit, any of the individual modules can be removed and restored as an individual unit.
- ❑ Depending on the engine model and design characteristics, thrust power, technical condition, and workscope definition, performance restoration shop visit costs may cost from \$3 million to more than \$12 million.

I. Trend Monitoring

Engines are governed by on-condition maintenance where maintenance is undertaken only when trend monitoring shows that work is required. Trend monitoring of engine parameters looks at successive snapshots of observations to help analyze deterioration trends.

Regular detailed measurements are taken of a number of critical engine parameters, most notably its' EGT margin (EGTM), operating speed, oil temperature & pressure, fuel flow and vibration levels. These parameters are tracked by Engine Condition-Monitoring (ECM) software to identify progressive deteriorating trends. By closely monitoring these trends it is possible to identify a potential problem(s) with the engine and rectify the problem before it becomes serious.

Typical Monitored Parameters:

- ▶ EGT Margin;
- ▶ Rotor (Shaft) Speed (e.g. N1 & N2);
- ▶ Fuel Flow;
- ▶ Oil Pressure, Temp & Consumption;
- ▶ Engine Vibration;
- ▶ Metal in System (Chip Detector)





II. Exhaust Gas Temperature (EGT)

As illustrated in **Figure 31**, an engine's Exhaust Gas Temperature (EGT) is a measure of the temperature of the gas as it leaves the turbine and is a primary indication of engine health. It is expressed in degrees centigrade and can be seen as one of the most important health monitoring parameters. Engine gas temperatures have to be closely monitored, as exceeding temperature limits may lead to serious heat damage to the turbine components. In addition, the EGT is a measure of the engine's efficiency in producing its design level of thrust.

A high EGT may indicate that the engine has suffered significant hardware deterioration during service. Engines are certified with temperature limits that are enforced via a limit on maximum take-off EGT, referred to as the **redline EGT**. Generally, the EGT reaches its maximum during take-off as engine temperatures are at its peak during this phase of operation.

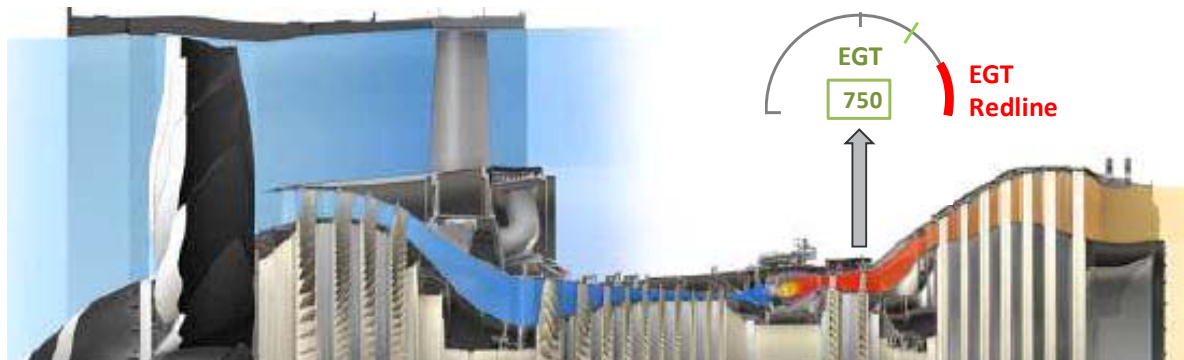


Figure 31. Engine Exhaust Gas Temperature (EGT)



III. EGT Margin (EGTM)

Due to the thermal inertia of the engine the EGT reaches a peak at either the end of the takeoff roll, close to rotation, or just after lift-off. As illustrated in **Figure 23**, an engine's EGT margin (EGTM) is the difference between the peak EGT incurred during take-off and the certified redline EGT – see **Figure 32**. EGTM is largely used as means to evaluate and track engine time on-wing & health.

The **redline EGT** is the absolute temperature limit, which cannot be exceeded without damaging the engine. As the EGT of an engine increases over time due to hardware deterioration the EGT margin decreases. Theoretically, an engine can remain on wing until its EGT margin has become zero, reaching its redline limit.

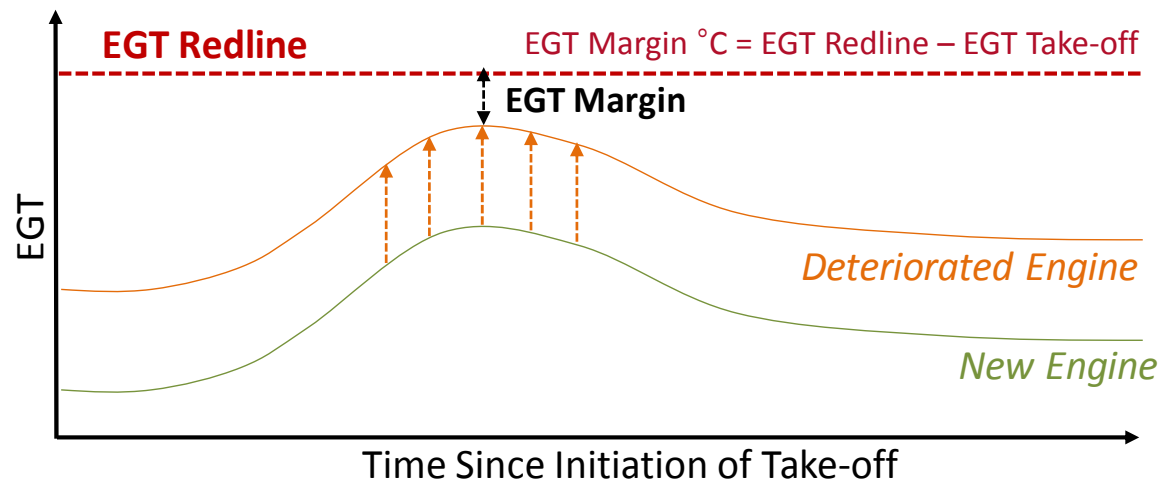


Figure 32. EGT Margins Measurement



III. EGT Margin (EGTM)

Red line limits are referenced in the Aircraft Flight Manual (AFM) and in each engine’s Type Certificate Data Sheet; for the 737-800 equipped with CFM56-7B engines, the red line limit is certified at 950 °C.

EGT margins are at their highest levels when the engines are new or just following refurbishment. Once an engine reaches a stage in its life where there is no EGT margin remaining, the engine will require specific maintenance in order to recover loss EGT margin. **Figure 33** illustrates the available EGT Margins for new CFM56-7B engines.

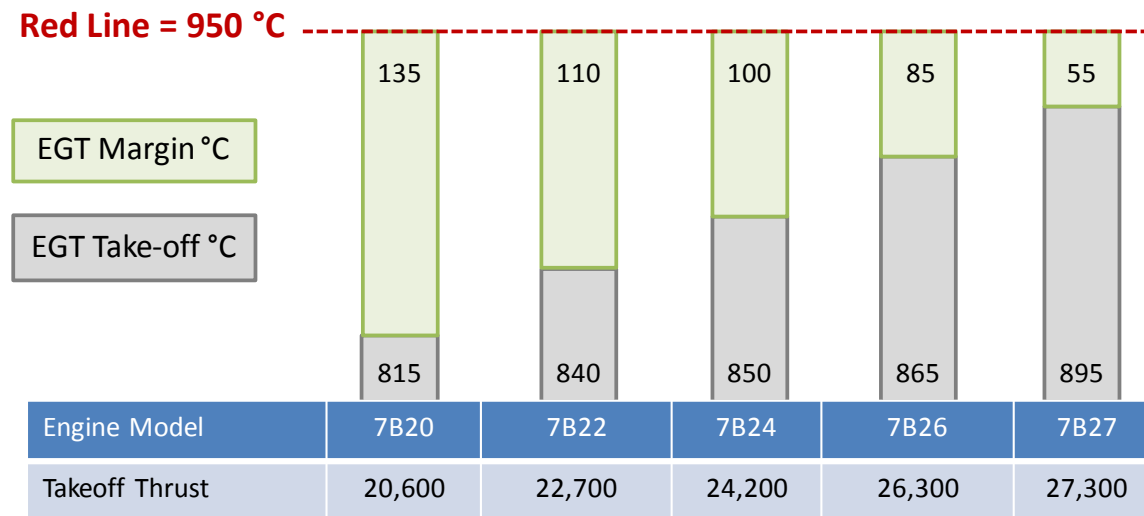


Figure 33. EGT Margins For New CFM56-7B Engines

IV. Removal Causes

Engine removal causes can be assigned into four general categories consisting of: **1.) EGT Margin (EGTM) Erosion; 2.) Expiry of Life Limited Parts (LLPs); 3.) Hardware Deterioration, and 4.) Other Unscheduled Removal Causes.**

1. EGTM Erosion is largely the result of compressor fouling, the gradual increase in blade tip clearances, seal leakage, and airfoil erosion – see **Figure 34**.

- ▶ **Compressor Fouling** - The airflow through a jet engine is often contaminated by sand, salt, chemicals and hydrocarbons, amongst others. These particles adhere to the surface of engine parts leading to a phenomenon known as compressor fouling. The contaminated engine has to work harder to compress a defined amount of air leading to temperature rising and more fuel to achieve the same level of thrust.

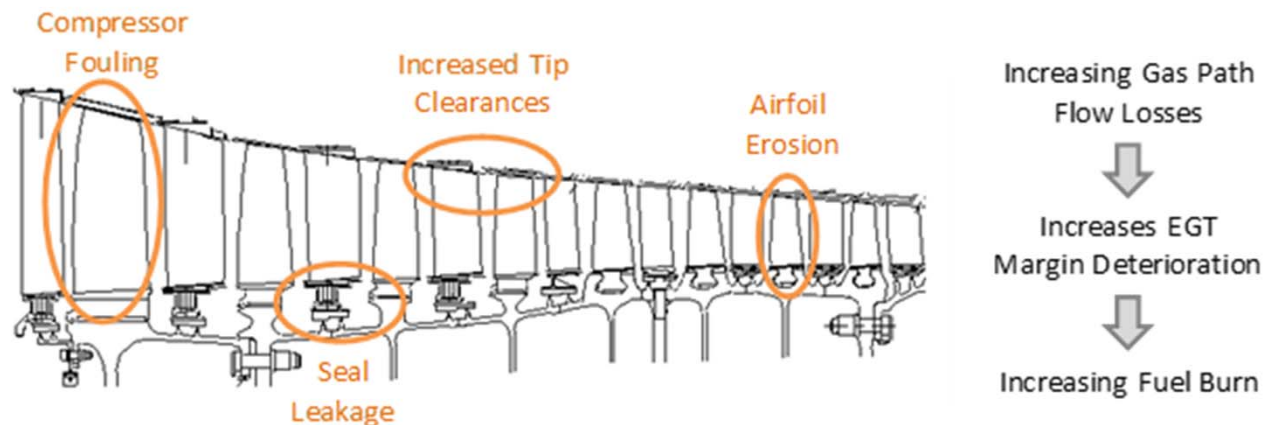


Figure 34. EGT Margin Deterioration Cycle



IV. Removal Causes

1. EGTM Erosion

- ▶ **Turbine Tip Clearance** - Turbine tip clearance is a critical parameter affecting the performance of propulsion engines. To operate at top efficiency, a turbine's tip clearance must be minimized under the constraint of positive clearance to the turbine case. A turbine's tip clearance varies throughout different operating conditions because of differential thermal expansion, manufacturing tolerances, stresses, creep, and erosion. Deterioration of the tip clearances increases the amount of flow losses and leakage of working fluid between blade tips and the surrounding shroud of both the turbine and compressor stages. Such leakage reduces overall engine efficiency hence raising the total specific fuel consumption.
- ▶ **Gas Path Seal Leakage** - Aircraft gas turbine engines have many sealing locations; along the shaft, over rotor blade tips, and between stages. A large engine may have dozens of sealing locations and the cumulative effect of leakage on EGTM erosion can be significant. Gas path sealing worsens as the engines accumulate more time on-wing.
- ▶ **Airfoil Erosion** - Airfoil erosion occurs if engines are operating in highly erosive & corrosive environments, such as areas near or around sandy environments such as the Middle East, near or around ocean coastlines where various sea salts may be present, or combinations of the above, or in other applications where the air contains corrosive chemical ingredients



IV. Removal Causes

1. EGTM Erosion

Figure 35 illustrates the relationship between EGT margin erosion and accumulated engine flight cycles. Rates of deterioration are highest in the initial 1,000 – 2,000 engine flight cycles of operation as the blade tips begin to wear. Initial rates of EGT margin loss are less for lower-rated engines.

EGT Margin erosion rates stabilize after the initial loss and reach a steady state level that remains fairly constant until the engine is scheduled for removal. EGT margin erosion rates can be a leading factor in determining the length of time the engine can remain on wing.

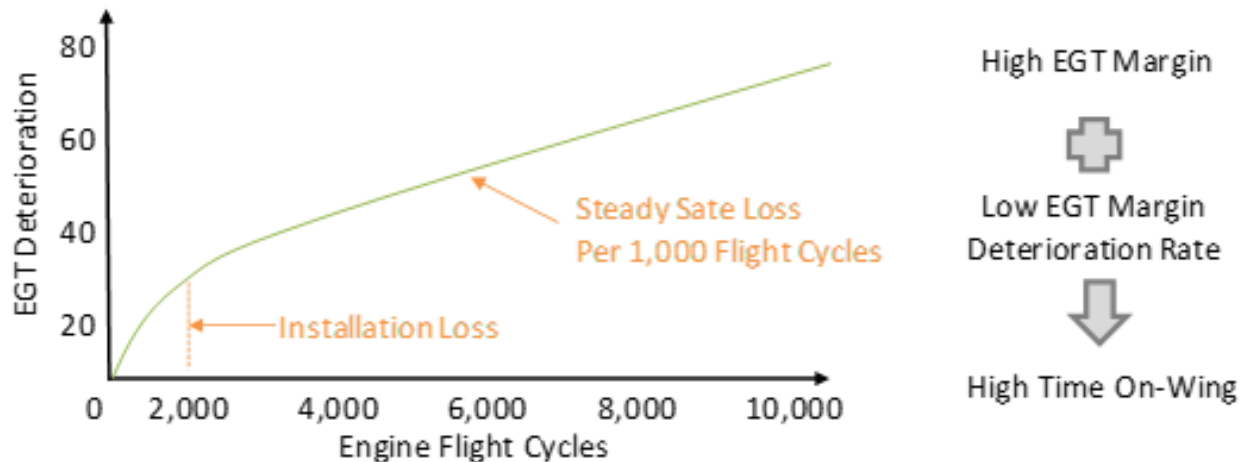


Figure 35. EGT Margin Erosion vs Accumulated Engine Cycles



IV. Removal Causes

1. EGTM Erosion

The “rate” of EGTM erosion is affected by how the engine is operated. Primary factors influencing the rate of EGTM erosion¹ consist of:

- ▶ Engine Thrust Rating,
- ▶ Flight Operation (flight leg, engine derate, operating environment),
- ▶ Age (first-run vs. mature-run)

Trend monitoring of EGT Margin looks at successive snapshots of observations to help analyze the deterioration trend of an engine – see **Figure 36**. By closely monitoring these trends it is possible to make accurate predictions as to when an engine’s scheduled removal is warranted, and by correlation, the interval remaining to its next shop visit.

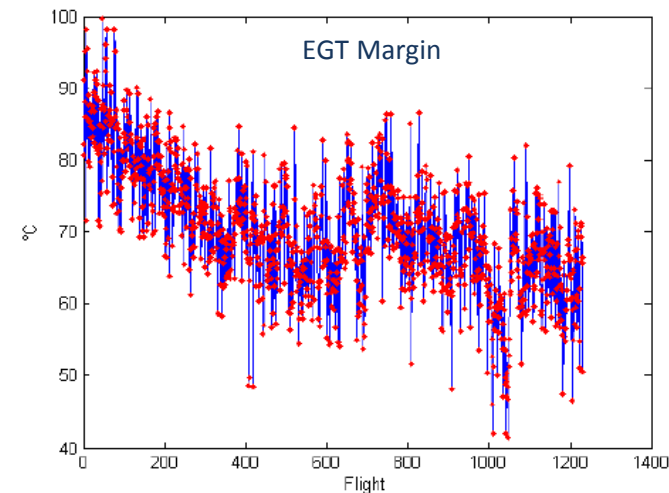


Figure 36. EGT Margin Trend Monitoring

1 – A full description of the factors influencing EGTM erosion is discussed in Section 5 - Factors Influencing Maintenance Reserves



IV. Removal Causes

- 2. Life-Limited Parts (LLP) Expiry** - Prudent LLP management is essential in minimizing shop visit maintenance cost, particularly for engines operating on high-cyclic short and medium-haul operations. For long-haul engines, LLPs account for a smaller recurring share of shop visit cost due to the low number of flight cycles (FC) these engines accumulate.

Most repair shops will assess the life remaining on LLPs when an engine is inducted for maintenance and will manage time limited components to coincide with subsequent shop visits. Ideally, the repair shop will ensure that LLP stub-lives closely match the expected time on-wing from EGT margin erosion. So, for example, if an engine's LLP stub-life is 10,000 FC then the repair center will ensure that the engine has sufficient EGT margin to stay on-wing for 10,000 FC. The 10,000 FC would then be called the **engine build standard**.

LLPs also requires a high degree of disassembly and reassembly. Man-hours for assembly works account for a large percentage of shop visit cost. LLP replacement during a light shop visit would increase the necessary workscope and therefore the cost. The lowest maintenance cost per EFH is accomplished when a heavy shop visit coincides with full LLP utilization.



IV. Removal Causes

- 3. Hardware Deterioration** - All engine components are exposed to different kinds of deterioration mechanisms. These include amongst others, low and high cycle fatigue, thermo-mechanical fatigue as well as corrosion. These mechanisms lead to a degradation of the part lives or in worst case to a part failure as well as to a loss of engine performance.

The engine's core module, being exposed to the highest temperatures and pressures within the engine, suffers more acutely from hardware deterioration. Engine Condition-Monitoring (ECM) systems are often capable of detecting such deterioration anomalies as they precipitate and therefore serve as a tool to prevent more severe damage.

- 4. Other Unscheduled Removal Causes** - Other removal causes include amongst others: Foreign Object Damage (FOD), Oil Leak / High Oil Consumption, Vibration, and Airworthiness Directives



IV. Removal Causes

The causes of engine removals depend heavily on the type of aircraft operation. Engines operating on short-haul routes show a higher percentage of removals caused by EGT margin degradation and LLP expiry, while medium- and long-haul operating engines tend to have a higher share of removals due to hardware deterioration and EGTM degradation. The distribution of the engine removals on the removal causes depending on the aircraft operation and the engine age status is illustrated in **Figure 37**.

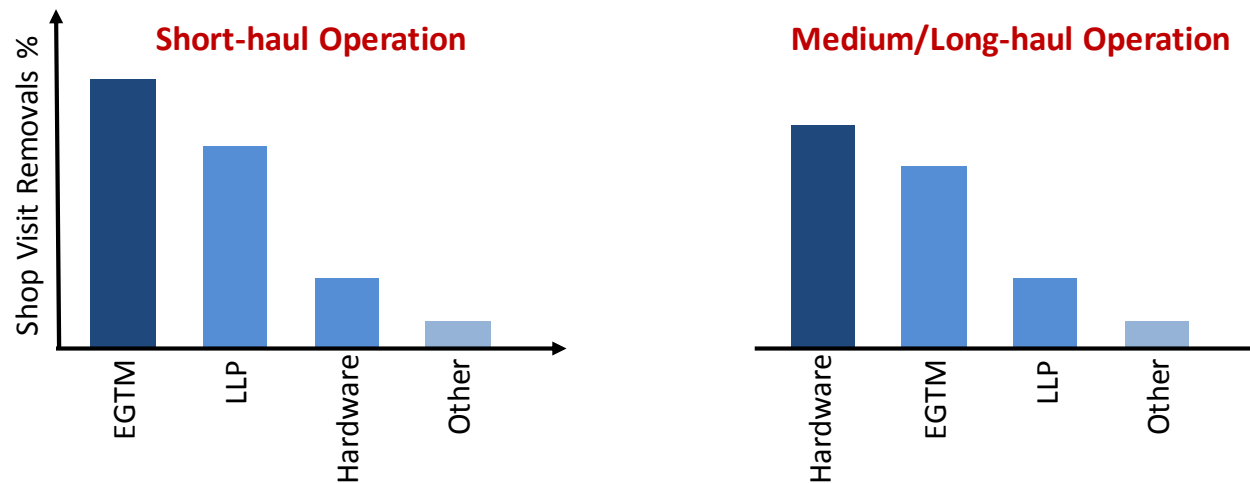


Figure 37. Distribution of Engine Removals by Operation



V. Shop Visit Rate

The **Shop Visit Rate (SVR)** quantifies the rate of engine replacements, or the pace at which engine removals change over a period of time. (e.g. for every 50,000 hours of combined engine flight hours, 1 unit was replaced).

The SVR is calculated by dividing the number of engine removals during a period by the number of engine operating hours for the period and multiplying the resultant by 1,000 – see **Figure 38**.

The SVR expresses the total number of removals (both scheduled and unscheduled) experienced for every 1,000 hours of engine operation. The SVR is traditionally measured on a 12-month rolling average basis, which is a form of cumulative analysis.

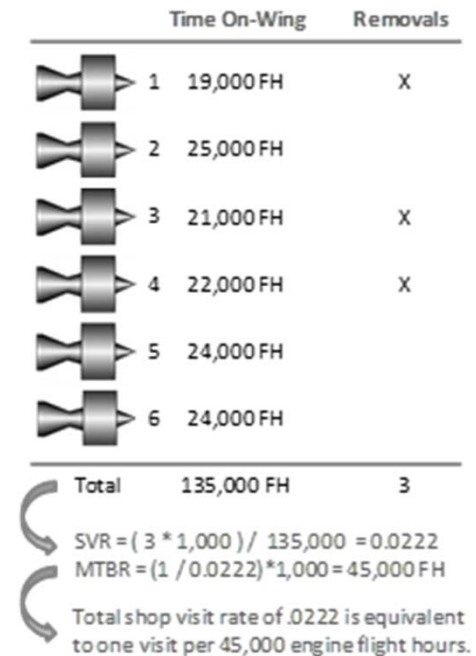


Figure 38. Engine SVR Calculation

An engine's **Mean-Time-Between Removal (MTBR)** is the reciprocal of the total SVR. The MTBR can be calculated by dividing the total engine flying hours by the number of engine removals (scheduled & unscheduled) that occurred during the same period.



V. Shop Visit Rate

The SVR can be calculated monthly as a fleet average and their absolute levels monitored and compared against established benchmarks. Key benefits of tracking an engine's SVR are:

- ▶ Provides an all-inclusive view of an engine's operational performance;
- ▶ Used as a method for airlines and engine OEMs to measure performance against stated goals;
- ▶ Useful for validating inherent design reliability, and engine product improvements;
- ▶ Useful in determining spare engine requirements

An engine's total SVR can be broken into constituent components consisting of the **Scheduled Engine Removal Rate (SER)** and **Unscheduled Engine Removal Rate (UER)**. – **Figure 39**. Each of these components provides further insight into engine reliability, most notably the UER given this parameter can help identify chronic problems.

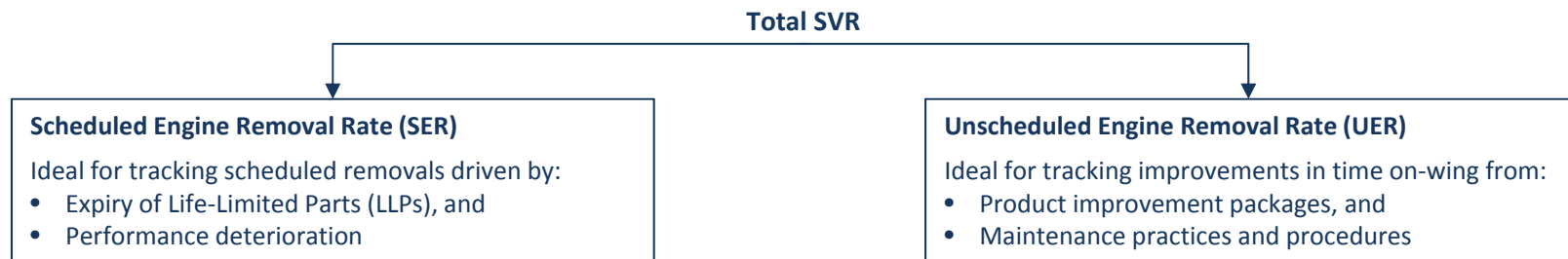


Figure 39. Scheduled Engine Removal (SER) rate versus Unscheduled (UER) rate



V. Shop Visit Rate

Scheduled Engine Removal Rate - The SER measures how often an engine model is removed to address planned, or scheduled removals due to required maintenance actions. References to engine scheduled maintenance refer to requirements for preventive or corrective maintenance that can be anticipated, planned for, and usually scheduled to minimize service inconvenience. Examples of scheduled removals consist of those resulting from a.) The expiry of Life-Limited Parts (LLPs), b.) Performance deterioration and c.) Service bulletin compliance.

Unscheduled Engine Removal Rate - The UER measures how often an engine is removed for repair or refurbishment before the normal maintenance intervals are reached, or due to an unexpected engine anomaly preventing it from continued safe operation. Therefore, whenever the frequency of unscheduled engine removals increases, this impact will have a direct adverse effect on operational reliability. If the engine OEM implements product improvement packages, or updates recommended maintenance practices, then the UER will capture expected improvements derived from these initiatives.

The **Mean-Time-Between Unscheduled Removals (MTBUR)** is the reciprocal of the UER. This parameter is calculated by dividing the total engine flying hours accrued in a period by the number of unscheduled engine removals that occurred during the same period. This measure has the same use as the UER but is often more intuitive to interpret due to its convention.

V. Shop Visit Rate

There are two popular methods of tracking SVRs that have been especially useful in monitoring reliability performance of engine fleets. These methods consist of the: 1.) Scorecard method and 2.) Time-series method. The following discusses the attributes of each.

The scorecard method gives managers an all-inclusive summary view of their SVR performance – see **Figure 40**. If the rate falls below stated goals this serves as validation that strategies put in place to address performance shortcomings are effective. Conversely, if the rate remains above target goals than this would warrant a course of action to remedy any shortcomings.

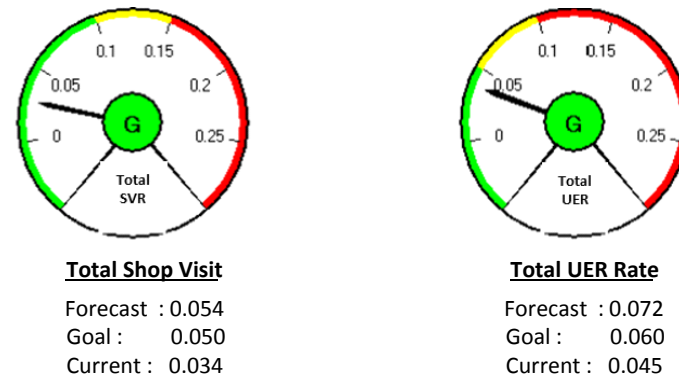


Figure 40. Example SVR Scorecard Method

The scorecard method can serve as an important organizational tool providing decision makers with a comprehensive view of the shop visit rate; however, the method will likely be ineffective if it is not in alignment with the organizational strategy.



V. Shop Visit Rate

The **time-series method** is used when observations are made on a repeated basis and serves as an effective means to monitor an engine's SVR as a **trending metric**. SVR trends are plotted against time intervals to measure shifts in this parameter that results from unknown deficiencies (e.g. hardware & component anomalies). The time-series method provides greater visibility into correlating the impact of both product improvement initiatives and updated maintenance practices over time. **Figure 41** illustrates a long-term trend report highlighting movements in engine total, scheduled, and unscheduled removal rates; the rates are trending lower, implying effectiveness in either product improvements, maintenance practices, or a combination of both.

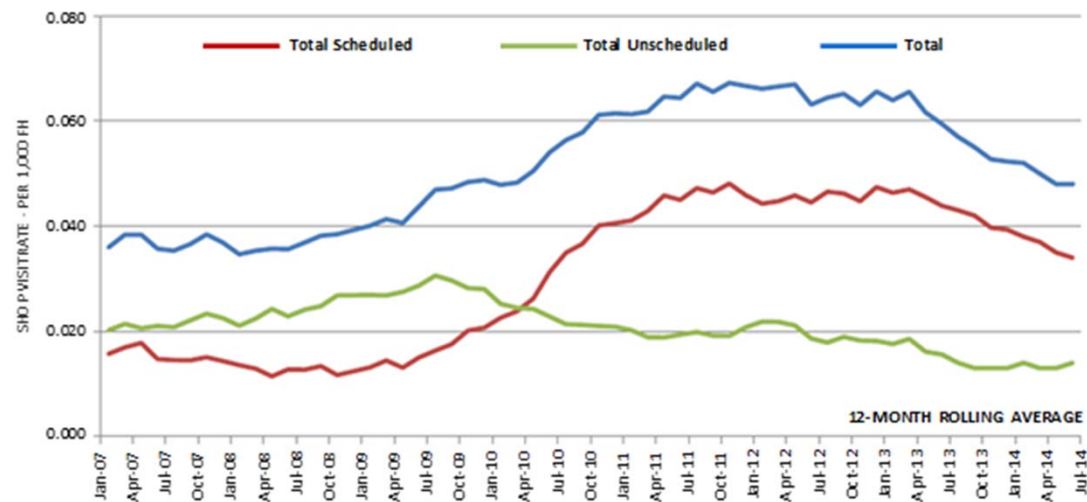


Figure 41. Example SVR Time-Series Method



V. Shop Visit Rate

The shop visit rate is one of many key metrics used by airlines and engine manufacturer's to track performance against an objective criterion; for example, comparing an airline's SVR reliability to overall fleet reliability to determine whether their performance is in line with the rest of the industry leads to an awareness of each airline's standing and provides a baseline for improvement. **Figure 42** illustrates an example comparing an airline's engine SVR to that of the engine's fleet.

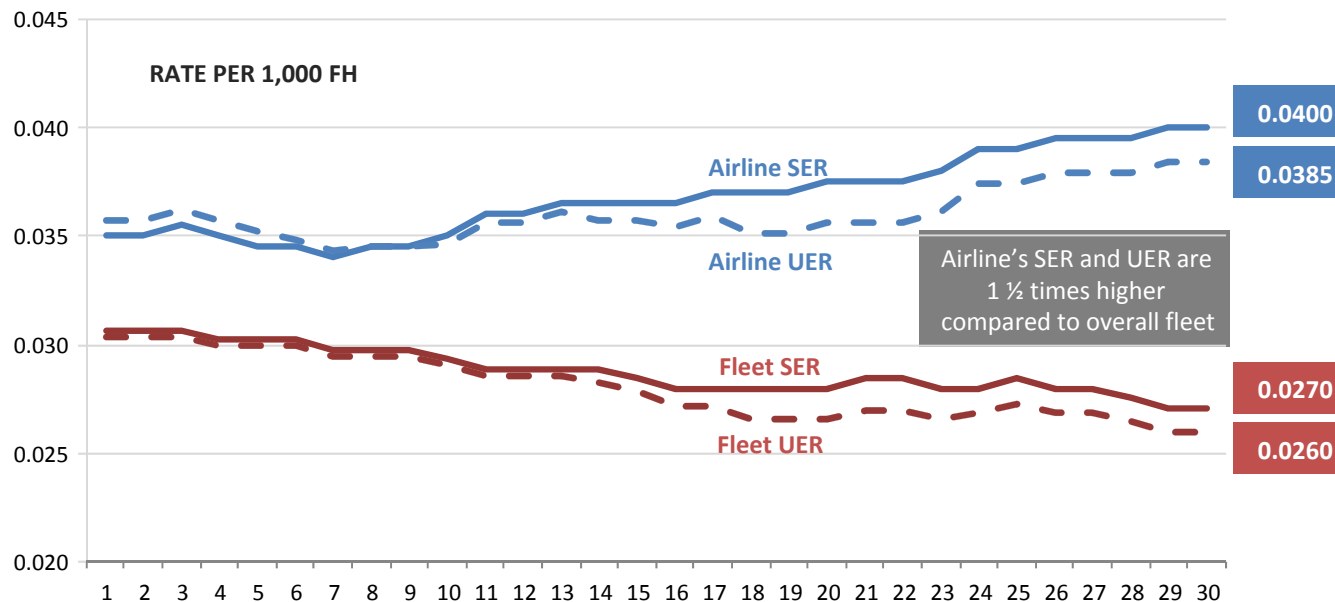


Figure 42. Example Comparison Between Airline & Fleet SVR



V. Shop Visit Rate

Although the shop visit rate is an effective parameter used to track operational performance, **the index can often be a misleading indicator of average time on-wing**, particularly during an engine's growth phase. During the period an engine enters service and grows its population base, the SVR becomes "diluted" from the effect of adding more engines to the existing pool already in operation. Because of dilution, the SVR should not be construed to be a reliable indicator of average time on-wing during the entry into service & growth phase.

As the engine ages, a disproportionate amount of parts experiences higher deterioration rates, higher scrap rates, and correspondingly higher SVRs. As illustrated in **Figure 43** however; the aging curve pattern of an engine's shop visit rate begins to stabilize and eventually normalizes into a mature SVR (MSVR) during which time the index closely aligns with average time on-wing.

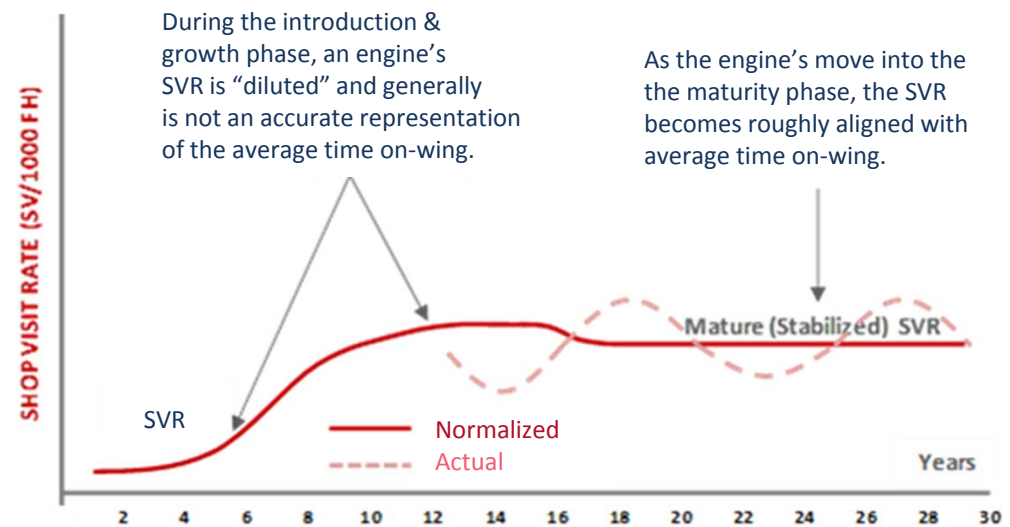


Figure 43. Mature (Stabilized) SVR



V. Shop Visit Rate

Engine maintenance costs are largely influenced by its associated shop visit rate. All things being equal, an engine with a higher shop visit rate will incur higher life cycle maintenance costs.

Figure 44 illustrates the drivers of engine maintenance costs, which can be broken down into line & shop maintenance costs, spares cost, and schedule interruption costs. As shown, the most significant parameter that directly contributes to three of the four elements is the engine removal rate.

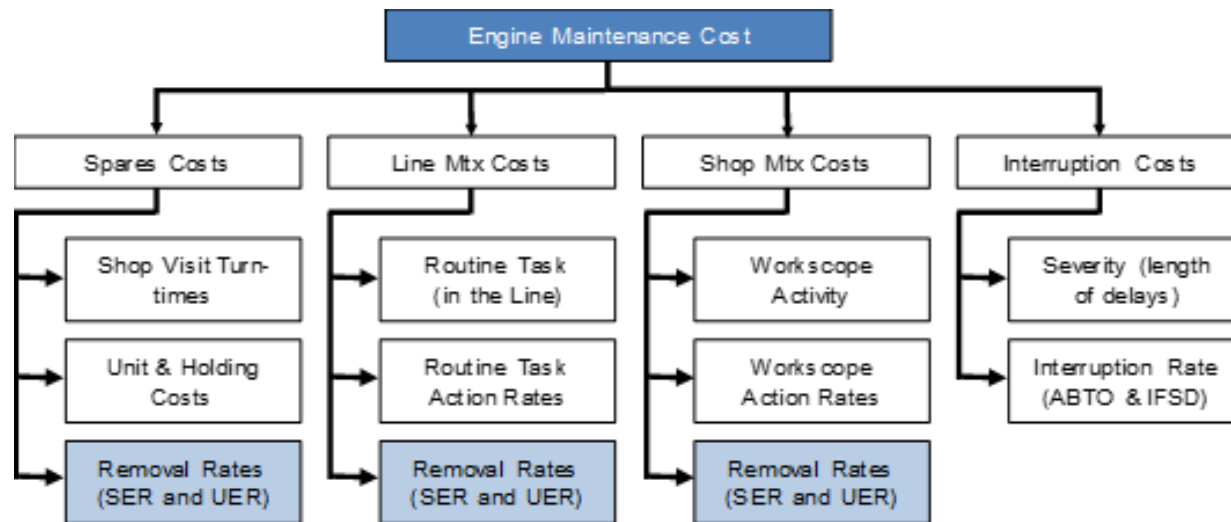


Figure 44. Engine Maintenance Cost Drivers



VI. Shop Visit Process

The breakdown of an engine's shop visit process is detailed in **Figure 45**. The primary cost driver of engine shop maintenance is material cost. Approximately 60% - 70% of the cost of an engine shop visit is due to replacement of material. If life-limited parts (LLP) require replacement the material cost will increase further. Direct labor will account for approximately 20%-30% of total cost, while repairs will account for 10%-20%.

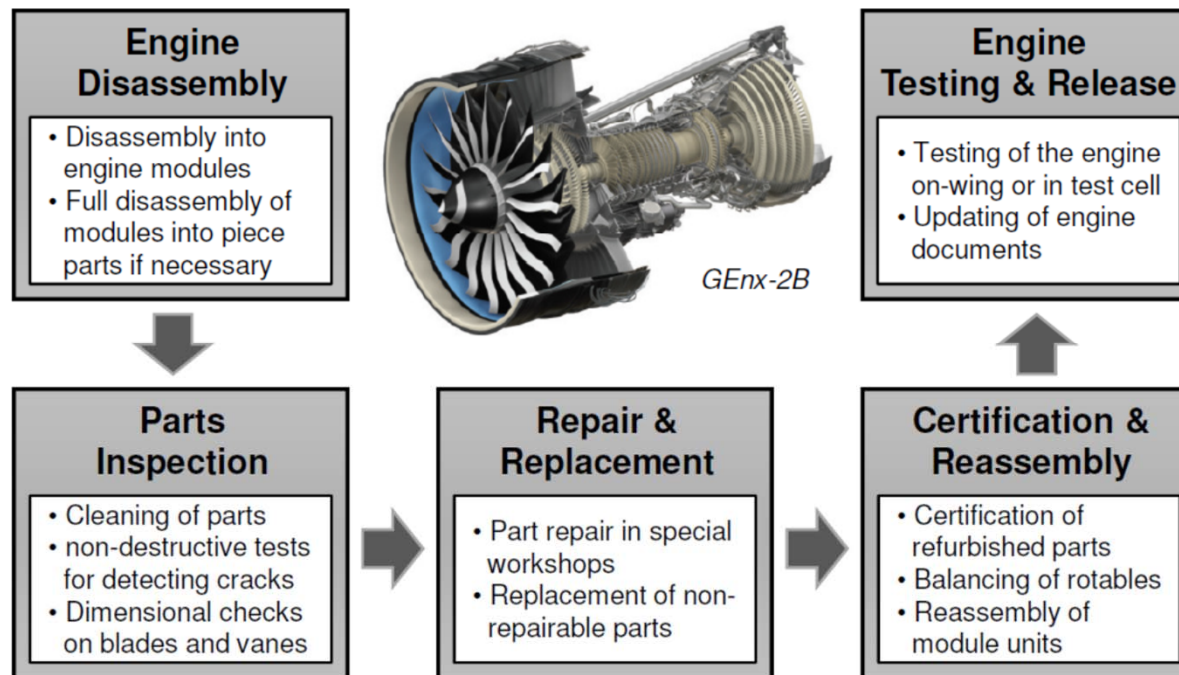


Figure 45. Engine Shop Visit Process



VII. Workscope Planning

The primary objective of the workscope is to restore the engines performance, and to build the engine to a standard that minimizes long-term engine direct maintenance cost, or cost per flying hour. This process, however, can be quite challenging given parts and modules have different rates of deterioration. **A qualified performance restoration shop visit** occurs whenever the engine maintenance performed entails a performance or higher level of work, which at a minimum:

- ▶ Accomplishes a prescribed package of inspections, maintenance checks and major refurbishments on an engine's Core Modules

This level of refurbishment does not specify 100% disassembly and 100% piece part inspection, but will generally :

- ▶ Zero-time the Core Modules to the highest build specification,
- ▶ Obtain max time between shop visits with resultant lowest cost per flight hour & the greatest potential for regaining EGT margin.
- ▶ Ensure that LLP stub-lives closely match the expected time on-wing from EGT margin erosion.



VII. Workscope Planning

A qualified performance restoration shop visit objective is to restore hardware and clearances between blade tips and engine casings. On average, 65% - 85% of the original EGT Margin will be restored following a performance restoration – see **Figure 46**.

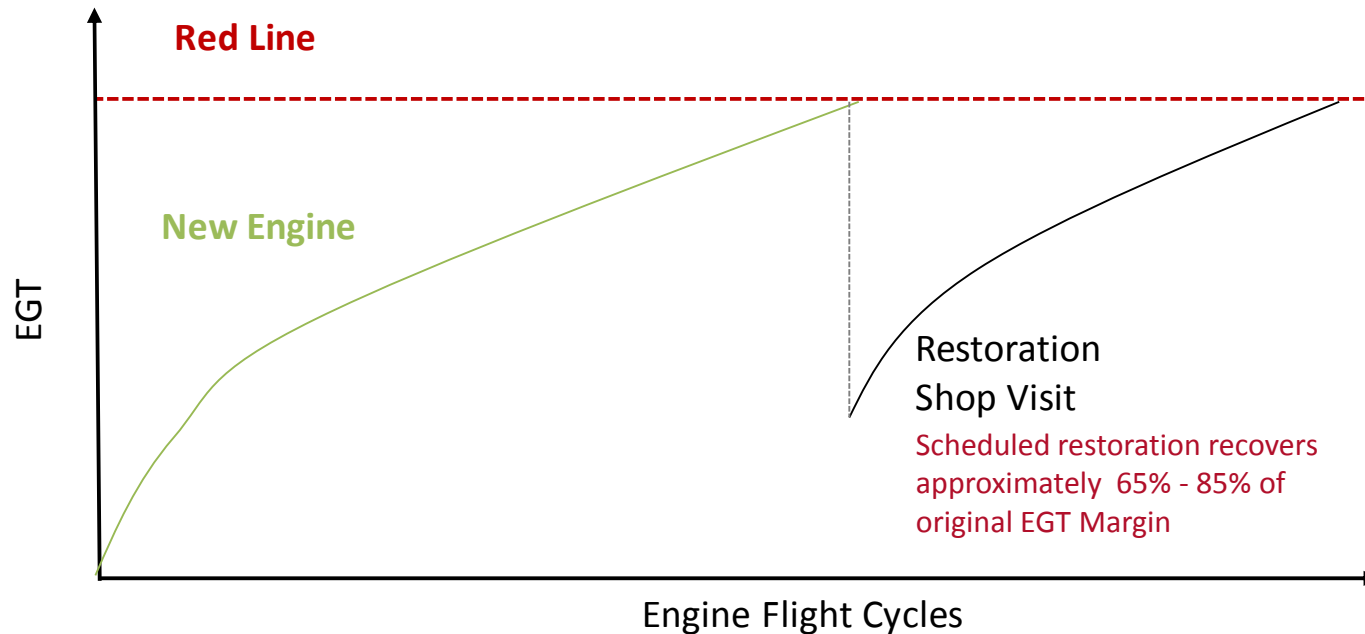


Figure 46. Effect of Engine Restoration on EGTM Recovery



VII. Workscope Planning

The **Workscope Planning Guide (WPG)** is a manual that details suggested levels of required maintenance on each module as well as a list of recommended **Service Bulletins**. Engines generally go through patterns of worksopes that vary based on time on-wing and business considerations. The WPG generally specify three **levels** of worksopes consisting of: 1.) Minimum Level, 2.) Performance Level, and 3.) Full Overhaul.

1. **Minimum Level Workscope** – Typically applies to situations where a module has limited time since last overhaul. The key tasks accomplished with this workscope level are external inspections, and to some extent, minor repairs. It is not necessary to disassemble the module to meet the requirements of a minimum level workscope.
2. **Performance Level Workscope** – Will normally require teardown of a module to expose the rotor assembly. Airfoils, guide vanes, seals, and shrouds are inspected and repaired or replaced as needed to restore the performance of the module. Cost-effective performance restoration requires determination of the items having the greatest potential for regaining both exhaust gas temperature (EGT) and Specific Fuel Consumption (SFC) margin.



VII. Workscope Planning

- 3. Full Overhaul Workscope** - Full overhaul applies to a module if its time / cycle status exceeds the recommended (soft-time) threshold, or if the condition of the hardware makes full overhaul necessary. The module is disassembled to piece-parts and every part in the module receives a full serviceability inspection and, if required, is replaced with new or repaired hardware.

Figure 47 illustrates the levels of workscope performed on individual engine modules an based on individual shop visits

Major Module	SV1 Workscope Level	SV2 Workscope Level	SV3 Workscope Level
Fan & LPC	Minimum Level	Performance Level	Minimum Level
Core	Performance Level	Full Overhaul	Performance Level
LPT	Minimum Level	Performance Level	Minimum Level
Gearbox	Minimum Level	Performance Level	Minimum Level

Figure 47. Example Engine Workscope Levels



VII. Workscope Planning

The level of workscope performed on an engine can be “target-oriented” to achieve either: 1.) Target on-wing time, 2.) Target shop visit cost, and 3.) Target LLP stub-life. The key determinants that affect the workscope inputs vary by operator but are generally influenced by:

- ▶ Removal cause(s);
- ▶ Time accumulated on the engine modules;
- ▶ Observed hardware conditions;
- ▶ Trend data at removal

Business decisions also influence the level of workscope performed, key among them is:

- ▶ Maximizing usage of LLP hardware, which often leads to lower shop visit costs but higher DMC (\$ / FH), or
- ▶ Building for minimum number of shop visits, which allows one to achieve lower DMC (\$ / FH) but higher shop visit costs.



VII. Workscope Planning

Example illustrating workscope alternative to either, 1.) build for maximum time on-wing resulting in lower unit cost (\$/FH) or 2.) minimum restoration cost (cash outlay) resulting in highest unit cost – **Figure 48.**

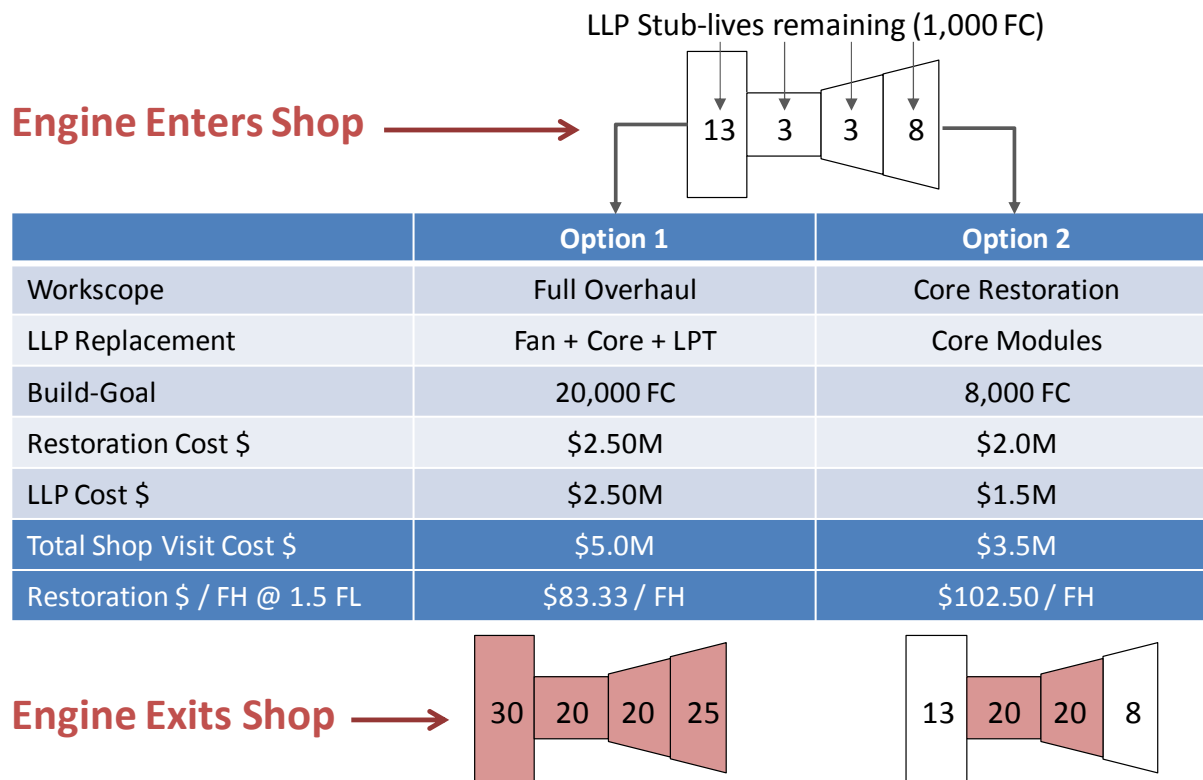


Figure 48. Example Engine Build-Goal Options



VII. Workscope Planning

Longer on-wing time leads to higher levels of wear and deterioration for engine internal piece parts, and thus higher degree of parts replacement. Increased time on-wing can therefore lead to higher average shop visit costs. A relationship therefore exists between time on-wing and cost per EFH. This generally takes the shape of a U-curve (**Figure 49**). The key to fine-tuning engine maintenance costs is knowing the U-curve characteristic of the engine, improving on-wing time and reducing the cost of the workscope for a corresponding removal interval.

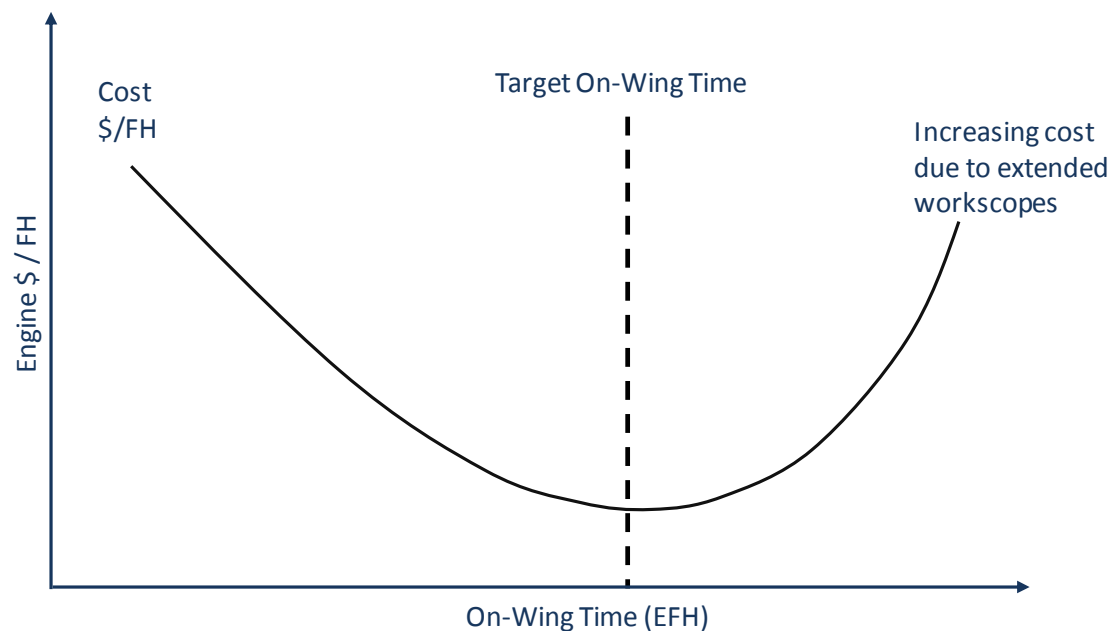


Figure 49. Influences Between TOW and Engine DMC



VIII. Borescope Inspection

Aircraft turbines are subject to ingested foreign object damage (FOD), corrosion, erosion, thermal deterioration, cracking, and distortion. Since the parts that are most vulnerable to damage are not readily available to unaided visual inspection, the only available method to determine the condition of a turbine is the use of a borescope. Areas of borescope inspection consist of:

- ▶ **Compressor** - access for a borescope is typically through the air inlet, a bleed port or specially designed borescope port. The last stages can often be accessed through an ignitor port. Leading and trailing edges of compressor blades and guide vanes are checked for foreign object damage (FOD) and erosion.
- ▶ **Combustion Chamber** - burner cans are checked for cracks, and misalignment. Fuel nozzles and other parts, including louvers are checked for excessive coking, cracking and distortion. Access is typically through and ignitor port.
- ▶ **Turbine Section** - the highest heat levels are in the first stage turbine. In this section, both the stationary nozzles and guide vanes are subject to burning and cracking, FOD, pitting, erosion and sulfidation. Second stage blades can be subject to shifting and rivet cracking. Access is typically through and ignitor port or specifically design borescope port.



IX. Commercial Considerations

Commercial considerations are often influenced based on where an engine is in its economic lifecycle – **Figure 50**.

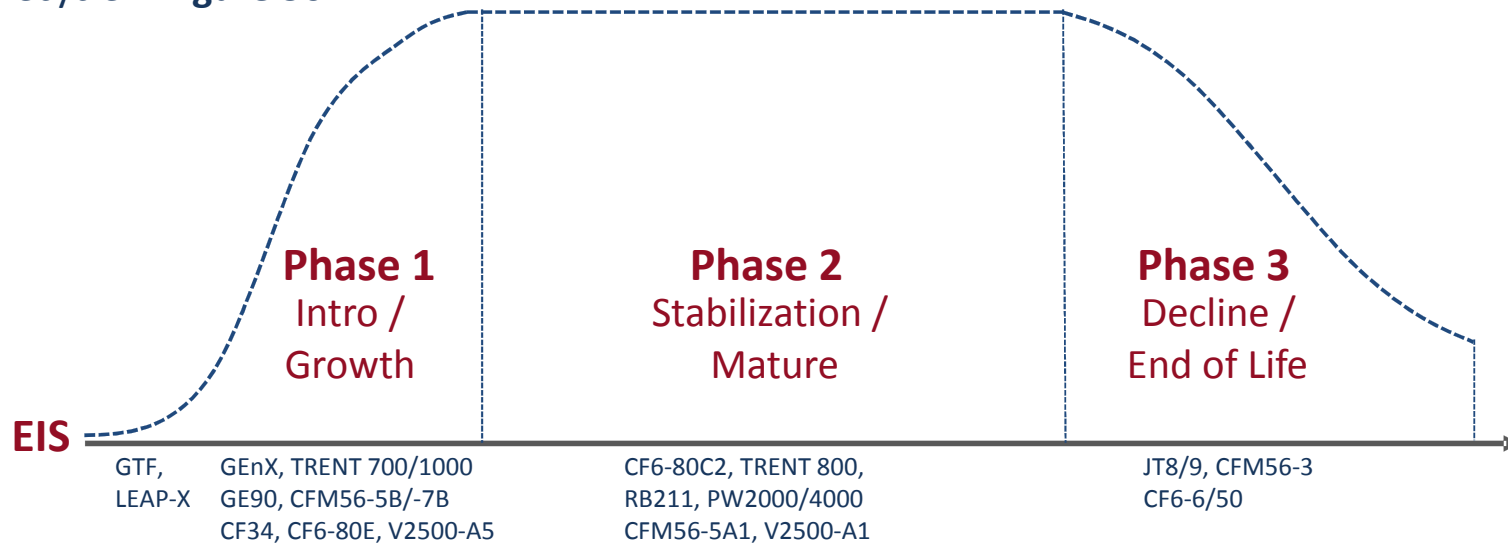


Figure 50. Engine Economic Lifecycle

- ▶ Entry Into Service (EIS) - engine first enters into service.
- ▶ Introduction / Growth Phase – engine gaining acceptance & orders are increasing,
- ▶ Stabilization / Mature Phase – engine sales are at a consistent, steady level.
- ▶ Decline / End of Life Phase - engine sales drop to a low level and are being sold for spare parts or scrap.



IX. Commercial Considerations

Management Considerations During Growth & Stabilization Phase

Goal : Preservation of asset values

Objective : Build to minimize shop DMC (\$ / FH)

- ▶ Use OEM parts & repairs
- ▶ Invest / benefit from latest SB modifications & technology
- ▶ Choose to replace parts over repair

Management Considerations During End of Life Phase

Goal : Preservation of cash

Objective : Build to minimize shop visit costs

- ▶ Maximizing usage of LLPs,
- ▶ Weigh benefits of purchasing green-time engines
- ▶ Weigh benefits of PMA parts and DER repairs



Section 4

Maintenance Reserves

- I. Maintenance Reserve Events
- II. Maintenance Reserve Data Sources
- III. Maintenance Reserve Payment Mechanisms
- IV. Maintenance Reserve Letter of Credit
- V. Use of Maintenance Reserves
- VI. Maintenance Reserve Accumulation
- VII. Maintenance Reserve Cost Sharing
- VIII. Maintenance Reserve Exposure



- ❑ **Maintenance reserves** are payments made by the lessee to the lessor to accrue for those scheduled major maintenance events that require significant aircraft grounding time and/or turn-around time for certain major component overhauls.
- ❑ The **contractual position** relating to maintenance reserve is always a subject of intense negotiation. Many airlines have sufficient credit stature that their prominence in the marketplace means they can reject paying maintenance reserves. On the other hand, lessors will show less flexibility for weaker credit lessees and require these operators to pay maintenance reserves.
- ❑ The **importance of maintenance reserves** to protecting asset value is a key consideration of lessors. In an ideal situation, the reserves plus the residual condition of select high cost maintenance events would essentially keep the economic condition of the aircraft whole.



I. Maintenance Reserve Events

A lease agreement will specify what maintenance events are to be covered through payment of reserves. Areas of maintenance covered by reserves account for 50%-60% of Total Direct Maintenance Costs, and consist of: a.) airframe heavy structural checks, b.) landing gear overhaul, c.) APU heavy repair, d.) engine performance restoration, e.) engine LLP replacements, and f.) thrust reverser overhaul (primarily widebody) – **Figure 51.**

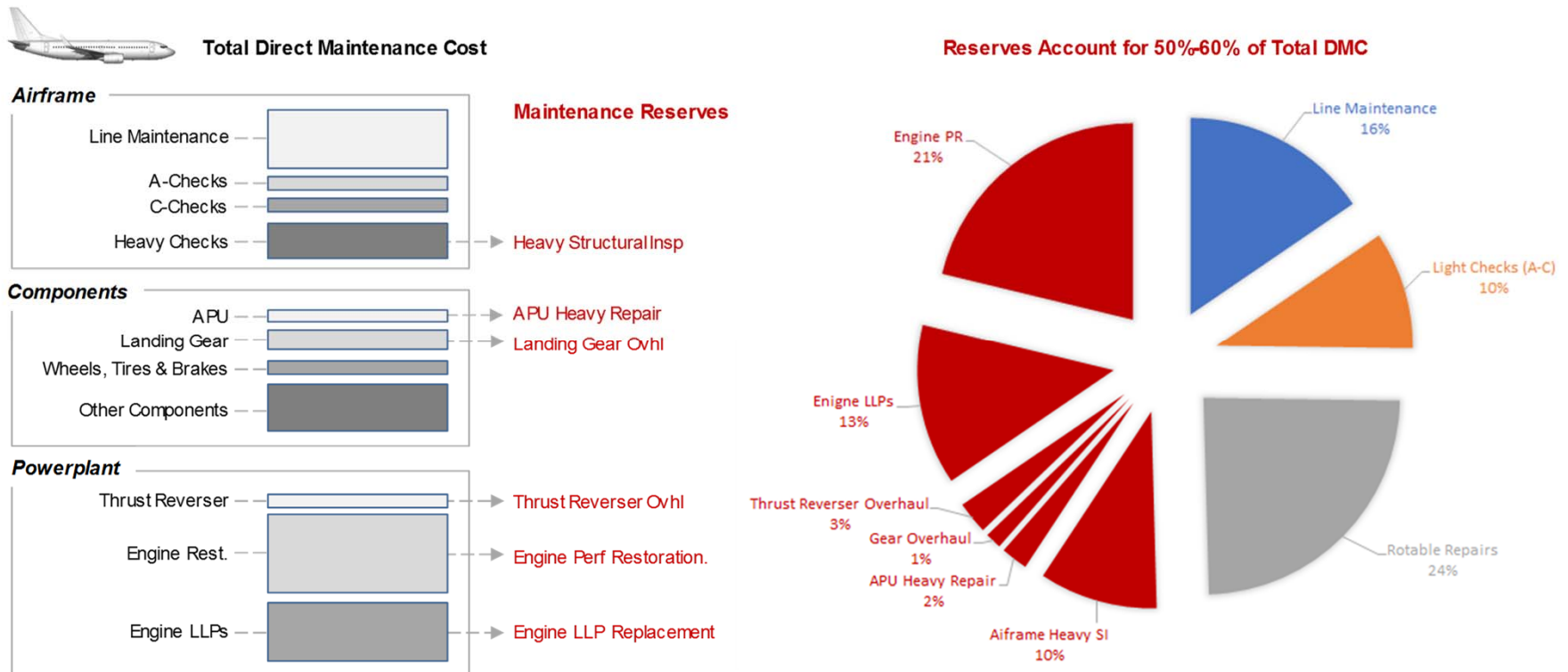


Figure 51. Maintenance Reserve Events

I. Maintenance Reserve Events



i. Airframe Heavy Structural Inspection (HSI):

- a. **Maintenance Process:** Hard-time
- b. **Equation:** Avg. HSI Cost / MPD Interval (Months)
- c. **Interval:** *Fixed* - typically every 6 – 12 years
- d. **Cost:** *Variable* - largely labor driven and generally includes costs affiliated with basic cabin refurbishment and paint
- e. **Downtime:** 15-30 days (narrowbody) and 30-45 days (widebody)
- f. **Scope of work:** Accomplishment of tasks affiliated with the Structural, Zonal, & Systems Maintenance Program and the rectification of any deficiencies resulting from performance of such tasks.
- g. **Charge Basis :** Usually charged on a “per-month” basis
- h. **Comment:** Costs can be difficult to project if aircraft is a new model



I. Maintenance Reserve Events

ii. Landing Gear Overhaul:

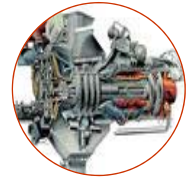


- a. **Maintenance Process:** Hard-time
- b. **Equation :** Avg. Gear Overhaul Cost / MPD Interval (Months or Flight Cycles)
- c. **Interval:** *Fixed* - defined in yearly & cyclic intervals (e.g. 10 years & 20,000 FC), whichever becomes more limiting
- d. **Cost:** *Variable* - largely labor driven and includes costs to overhaul & repair components, and often includes the exchange fee cost
- e. **Downtime :** 35-45 days (narrowbody gear) & 55-65 days (widebody gear)
- f. **Scope of Work:** Labor for complete teardown & rebuild, removal and/or prevention of corrosion, visual & NDT inspections, repair & overhaul of components
- g. **Charge Basis:** Usually charged either “per-month” or “per-cycle” basis depending on operator utilization
- h. **Comment:** Costs can be difficult to project if unit is a new model



I. Maintenance Reserve Events

iii. Auxiliary Power Unit (APU) Heavy Repair:



- a. **Maintenance Process:** On-condition
- b. **Equation :** Avg. Heavy Repair Cost / Mean-Time Between Heavy Repair (APU FH)
- c. **Interval:** *Variable* - removal intervals influenced by cycles, area of operation, and maturity (first-run vs. mature-run).
- d. **Cost:** *Variable* - largely material driven through repair & replacement of piece parts and, where applicable, LLPs. Piece part escalation a significant contributing factor.
- e. **Downtime:** 30-60 days
- f. **Scope of Work:** Repair & restoration of the power section, load impeller & gearbox modules.
- g. **Charge Basis:** Charged on a “per-APU FH” basis for heavy repair and, where applicable, “per-cycle” basis for LLP replacement.
- h. **Comment:** Both costs and timing heavily influenced by operation, and often difficult to quantify if APU model is new.

I. Maintenance Reserve Events



iv. Engine Performance Restoration:

- a. **Maintenance Process:** On-condition
- b. **Equation** : Avg. Performance Restoration Cost / Mean-Time On-Wing Between Performance Restoration (FH)
- c. **Interval:** *Variable* - removal intervals influenced by operational factors (flight leg, thrust, derate, environment) and maturity
- d. **Cost:** *Variable* - Largely material driven through repair & replacement of parts. Piece part escalation a significant contributing factor. Engine thrust, operational profile and area of operation also impacts PR costs.
- e. **Downtime:** 90-120 days
- f. **Scope of Work:** Performance restoration of an engine's major modules (e.g. fan/booster, high pressure compressor, high pressure turbine, combustor, low pressure turbine).
- g. **Charge Basis:** Charged on a "per-engine FH" basis.
- h. **Comment:** Engine PR costs and timing heavily influenced by age & operation, and often difficult to quantify if engine model is new.

I. Maintenance Reserve Events

v. Replacement of Engine Life-Limited Parts:



- a. **Maintenance Process:** Hard-time
- b. **Equation :** $\text{OEM Published LLP Cost} / \text{OEM Published Cycle Interval (FC)}$
- c. **Interval:** *Fixed* – governed by life limits published in Chapter 5 of the OEM shop manual
- d. **Cost:** *Fixed* – derived from manufacturer’s catalog prices. LLP escalation a significant contributing factor.
- e. **Downtime:** Coinciding with engine performance restoration – 90-120 days
- f. **Scope of Work:** Replacement of LLPs
- g. **Charge Basis:** Charged on a “per-cycle” basis
- h. **Comment:** Some manufacturers certify ultimate lives of LLPs at the time they certify an engine model. Other manufacturers certify the lives as experience is accumulated. In these scenarios, ultimate lives are reached after one or several life extensions.

I. Maintenance Reserve Events

vi. Thrust Reverser Overhaul (*primarily widebodies*):



- a. **Maintenance Process:** On-condition
- b. **Equation :** Avg. Overhaul Cost / Avg. Time On-Wing Between Overhaul (FH)
- c. **Interval:** *Variable* - influenced by accumulated FH & FC
- d. **Cost:** *Variable* - largely labor driven and includes costs to overhaul & repair components
- e. **Downtime:** 40-60 days
- f. **Scope of Work:** Labor for complete teardown & rebuild, removal and/or prevention of corrosion, visual & NDT inspections, delamination & dis-bonding repair, and repair & overhaul of components
- g. **Charge Basis:** Usually charged on either “per-month” or “per-flight hour” basis depending on operator utilization
- h. **Comment:** Costs can be difficult to project if unit is a new model



II. Maintenance Reserve Data Sources

There are numerous sources used to derive maintenance reserves. The more popular come from:

- ▶ Maintenance Reserve Invoice Claims
- ▶ Maintenance Repair & Overhaul Centers (MROs) Quotes
- ▶ Competitor Reserve Rates
- ▶ Aviation Journals (e.g. Aircraft Commerce)
- ▶ Original Equipment Manufacturers (OEM) Handbooks & Calculators



Figure 52. Example Derivation of Narrowbody APU Reserves



II. Maintenance Reserve Data Sources

Challenges are encountered when predicting costs and on-condition intervals for **new equipment that have no documented maintenance history**. If reserves are to be collected monthly in arrears then the most convenient methods for developing reserve rates consists of either basing them on manufacturers' recommendations or **using comparable maintenance costs** from competing alternatives - see **Figure 53** illustrating GE90X mature shop visit costs based on comparable engines.

Engine	PW 4098	GE94-94B	Trent 895	GE90-110	GE90X
Rating (lbs.) :	97,900	93,700	95,000	110,000	95,000
Aircraft :	777-300	777-300	777-200ER	777-200LR/F	777-9X
Avg. Mature SV Cost (\$M) :	\$12.3M - \$12.8M	\$11.7M - \$12.2M	\$12.0M - \$13.5M	\$13.0M - \$13.5M	\$12.2M - \$12.7M
Avg. Mature Time On-Wing (FH) :	15,000 – 17,000	17,000 – 19,000	16,000 – 18,000	16,000 – 18,000	16,500 – 18,500
Avg. Mature SV Rate (\$/FH) :	730 - 780	700 - 750	720 - 770	760 - 810	700 - 750

Figure 53. Example Use of Comparable Maintenance Cost



III. Maintenance Reserve Payment Mechanisms

There are two principle mechanisms that lessees use to pay lessors for maintenance utility:

- i. Cash Maintenance Reserve Payments; or
 - ii. End of Lease Adjustments
-
- i. **Cash Maintenance Reserve Payments.** These are payments made on a regular, usually monthly, basis by the lessee to the lessor, and are generally based upon the aircraft type and actual utilization. Therefore, at the time an aircraft is taken out of service for maintenance, the lessor should have funds to reimburse lessee to cover the cost of major maintenance events. In the event of default by lessee, the assumption is that the lessor would generally not incur any shortfall exposure.
 - ii. **End of Lease Adjustments.** This option would expose a lessor to a greater risk of incurring maintenance costs and is thus usually only offered to better quality credits or airlines that have demonstrated a good track record of payment. There are **two types of end-of-lease payment structures** consisting of:
 1. Upsy; and
 2. Upsy-Downsy



III. Maintenance Reserve Payment Mechanisms

1. **Upsy** – A payment whereby the lessor receives payment for time used since last overhaul or since new (typical of new aircraft transactions).
2. **Upsy / Downsy** – An adjustment can either be one-way, where the Lessee is required to pay an adjustment when a certain maintenance event is returned with less time remaining than at delivery, or an adjustment whereby lessor may have to pay the lessee if a certain maintenance event is returned in better condition than at delivery (typical of used aircraft transactions)



IV. Maintenance Reserve Letter of Credit

In some leases, the lessee may have the option, rather than paying cash reserves, to provide the lessor with a **Maintenance Reserve Letter of Credit (MRLC)** in an amount equal to an agreed projected aggregate notional value of maintenance reserves.

While this approach can reduce the immediate cash flow impact of paying monthly reserves, the benefit to the lessee needs to be offset against:

- ▶ The administrative burden associated with annual reconciliation, monitoring of bank credits, storage of physical forms, etc.;
- ▶ The corresponding reduction to the Lessor's cash-flow;
- ▶ The "drawdown risk" associated with MRLCs;
- ▶ Bank fees payable for transfers of MRLCs upon sale, and;
- ▶ Less attractive for sale as less upfront cash to buyer.



IV. Maintenance Reserve Letter of Credit

The MRLC amount is typically **“forward projected”**, based on the estimated utilization of the aircraft over an agreed period (e.g. 6 or 12 months). At the end of this period the parties will:

1. Carry out a reconciliation of the estimated utilization against actual utilization,
2. Account for any maintenance events which have occurred, and
3. Provide a new or revised MRLC in an amount equal to the “actual” reserve amount for the previous period plus the projected aggregate notional value of maintenance reserves over the next reconciliation period.

The MRLC amount can also reflect a **“capped amount”** based on the projected maximum exposure during the lease. General requirements for an MRLC:

- ▶ Be denominated in and payable in Dollars.
- ▶ Be a first demand, irrevocable and absolute payment undertaking of the issuing bank payable on written demand without proof or evidence of entitlement or loss required;
- ▶ Be issued or confirmed and payable by a first-class international bank



V. Use of Maintenance Reserves

The workscope and estimated cost of each maintenance reserve event shall be agreed by lessor and lessee prior to the commencement of any work. Lessor shall be entitled to observe such work and shall be provided with copies of pertinent documents. In general, reimbursement will be made up to the amount in the reserve account at the time of the maintenance event and no reimbursement shall be made for any material markup, outside vendor fees, handling fees, packaging and shipping charges.

In order to be eligible for reserve reimbursement many lessors require that lessees perform each qualifying maintenance event with an **Approved Maintenance Performer**. Approved Maintenance Performer means:

- i. for all major checks, repairs and maintenance (including any shop visit for an Engine or the APU, any Landing Gear Overhaul) and all Major Modifications, any maintenance facility approved by (a) the Aviation Authority and (b) either EASA or the FAA or,
- ii. for all lower level checks, repairs and maintenance, any maintenance facility approved by the Aviation Authority which, provided Lessee has the requisite licenses and approvals, may be Lessee.



V. Use of Maintenance Reserves

Maintenance reserves will be available for reimbursement against the cost of prescribed events, and reimbursement will be subject to certain exclusions agreed in the lease. The exclusions usually relate to items which are not directly related to the time or materials cost of the eligible maintenance or replacement part and which were not factored into the cost assumption for the relevant event.

Examples of Exclusions:

- ▶ For any repair overhaul or inspection caused by foreign object damage (FOD),
- ▶ Work performed for Airworthiness Directives (ADs) , Manufacturer's Service Bulletins (SBs) and Service Information Letters (SILs),
- ▶ Cabin and Systems Modifications,
- ▶ Repair of damage from accidental cause, improper operation, improper maintenance, misuse or abuse.



V. Use of Maintenance Reserves

The applicable maintenance reserve areas are discussed as follows:

- 1. Airframe Reserves** - Lessor will reimburse lessee from the Airframe Reserves for the actual cost of performing those tasks affiliated with the Structural, Zonal, & Systems Maintenance Programs and the rectification of any deficiencies resulting from performance of such tasks.
- 2. Landing Gear Overhaul Reserves** - Lessor will reimburse lessee from the Landing Gear Reserves for the actual cost of a Landing Gear Overhaul, which means an overhaul of a Landing Gear assembly in accordance with the Manufacturer's repair manual that restores such Landing Gear to a "**zero time-since overhaul**" condition in accordance with the Manufacturer's repair manual and is performed in accordance with the Manufacturer's overhaul specifications and operating criteria.

V. Use of Maintenance Reserves

- 3. Engine Performance Restoration Reserves** - Lessor will reimburse Lessee from the Engine Performance Restoration Reserves for the actual cost associated with a qualified performance restoration or permanent repair of on-condition parts in the basic engine during completed engine shop visits. Repair, overhaul or replacement of thrust reversers and non-modular components, such as Quick Engine Change (QEC) units, Line Replaceable Units (LRUs) or accessory units is not eligible for reimbursement from Engine reserves. Reimbursement from the Engine Performance Restoration Reserves **will be limited to each module of such Engine** in accordance with industry standard cost allocations – example cost allocation is illustrated in **Figure 54**.

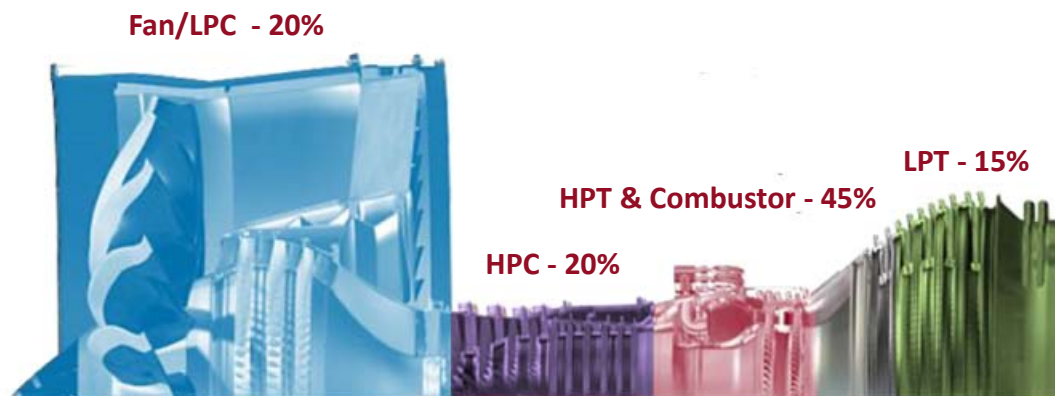


Figure 54. Example Engine Module Cost Allocation

V. Use of Maintenance Reserves

4. **Engine LLP Reserves** - Lessor will reimburse Lessee from the Engine LLP Reserves for the out-of-pocket materials cost without overhead, mark-up or profit factor associated with the replacement of life-limited parts in such engine during completed engine shop visits requiring off-wing teardown and/or disassembly. Most lessors will require that such replacement LLP parts are new, with zero-time status

5. **APU Heavy Repair Reserves** - Lessor will reimburse Lessee from the APU Reserves for the actual cost of a completed APU Heavy Repair, where Heavy repair means, at a minimum, complete disassembly of the power section and load compressor modules (**Figure 55**) according to the Manufacturer's then current full gas path overhaul criteria in order to restore full service release life for such modules.

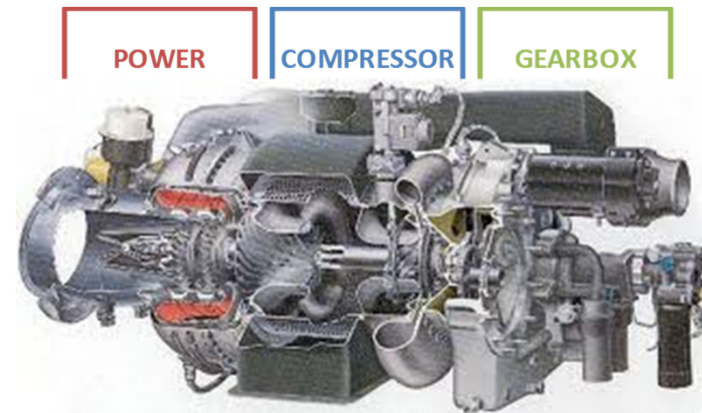


Figure 55. Typical APU Modules



VI. Maintenance Reserve Accumulation

Maintenance reserves accumulate, in relation to a specified future maintenance event for a particular item of equipment, and can usually be accessed to cover the cost of that event when it occurs, whether during the present lease term, in which case the Lessee would seek reimbursement from the relevant reserve account for qualifying maintenance, or during a future lease term with another operator, where maintenance reserves paid by a previous Lessee and held by Lessor might translate to a corresponding Lessor contribution. **Figure 56** illustrates the accumulation of reserves for an A320's 6-year and 12-year structural check.

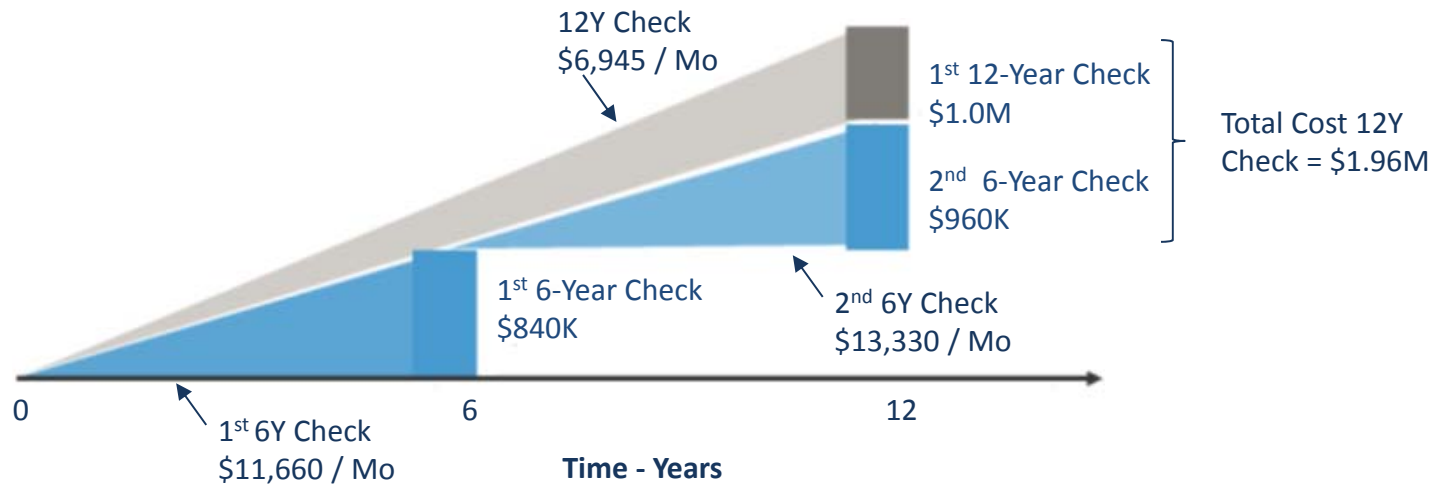


Figure 56. Reserve Accumulation for A320 6Y and 12Y Heavy Structural Checks (*no escalation*)



VI. Maintenance Reserve Accumulation

Example : Maintenance reserve cash flows for an A320 aircraft under a 12-year term where maintenance events have been appropriately reserved for.

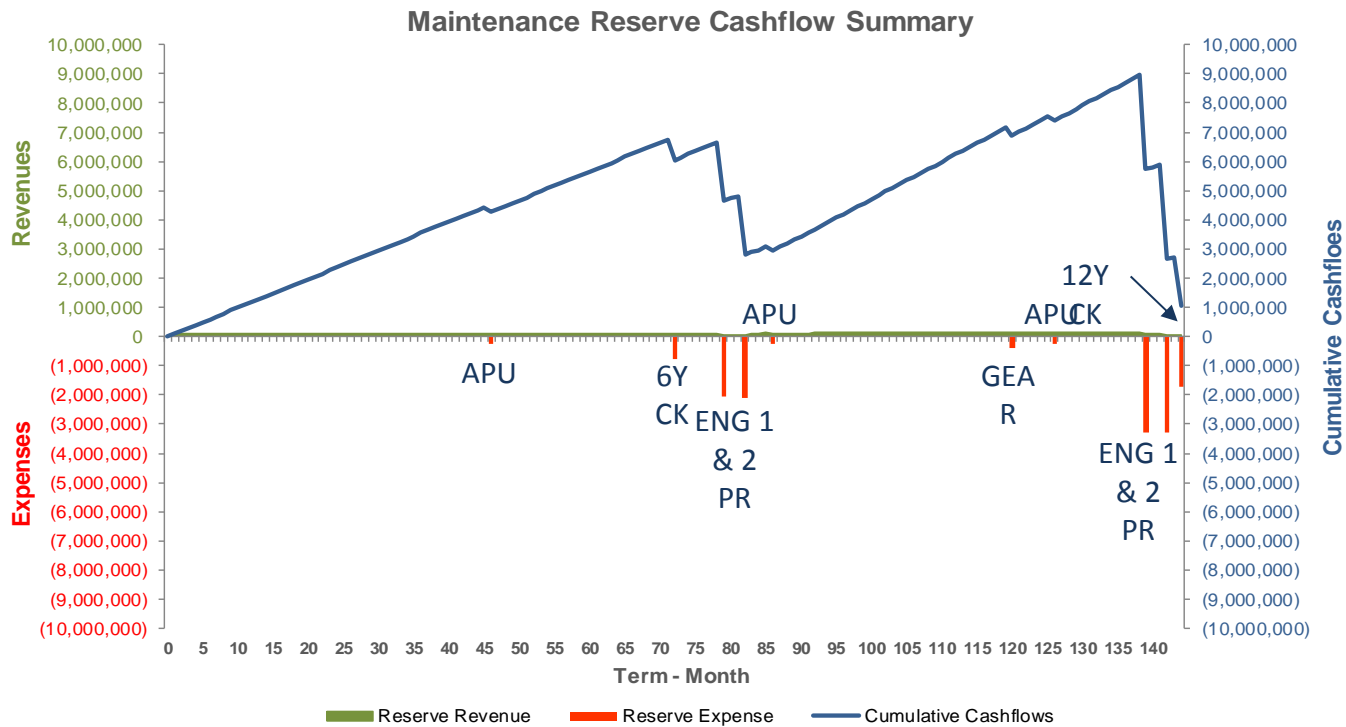


Figure 57. Example Maintenance Reserve Cash Flow Inflows & Outflows



VII. Maintenance Reserve Cost Sharing

In the case of an aircraft that was previously operated by a lessee, the reserve balance at the end of the lease term will represent the lessor's pro-rata fund, which will be allocated towards future contributions with subsequent lessee(s). On this basis, the cost of such an event will be distributed pro-rata over the interval to the various lessees. One method to estimate pro-rata contributions is to apportion the cost of a maintenance consumed by both the previous lessee and subsequent lessee. **Figure 58** illustrates the allocation of costs for an A320's 6Y and 12Y structural checks based on the apportionment of lessee pro-rata intervals.

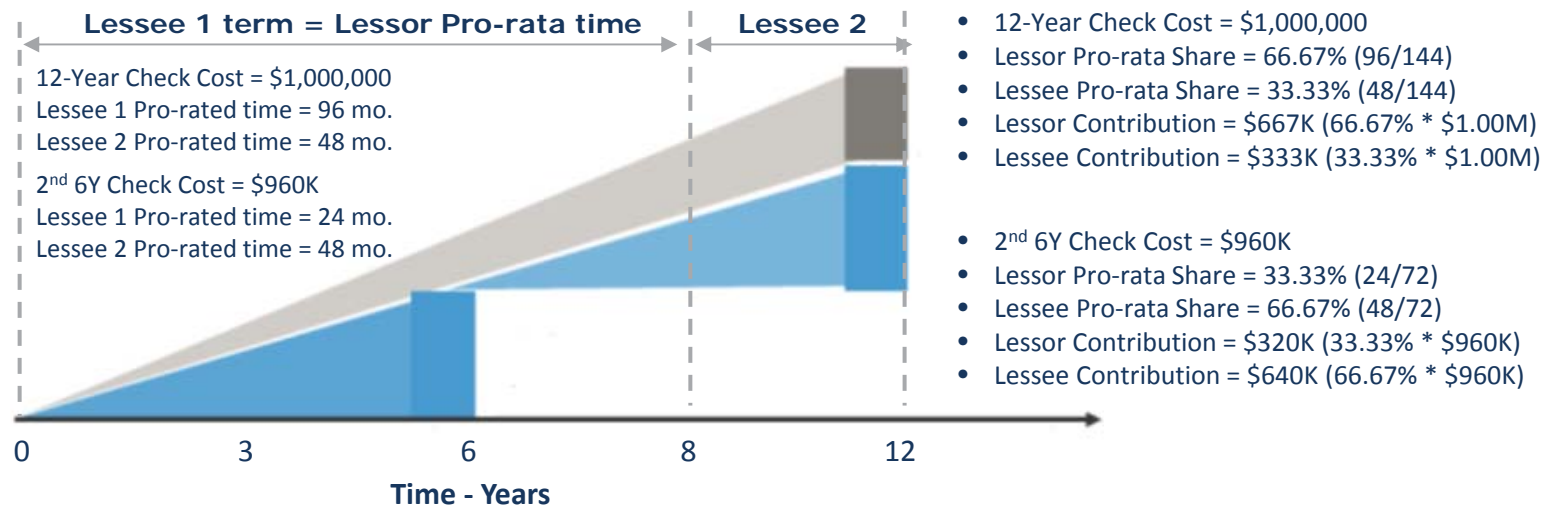


Figure 58. Pro-rata contribution for the A320, 12Y Heavy Structural Check



VIII. Maintenance Reserve Exposure

If maintenance reserves are either not collected, subject to a redelivery payment scheme, or are under-funded, than the lessor will be subject to maintenance exposure. In monetary terms, maintenance exposure equals the **value of maintenance utility consumed less the value of maintenance reserves** collected at a particular point in time.

Example: maintenance exposure for an A320 aircraft following an event of default at year four since entry into service; the unfunded maintenance exposure of the aircraft would total approximately \$6.61M, which lessor would have to pay from internal sources.

Aircraft	Interval	Consumed	Remaining	Full-Life \$	Residual \$	Consumed \$	Reserve \$	Exposure\$
6Y SC CK	72 Mo	48 Mo	24 Mo	\$960K	\$320K	\$640K	0	(\$640K)
12Y SC CK	144 Mo	48 Mo	96 Mo	\$1.00M	\$667K	\$333K	0	(\$333K)
Gear Ovhl	120 Mo	48 Mo	24 Mo	\$460K	\$276K	\$184K	0	(\$184K)
Engine 1 PR	26,000 FH	13,000 FH	13,000 FH	\$3.2M	\$1.6M	\$1.6M	0	(\$1.6M)
Engine 2 PR	26,000 FH	13,000 FH	13,000 FH	\$3.2M	\$1.6M	\$1.6M	0	(\$1.6M)
Engine 1 LLP	20,000 FC	6,500 FC	13,500 FC	\$3.6M	\$2.6M	\$1.0M	0	(\$1.0M)
Engine 2 LLP	20,000 FC	6,500 FC	13,500 FC	\$3.6M	\$2.6M	\$1.0M	0	(\$1.0M)
APU Ovhl	8,000 APU FH	6,000 APU FH	2,000 APU FH	\$325K	\$75K	\$250K	0	(\$250K)
Totals :				\$16.35M	\$9.74M	\$6.61M	\$0	(\$6.61M)

Figure 59. Example Maintenance Reserve Exposure Analysis



VIII. Maintenance Reserve Exposure

Example : An event of default under Lessee 1 occurring at year four where no reserves were collected, followed by an 8-year lease with Lessee 2 where maintenance events have been appropriately reserved for.

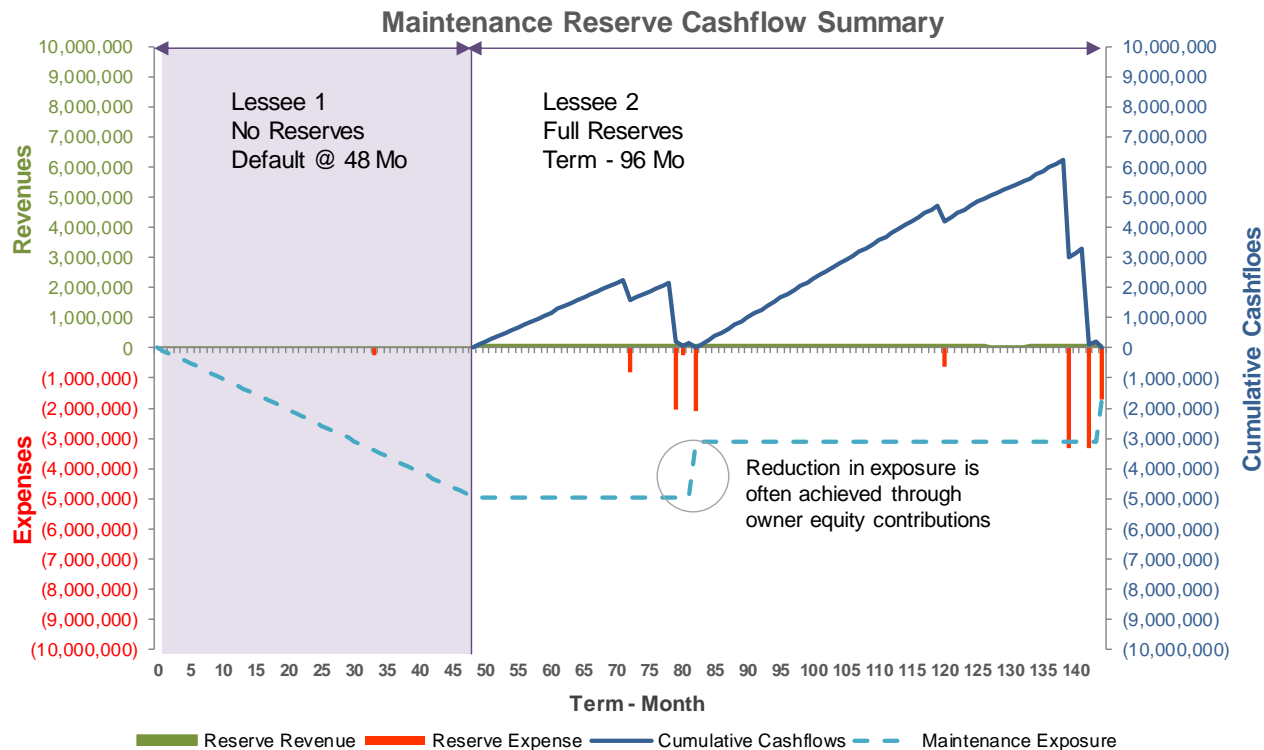


Figure 60. Example Maintenance Reserve Default Exposure Cash Flow Analysis



Section 5

Factors Affecting Maintenance Reserves

- I. Airframe Heavy Structural Check
- II. Landing Gear Overhaul
- III. Engine Performance Restoration
- IV. Engine Life-Limited Parts
- V. APU Heavy Repair
- VI. Thrust Reverser Overhaul

5.0 Factors Affecting Maintenance Reserves



- ❑ The greatest challenge of deriving maintenance reserve rates is attempting to predict the costs, and on-condition intervals, of maintenance events and fairly spreading these costs to both lessor and lessee. In theory it sounds simple, however the uncertainty in predicting both costs and on-condition intervals can lead to all kinds of difficulties, particularly with new equipment that has no documented maintenance history.
- ❑ Each major maintenance event costs, and time on-wing performance, are influenced by a range of factors. A summary of factors affecting each major maintenance event are detailed in **Figure 61** below and further explained in this section.

Mx Event	Factors Affecting Cost & Time On-Wing
Airframe Heavy Structural Inspection	Prevailing labor rates, maintenance phase (initial, aging), time between structural inspections, packaging of tasks
Landing Gear Overhaul	Size & complexity, time between overhaul, maintenance phase (initial, aging), cost of exchange fee, operation (accumulation of flight cycles), market penetration of repair centers support the gear
APU Overhaul	Overhaul phase (first or mature), region of operation, workscope
Engine Performance Restoration	Restoration phase (first or mature), flight leg, engine thrust & derate, region of operation, workscope
Engine Life-Limited Parts (LLPs)	OEM escalation, life-limits (current vs. target), stub factor, flight leg (accumulation of flight cycles)
Thrust Reverser Overhaul	Overhaul phase (first or mature), complexity of reversers

Figure 61. Summary of Factors Affecting Maintenance Reserves



I. Airframe Heavy Structural Inspection



Airframe HSI costs and timing of events are influenced by:

- a. **Material:** From a maintenance perspective, composites have a far better resistance than aluminum to fatigue (or the formation of cracks) and they do not corrode. These properties produce immediate benefits when it comes to the number and frequency of inspections that have to be performed on an aircraft.
- b. **Time Between Structural Inspection:** MPD inspection intervals for corrosion and zonal tasks are used to assess optimal timing of structural inspection intervals. Most commercial aircraft time such events every 6-12 years.
- c. **Packaging of Tasks:** The MPD outlines the tasks used to build a customized airframe maintenance program. The routine maintenance tasks, and the rectification of any deficiencies resulting from performance of such tasks, forms the basis for the qualifying scope of work that is used to quantify airframe maintenance reserves.
- d. **Maintenance Phase:** As an airframe ages its maintenance costs increases, primarily due to higher levels of man-hours & material required to rectify deficiencies resulting from performance of routine maintenance tasks. Airframe HSI reserves are thus adjusted to account for the phase of an airframe's age.



I. Airframe Heavy Structural Inspection

Example : Heavy Structural Inspection Calculation



- ▶ HSI Interval : 1st HSI = (108 Mo) , 2nd HSI (72 Mo) , 3rd HSI (72 Mo)
- ▶ HSI Cost : 9-Year = \$850K, 15-Year = \$1.2M, & 21-Year = \$1.5M
- ▶ Reserve Rate = HSI Cost (\$) / HSI Interval (Months)

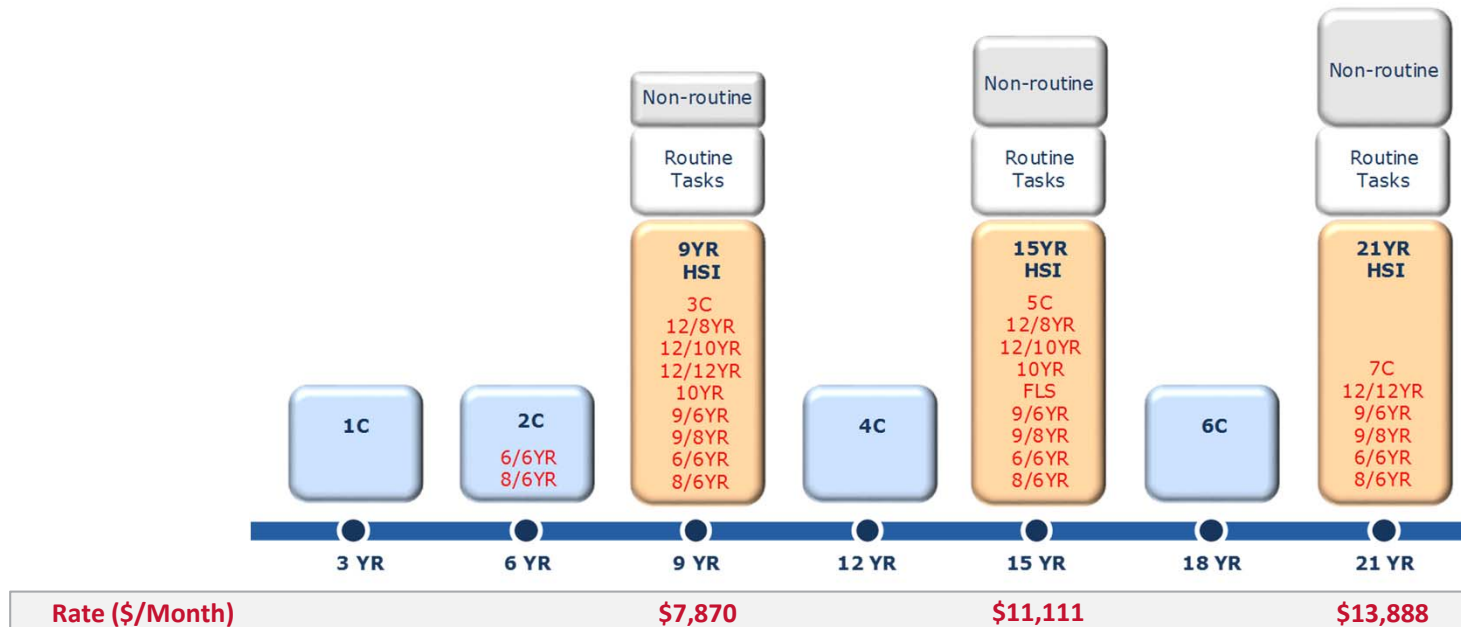


Figure 62. Calculation of Airframe HSI Reserve Rates Based on Packaging of Tasks and Changes in Aircraft Age



II. Landing Gear Overhaul



Landing gear overhaul costs and timing of events are influenced by:

- a. **Size & Complexity:** Number of parts to inspect, repair and/or replace. Number of modifications to incorporate
- b. **Time Between Overhaul:** MPD overhaul intervals for landing gears are generally calendar & cyclic limited, and for most models are in the region of 10-12 years and 18,000-21,000 flight cycles. The timing of when the overhaul occurs is based on which of the above MPD intervals is more limiting (i.e. calendar time or cycles).
- c. **Maintenance Phase:** Corrosion and metal fatigue increases markedly after the first 8-12 years of operation. Costs will subsequently increase after the first overhaul.
- d. **Exchange fee:** Most airlines outsource their landing gear overhauls. Often times the repair center performing the overhaul will exchange the timed-out unit with a zero-timed unit. The cost for such exchange unit will account for an exchange fee, which is added to the cost of overhaul. Exchange fees can range from \$40K - \$80K for narrowbody gears and from \$150K - \$250K for widebody gears.



II. Landing Gear Overhaul



Example: Landing Gear Reserve Computation

The following illustrates the derivation of landing gear reserve rates based on changes in aircraft utilization assuming:

- ▶ Overhaul Intervals : 120 Months & 20,000 FC, *whichever is more limiting*
- ▶ Overhaul Cost : \$420,00 (*inclusive of exchange fee*)
- ▶ Reserve Rate = Cost (\$) / Overhaul Interval (Months)

Operator	Utilization	Ratio	Cyclic Limiter ¹	Calendar Limiter	Overhaul Limiter	Reserve Rate
A	3,500 FH / 1,500 FC	2.30	160 Mo	120 Months	120 Months	\$3,500 / Month
B	3,500 FH / 2,000 FC	1.75	120 Mo	120 Months	120 Months	\$3,500 / Month
C	3,500 FH / 2,500 FC	1.40	96 Mo	120 Months	96 Months	\$4,375 / Month
D	3,500 FH / 3,000 FC	1.12	80 Mo	120 Months	80 Months	\$5,250 / Month

1 – Computed by dividing the gear cycle limiter (20,000 FC) by operator cyclic utilization

Figure 63. Example Landing Gear Reserve Rates Calculations Accounting for Changes in Aircraft Utilization



III. Auxiliary Power Unit (APU) Heavy Repair

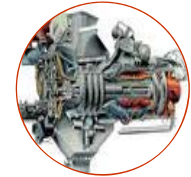


APU Heavy Repair costs & time on-wing performance are influenced by:

- a. **Performance Degradation Factors:** APU's are on-condition components subject to the following performance degradation factors impacting cost and average time on-wing:
 - ▶ **Flight Operation:** APU average time on-wing is sensitive to APU cycles; the greater the cyclic operation, the greater wear & tear on internal hardware, which leads to lower the time on-wing performance;
 - ▶ **Maintenance Phase:** The time to first removal is typically the longest. Subsequent runs and time on-wing performance reduces as the APU ages.
 - ▶ **Environment:** Operation in hot & erosive/corrosive environments leads to greater performance degradation, and lower time on-wing
- b. **Workscope:** APUs have a modular construction, general made up of: a.) Power section, b.) Load compressor, and c.) Gearbox. At a minimum, a qualifying workscope will generally require complete disassembly of the power section and load compressor. Effective APU workscooping requires consideration of the following:
 - ▶ Reason for removal and work accomplished at last shop visit
 - ▶ APU hours since last shop visit and since last Heavy Repair



III. Auxiliary Power Unit (APU) Heavy Repair



Example: APU Heavy Repair Reserve Computation:

The following illustrates the derivation of APU reserve rates based on maturity status:

- Mean-Time Between Removal (MTBR): 8,200 APU FH (Initial) / 6,900 APU (Mature)
- Average Heavy Repair Cost : \$300,000 (Initial) , \$325,000 (Mature)
- Reserve Rate = Heavy Repair Cost (\$) / MTBR (APU FH)

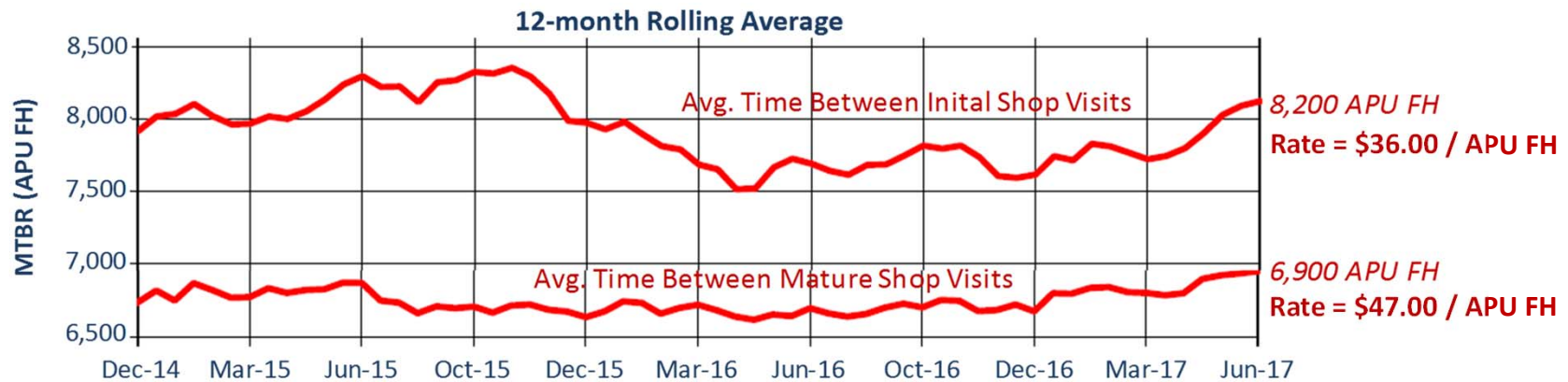


Figure 64. Example Initial and Mature APU Overhaul Reserve Rate Calculation



IV. Engine Performance Restoration

Engine performance restoration costs & time on-wing performance are influenced by:



a. Engine Performance Degradation (EGT Margin Erosion)

- i. Engine Thrust Rating,
- ii. Flight Operation
 - ▶ Flight Leg;
 - ▶ Average Thrust Derate;
 - ▶ Ambient Temperatures
 - ▶ Operating Environment;
- iii. Age (first-run vs. mature-run)

b. Engine Workscope Planning



IV. Engine Performance Restoration



a. Engine Performance Degradation :

i. Engine Thrust Rating

For a given engine variant, EGT margin deteriorates faster when operating at higher thrust levels – see **Figure 63**. Higher thrust generates higher core temperatures, which exposes constituent parts in the engine to greater thermal stress. Reducing thrust will: a.) Slow EGT deterioration, b.) Reduces fuel-flow and c.) Lowers maintenance costs by increasing time between shop visits.

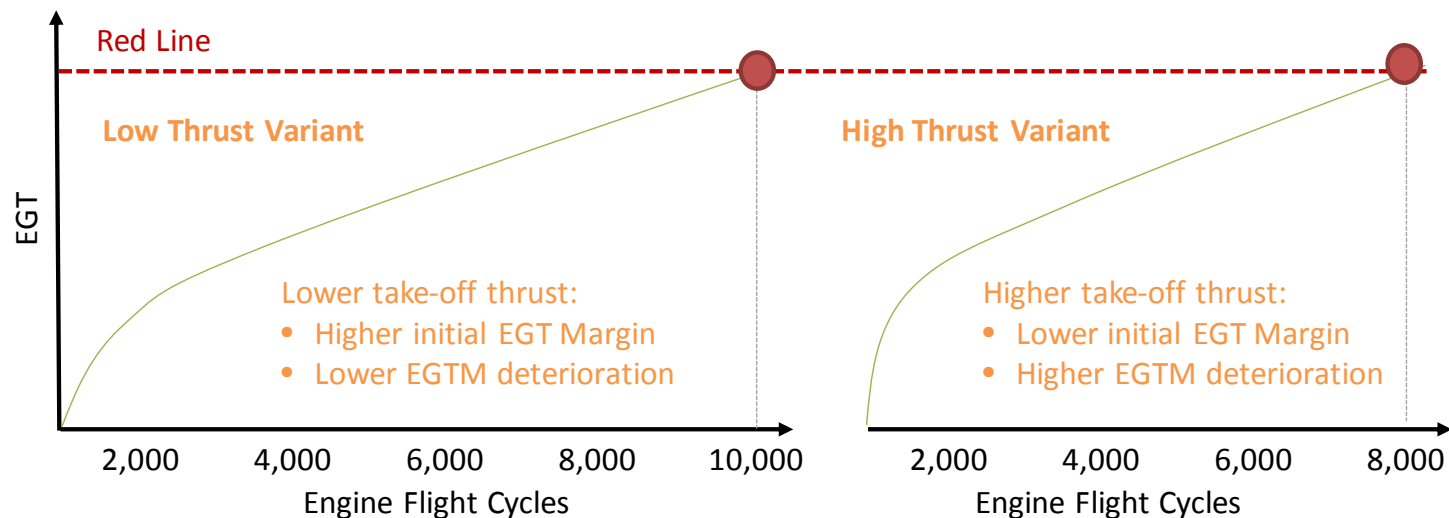


Figure 65. Effect of Thrust on Engine Time On-Wing



IV. Engine Performance Restoration

a. Engine Performance Degradation :

ii. Engine Flight Operation

▶ Average Flight Leg Definition



The flight profile of an aircraft can be expressed by the flight-hour to flight-cycle ratio (FH:FC), also known as the **flight leg length** – **Figure 66**.

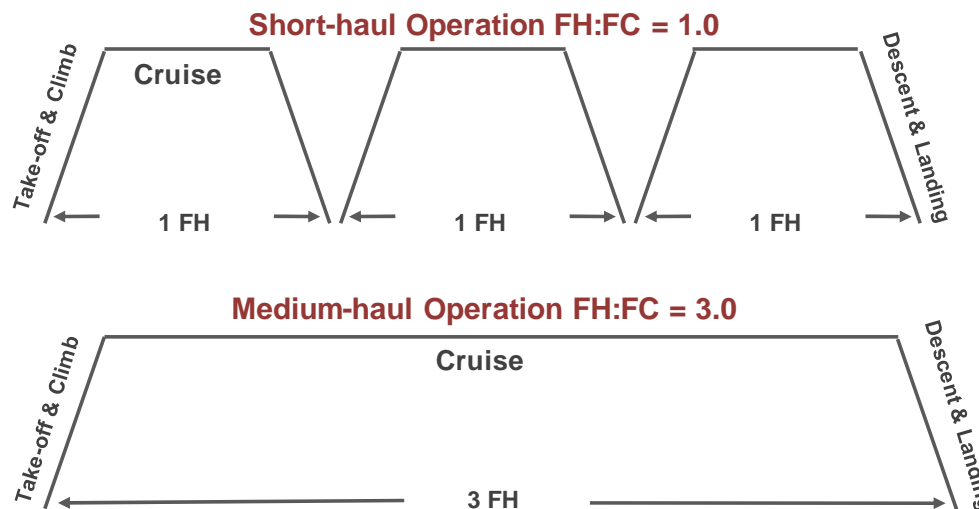


Figure 66. Example Flight Profiles

IV. Engine Performance Restoration

a. Engine Performance Degradation :

ii. Engine Flight Operation

▶ Average Flight Leg

As the flight length reduces an engine spends a larger proportion of total flight time using take-off and climb power settings. In most instances the effect of shorter stage length operation is more rapid performance deterioration leading to greater direct maintenance cost per flight hour while longer flight legs equates to higher time on-wing (TOW) & lower Direct Maintenance Costs (DMC) – **Figure 67**.

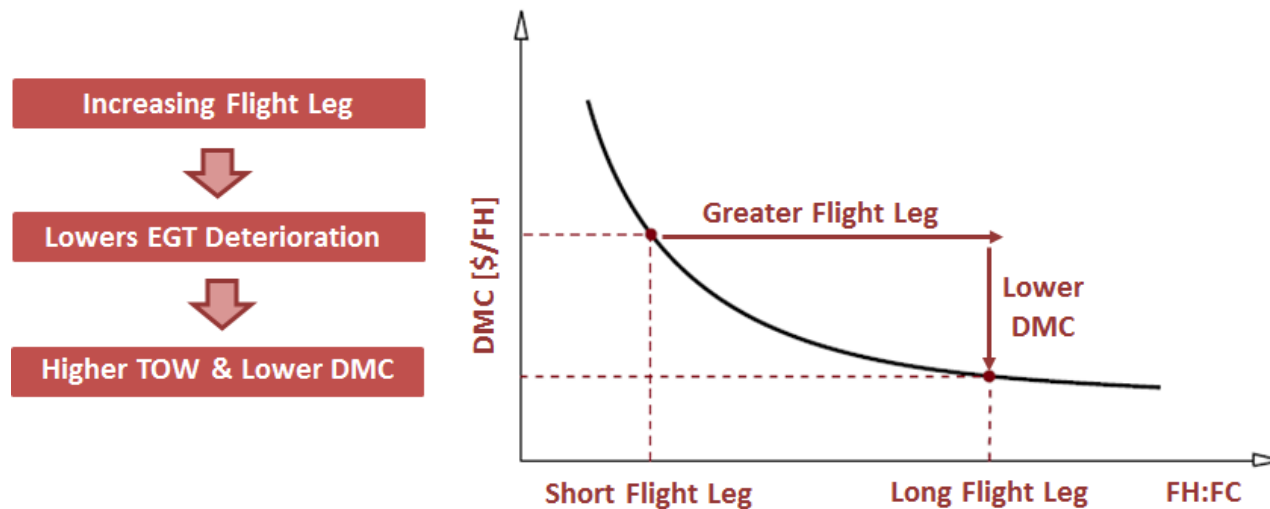


Figure 67. Effect of Flight Leg on Engine DMC



IV. Engine Performance Restoration

a. Engine Performance Degradation :

ii. Engine Flight Operation

▶ Average Thrust Derate



The take-off derate thrust is a takeoff thrust setting that is below the maximum thrust level; a derate selection electronically reduces the rated thrust of the engine to either one or more pre-specified values or by a selectable percentage of the normal flat rated thrust. Larger derate translates into lower take-off EGT and lower engine deterioration rates, longer on-wing life & reduced direct maintenance cost, while lower derate generates higher core temperatures, which exposes constituent parts in the engine to greater thermal stress – **Figure 68**.

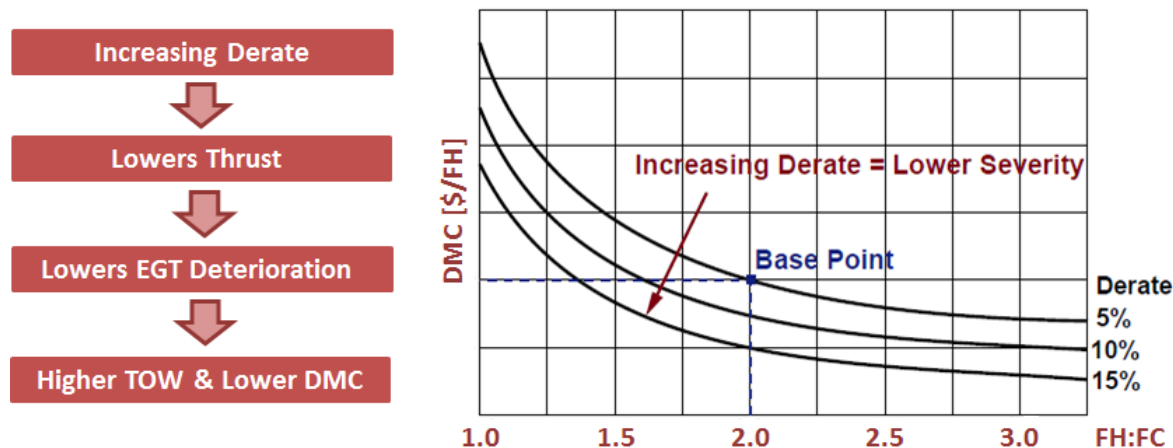


Figure 68. Effect of Derate on Engine DMC



IV. Engine Performance Restoration

a. Engine Performance Degradation :



Example: Figure 69 - Engine Reserves Accounting for Flight-Leg & Engine Derate

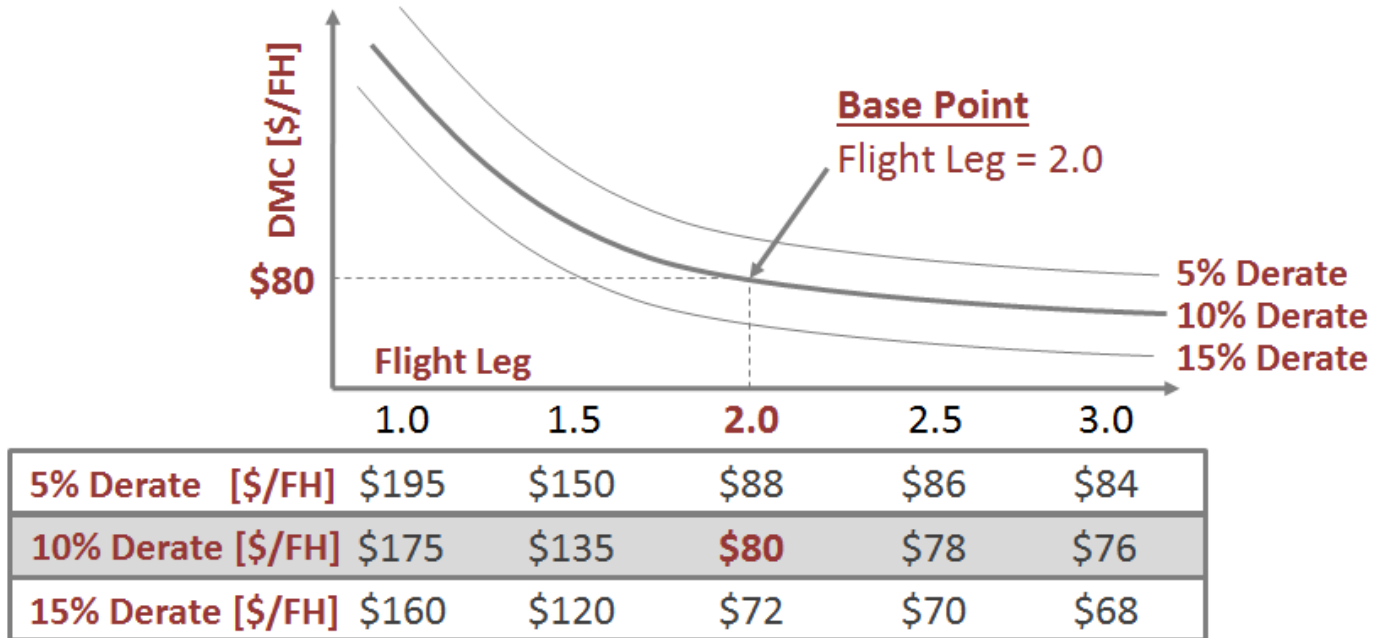


Figure 69. Example Engine Performance Restoration DMC Matrix Accounting for Flight Profile and Derate



IV. Engine Performance Restoration



a. Engine Performance Degradation :

ii. Engine Flight Operation

▶ Ambient Temperatures

Turbofan engines are normally flat rated to ambient air temperatures around International Standard Atmosphere (ISA) + 15°C, which is equivalent to 30°C at sea level conditions. The turbine entry temperature at max take-off and max climb rating increase as ambient air temperature increases, up to their limit value. Therefore, an engine exposed to high ambient temperatures will experience lower available EGT margin and greater performance degradation. **Figure 70** illustrates the variation of available EGT margin deterioration as a function of Outside Air Temperature (OAT) for a sample turbofan engine.

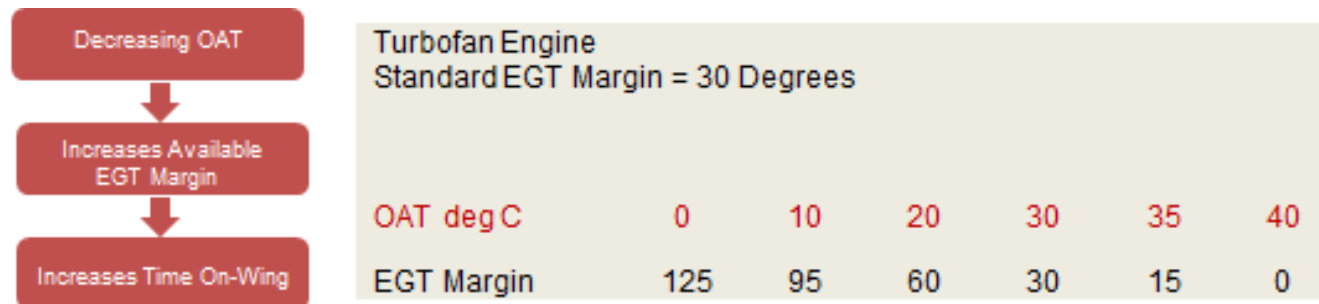


Figure 70. Effect of Ambient Temperatures on Engine EGTM



IV. Engine Performance Restoration

a. Engine Performance Degradation :

ii. Engine Flight Operation

▶ Operating Environment

Engines operated in hot-sandy and/or erosive-corrosive environments are exposed to greater hardware distress and thus greater EGT margin deterioration, which translates into both higher shop visit costs and lower time on-wing (TOW) performance – as illustrated in **Figure 71**.

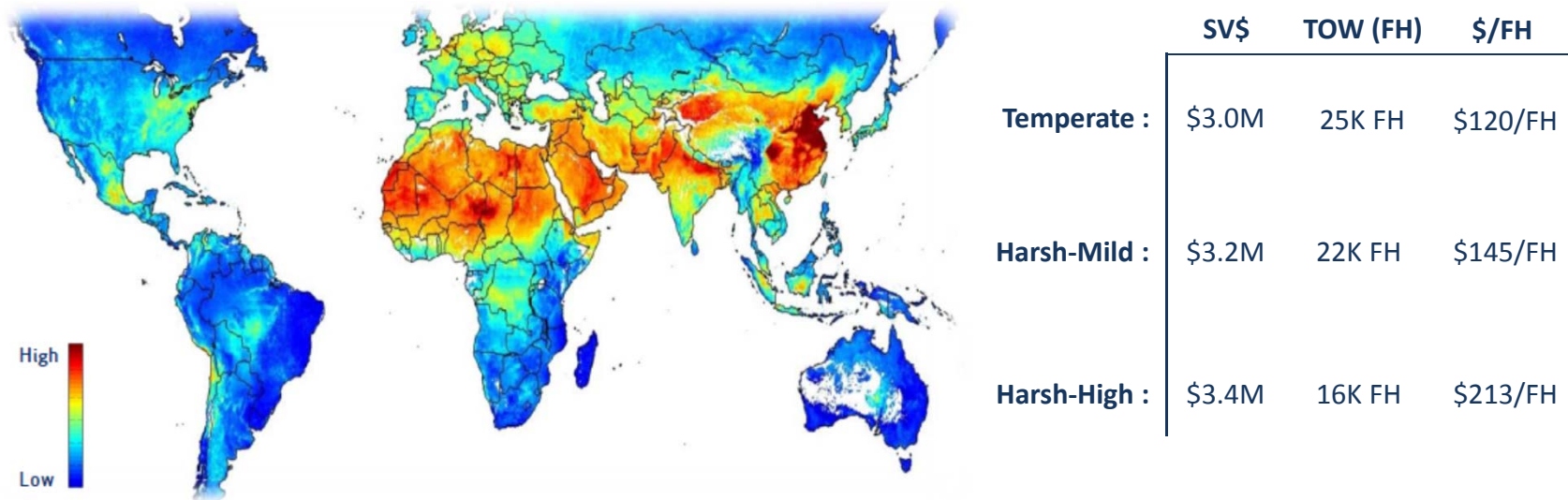


Figure 71. Effect of Environment on Engine DMC



IV. Engine Performance Restoration



a. Engine Performance Degradation :

ii. Engine Flight Operation

- ▶ Operating Environment - example effects from operation in harsh environment – **Figure 72.**

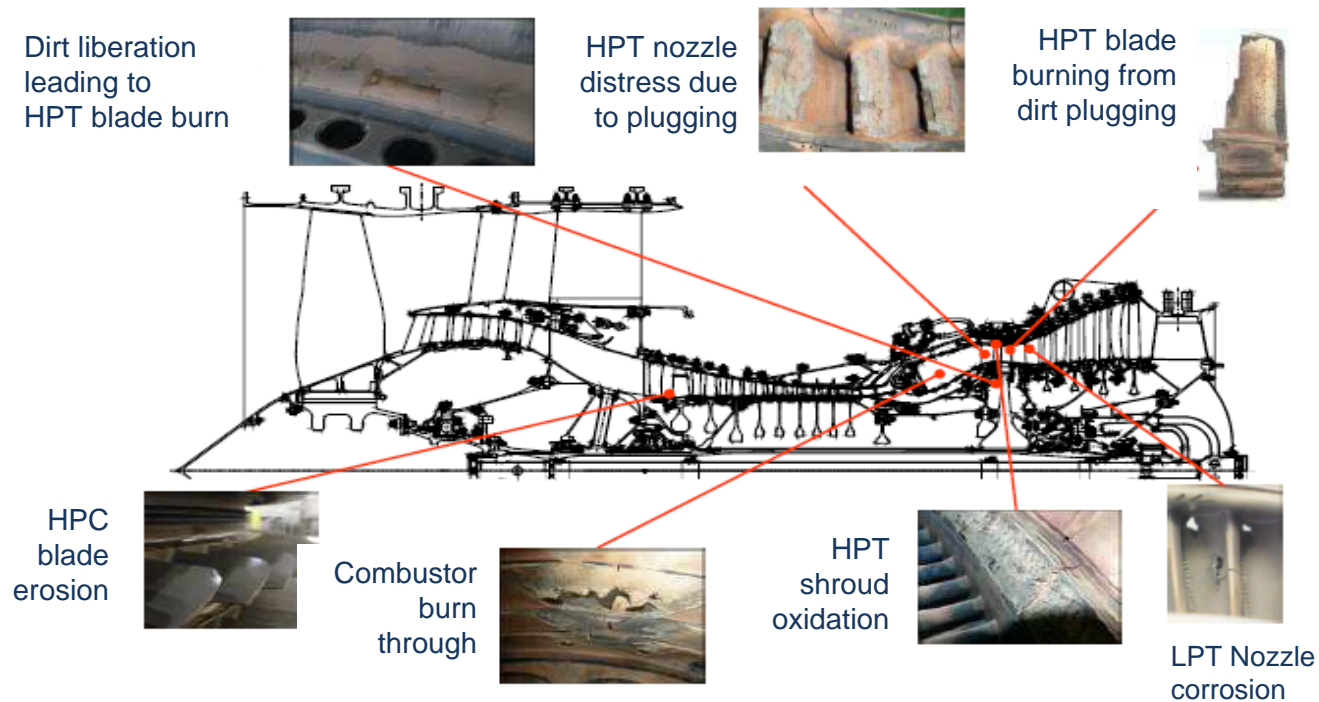


Figure 72. Impact of Harsh Environmental Operation on Engine Components

IV. Engine Performance Restoration

a. Engine Performance Degradation :

iii. Engine Age



Older engines generally cost more to maintain than newer engines. As an engine ages its average time to shop visit lessens - **Figure 73**. First-run engines often operate considerably longer on-wing than mature engines. In fact, it is not uncommon to see first-run engines remaining on-wing 20%-30% longer than mature run engines. As the engine ages a disproportionate amount of parts experience higher deterioration rates, higher scrap rates, and correspondingly higher engine maintenance cost.

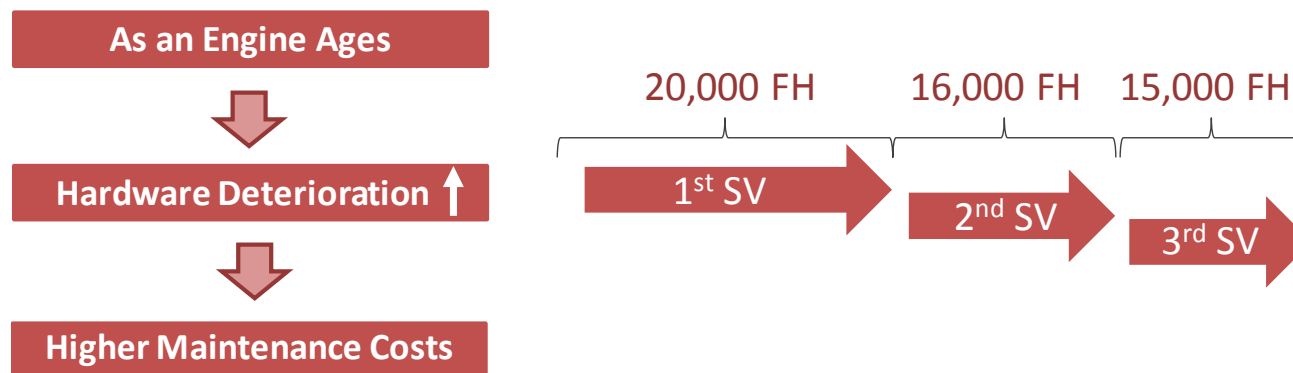


Figure 73. Impact of Engine Age on Time On-Wing and DMC



IV. Engine Performance Restoration



a. Engine Performance Degradation :

Example: Figure 74 - Engine Reserves Accounting for Flight-Leg, Derate, Age & Operating Environment

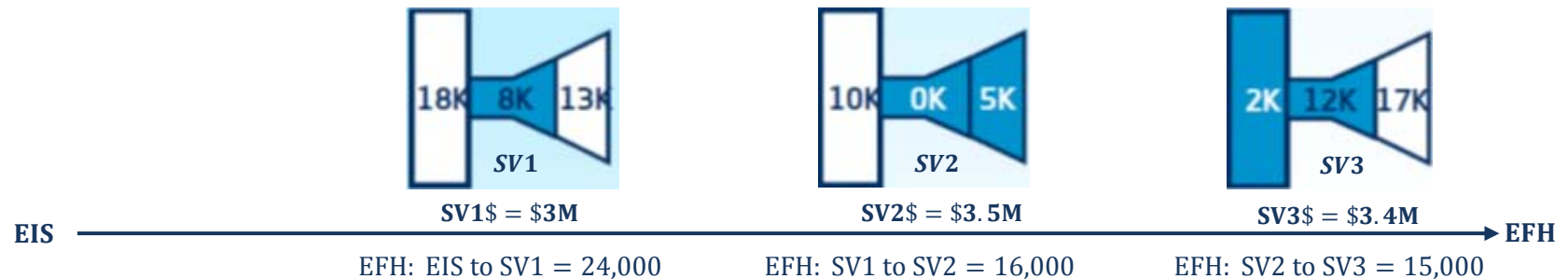
		1.0	1.5	2.0	2.5	3.0
First-Run	5% / Temperate	\$195	\$150	\$88	\$86	\$84
	10% / Temperate	\$175	\$135	\$80	\$78	\$76
	5% / Hot - Harsh	\$215	\$170	\$100	\$98	\$96
	10% / Hot - Harsh	\$225	\$180	\$110	\$108	\$106
Mature-Run	5% / Temperate	\$235	\$200	\$135	\$110	\$100
	10% / Temperate	\$225	\$175	\$125	\$105	\$95
	5% / Hot - Harsh	\$275	\$235	\$200	\$190	\$180
	10% / Hot - Harsh	\$250	\$210	\$180	\$170	\$160

Figure 74. Example Engine Performance Restoration DMC Matrix Accounting for Flight Profile, Derate, Environment & Age



IV. Engine Performance Restoration

Engine Performance Restoration Rate Calculations :



$$\text{First run rate} = \frac{\text{SV1\$}}{\text{EFH to SV1}} = \frac{\$3,000,000}{24,000 \text{ EFH}} = \$125/\text{FH}$$

$$\text{Mature run rate}_{n \geq 2} = \frac{\text{SV2\$} + \Sigma \text{SVn\$}}{\text{EFH from SV1 to SVn}} = \frac{(\$3,500,000 + \$3,400,000)}{(16,000 \text{ EFH} + 15,000 \text{ EFH})} = \$222/\text{FH}$$

$$\text{Blended Rate} = \frac{\text{SV1\$} + \text{SV2\$}}{\text{EFH from EIS to SV2}} = \frac{(\$3,000,000 + \$3,500,000)}{(24,000 \text{ EFH} + 16,000 \text{ EFH})} = \$163/\text{FH}$$

$$\text{Life Cycle Rate} = \frac{\text{SV1\$} + \text{SV2\$} + \text{SV3\$}}{\text{EFH from EIS to SV3}} = \frac{(\$3,000,000 + \$3,500,000 + \$3,400,000)}{(24,000 \text{ EFH} + 16,000 \text{ EFH} + 15,000 \text{ EFH})} = \$180/\text{FH}$$



V. Engine Life-Limited Parts (LLP)



Engine LLP costs & time on-wing are influenced by:

- a. **Engine manufacturer's catalog piece-part price** : LLPs are subject to annual OEM escalation averaging over 5%/yr. for narrowbody engines and over 7%/yr. for widebody.
- b. **Engine manufacturer's published life limits** : The declared lives of LLPs are referenced in Chapter 5 of an engine's shop/overhaul manual, and typically range between 15,000 - 30,000 cycles. Some manufacturers certify ultimate lives of LLPs at the time they certify an engine model. Other manufacturers certify the lives as experience is accumulated. In these scenarios, ultimate lives are reached after one or several life extensions.
- c. **LLP stub-life factor** : The term stub-life is used to represent the shortest life remaining of all LLPs installed. Industry standard is to assume Engine LLPs will never consume 100% of their life limits, and instead will retain 5%-15% at replacement – **Figure 75**.

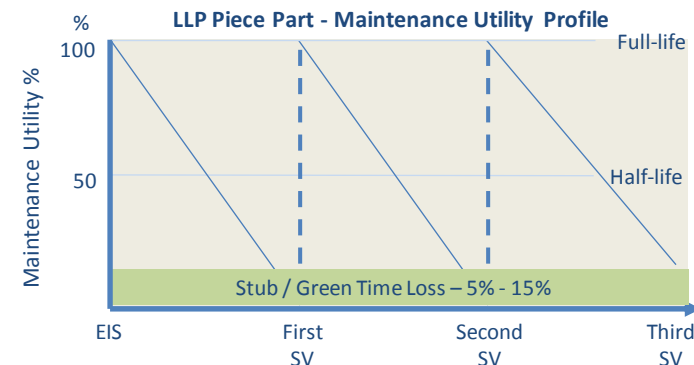


Figure 75. LLP Stub-Life Factor



V. Engine Life-Limited Parts (LLP)

Example: Engine LLP calculation accounting for a 10% stub-factor



$$\text{LLP Rate} = \frac{\text{LLP Cost\$}}{\text{LLP Life Limit}}$$

$$\text{LLP Rate (10\% Stub Factor)} = \frac{\text{LLP Cost\$}}{90\% * \text{LLP Life Limit}}$$

Item	Cost \$	Chapter 5 - Life Limit (FC)	LLP Rate (\$/FC)	LLP Rate (10% Stub)
Disk	\$ 150,000	20,000	\$7.50 / FC	\$8.33 / FC
Spool	\$ 250,000	20,000	\$12.50 / FC	\$13.89 / FC
Shaft	\$200,000	20,000	\$10.00 / FC	\$11.11 / FC
Seal	\$100,000	20,000	\$5.00 / FC	\$5.56 / FC

Figure 76. Example LLP Rate Calculations



VI. Thrust Reverser Overhaul



Thrust reverser overhaul costs and timing of events are influenced by:

- a. **Size & Complexity:** High bypass ratio engines have wider intakes and bypass ducts, use complex blocker door reversers and more sophisticated actuation systems.
- b. **Time Between Overhaul:** Thrust reversers are on-condition components subject to the following performance degradation factors that impact average time on-wing:
 - ▶ **Flight Operation:** Hard reversing action at landing by flight crews will accelerate degradation. The same applies to corrosive environments.
 - ▶ **Soft-time Removals:** Removal intervals as a guide are decided by each airline and repair agency, rather than pure on-condition removals.
- c. **Workscope Planning:** Reverser repair or overhauls are based on the manufacturers' workscope planning guide, which include basic overhaul, routine repairs and out of workscope items. These are the replacement of parts due to conditions that exceed the repairable limits.



Section 6

Flight Hour Agreements

- I. Advantages & Disadvantages
- II. Payment Options
- III. Term Options
- IV. Flexibility & Portability Options



- ❑ Under a Flight-Hour Agreement (FHA) an operator pays a service provider an hourly rate based on the number of engine hours flown & the engine OEM covers all product upgrades & shop visits during the FHA term. Rates offered by the engine OEM are conditional upon specific operating conditions (e.g. average flight leg, derate, operating environment), the term of the FHA, and the hardware standard of engines.
- ❑ Inducting new engines into an FHA is generally simple, however if the airline/financier intends to add used engines into the agreement, then it can become complicated. If the parameters of the engines to be added are significantly different from the assumed parameters, the airline/financier will need to do a qualifying shop visit on the relevant engines before they are inducted into the OEM agreement. Such qualifying shop visits will usually be charged on time and material basis and usually significantly more expensive.



I. Advantages & Disadvantages

FHA Advantages:

- ▶ Cost visibility - smoothing of expenditure designed principally to address the cost and timing uncertainties inherent in traditional time and material contracts;
- ▶ Reduces resource constraints - relieves operators with limited resources and technical expertise for the need to hire personnel and purchase stocks of engines and accessories;
- ▶ Mitigates new engine technology risks – risks associated with next generation technology engines can be mitigated;
- ▶ Comfort that engines are maintained to highest standards - assurance that engines are being maintained to the highest standards by excluding use of Part Manufacturing Approval (PMA) parts and Designated Engineering Representative (DER) repairs

FHA Disadvantages:

- ▶ Access to Cash – some packages don't allow for any cash to be refunded at any point, only credits for future maintenance work will be provided;
- ▶ Reduces Aftermarket Competition – creating situations where there is no aftermarket competition on any level, and where the OEM controls all commercial aspects;
- ▶ Increasingly complicated agreements that are difficult to decipher and analyze



II. Payment Options

1. Pay-As-You-Go – Payments are made to the service provider as the engines accrue time most FHA contracts are PAYG
2. Pay-At-Shop Visit – Payments are made at shop visit based on a hourly rate provided by the service provider.

III. Term Options – Figure 77

1. Fixed - Fixed period of time: e.g. 12 years from EIS
2. Shop Visit - Fixed number of shop visits: e.g. coinciding with 1st shop visit
3. Hybrid - In effect until the later of a fixed term or until such engine has received a shop visit
4. Engine Life Based – Through economic life of aircraft

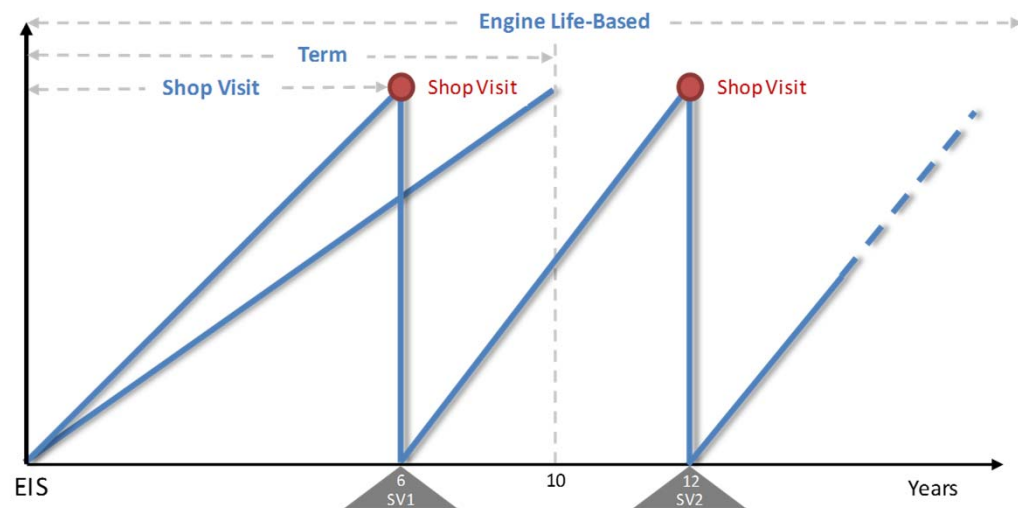


Figure 77. FHA Term Options



IV. Flexibility & Portability Options

► Step-in Option – Figure 78

- Lessor or subsequent lessee assumes relevant rights & obligations and shall be entitled to apply the paid-in funds as credits toward the costs of restoration shop visit performed by OEM.
- FHA continues with lessor or next lessee until next SV or beyond

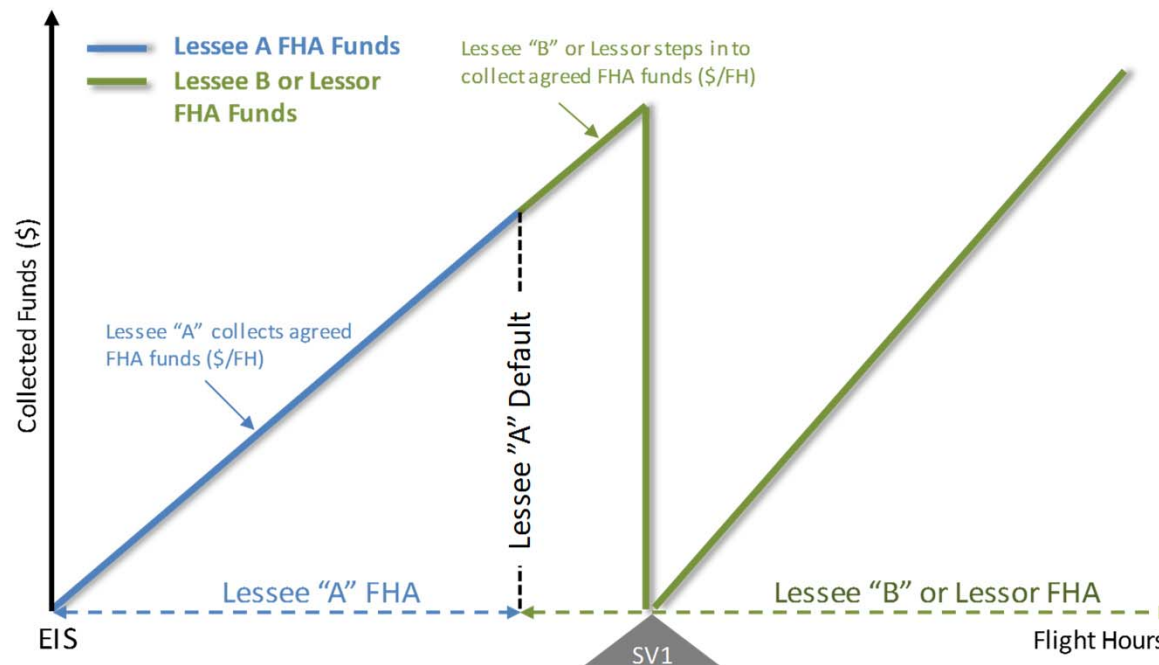


Figure 78. FHA Step-In Option



IV. Flexibility & Portability Options

▶ Subsequent Shop Visit Option – Figure 79

- FHA terminates at default and next lessee opt out of FHA
- OEM and lessor shall cover the cost of the next shop visit ; lessor free to collect maintenance reserves
- The costs of such visit shall be determined either at the time of such shop visit or fixed in advance

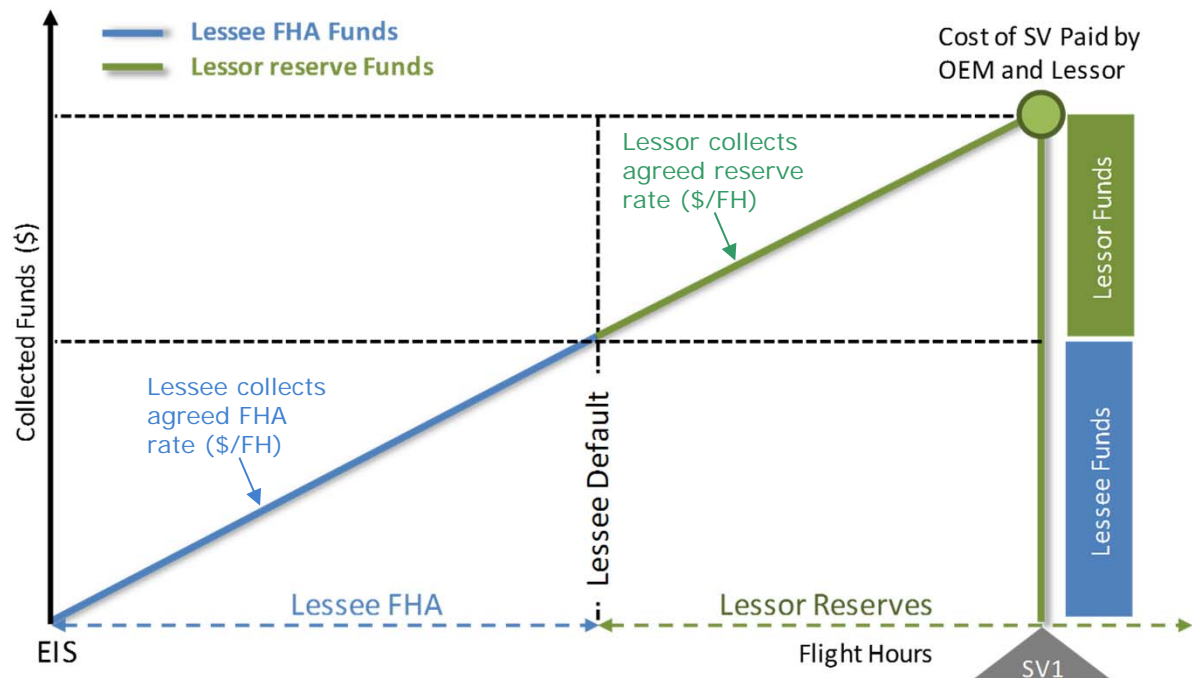


Figure 79. FHA Subsequent Shop Visit Option



Section 7

Part Manufacturing Approval (PMA)

- I. PMA Background
- II. Licensed vs. Competitive PMA
- III. PMA Part Classification
- IV. Financier Concerns

7.0 Parts Manufacture Approval (PMA)



- ❑ The **PMA (Parts Manufacturer Approval)** is a combined design and production approval by the FAA for replacement parts for type-certificated aircraft, engines, and propellers – **Figure 80**. A manufacturer who holds the PMA is allowed to produce and sell FAA approved parts that are eligible for installation on type certificated aircraft. In the FAA’s view, there is no distinction in status from the OEM part to the PMA part - both have equal standing. Additionally, the certification standards for the PMA part are the same as for the original part.

- ❑ Aerospace Original Equipment Manufacturers (OEMs) tend to have a strong monopoly position on replacement parts resulting in generally high prices for such parts in the aftermarket. The OEMs justify higher margins due in large part to the high level of investment in research and development required to manufacturer such parts. PMA parts are considerably cheaper to manufacturer, with savings potential in the range of 45%-75% compared to OEM pricing.



U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

National Policy

ORDER
8110.42C

Effective Date:
June 23, 2008

SUBJ: Parts Manufacturer Approval Procedures

In this order, we describe the procedures for evaluating and issuing a parts manufacturer approval (PMA) for replacement and modification parts on type-certificated products. These procedures apply to all engineering personnel in the Federal Aviation Administration. The associated procedures for manufacturing personnel are now in FAA Order 8120.2, *Production Approval and Certificate Management Procedures*. This revision consolidated customer and stakeholder feedback to refine the previous guidance, improve clarity and make opportune corrections. Also this revision makes timely adjustments for the new privileges of delegated organizations in PMA.

/s/
Dave W. Hempe
Manager, Aircraft Engineering Division
Aircraft Certification Service
Federal Aviation Administration

Figure 80. FAA PMA Authorization



I. Approval Process

The applicant for a PMA must apply in a form and manner prescribed by the FAA. To obtain FAA approval to produce (manufacture) PMA parts for sale, the PMA applicant must:

- ▶ Provide a design package to the FAA showing that the PMA part is at least equal to the OEM part in form, fit and function (without having to rely on the OEMs proprietary drawings).
- ▶ Submit an extensive data package describing the design, including materials, processes, test specifications, compatibility and interchangeability analysis and maintenance instructions.
- ▶ Prove that they have a production system with the necessary quality controls to reliably and repetitively produce parts that conform to the approved design.
- ▶ Include a review of the OEMs maintenance instructions and any Instructions for Continued Airworthiness (ICAs) and life limits. The applicant must state that the existing maintenance instructions, ICAs and life limits are still applicable with the PMA parts installed or the applicant must provide replacement instructions, ICAs and life limits.
- ▶ Indicate the aircraft and model types on which the parts are to be installed and the FAA approval will reflect this limitation.



I. Approval Process

All PMA parts must be identified and in most cases marked with specified information:

- ▶ The words “FAA-PMA”
- ▶ The PMA manufacturer’s name, trademark or symbol
- ▶ A part number
- ▶ Exceptions are allowed where it is impractical to mark the part but, in this case, a tag must have the above information.

This information is required for traceability of the PMA part and to distinguish it from the OEM part. Airlines should add the PMA part number to their purchasing and inventory control system, and update the appropriate IPC showing maintenance personnel where use of the part has been authorized.

PMA parts can be used in any country that has a bilateral agreement with the FAA, provided the agreement or implementation procedure permit PMA parts.

II. Licensed vs. Competitive PMA

There are generally two standards of PMA suppliers: 1.) Licensed PMA suppliers , and 2.) Competitive PMA Suppliers. **Licensed PMA suppliers** cooperate with the OEMs to produce parts for aircraft. Since the OEM is providing a design that has already been approved by the FAA to the PMA applicant, there is no requirement for the FAA to provide design approval. Licensed parts meet the following requirements:

- ▶ Same parts as production
- ▶ Same quality and process control as original equipment
- ▶ License meets PMA by FAA identity classification

An example of a **licensed PMA supplier** is Goodrich Corporation, which entered into a data license with Boeing allowing the use of detail engineering design to obtain Parts Manufacturing Approval (PMA) for replacement landing gear spare parts. The license will permit Goodrich to manufacture licensed PMA parts under Goodrich's FAA approved quality system and distribute directly to operators – **Figure 81**.



Figure 81. Example Licensed PMA Supplier



II. Licensed vs. Competitive PMA

Competitive PMA suppliers actively compete with OEMs. These suppliers use test & computation (reverse-engineering) as the means to prove the PMA part is equal to or better than the approved original part. Most PMA parts now use test & computation for design substantiation. An example of a competitive PMA part is PW4000 HPT blades manufactured by BELAC – **Figure 82**.



Figure 82. Example Competitive PMA Supplier

III. PMA Part Classification

PMA suppliers are required to identify the criticality of the part. This is done by means of a failure modes & effects analysis for the particular part in addition to the part's next higher assembly. Every possible way the part could fail is examined and the consequences of the failure are assessed. Based on this analysis the part is classed as **critical / complex** (possibly affecting the performance of either the equipment), or **non-critical** (all the rest) – see **Figure 83**. A part is often considered critical if the assessment shows hazardous condition from the effects of failure.



Non-Critical Consumable Parts



Critical HPC & HPT Blades

Figure 83. Example Critical vs. Non-Critical PMA Parts



IV. Financier Concerns

Financiers policy with regards to PMA will vary depending on the aircraft/engine vintage and where such parts are to be used. Lessors, in particular, continue to highlight key concerns regarding PMA parts, which relate to: 1.) Asset re-marketability & transferability, and 2.) Residual value impairment

1. Asset re-marketability and the ability to seamlessly transition aircraft between regulatory jurisdictions are often cited as the leading factors that drive aircraft lessor's aversion to PMA parts.
2. Residual value impairment, both related to decreased marketability and due to perceived lower cost PMA parts.

For these reasons, as well as the fact that many PMA parts are classed critical, most lessors will make a clear distinction between non-critical PMA parts versus critical; The policy will generally dictate that acceptance of non-critical PMA parts for usage on the airframe or cabin interior is generally accepted, and use of critical PMA parts will not be approved for usage under any circumstances.



Section 8

Designated Engineering Representative (DER) Repairs

- I. Background
- II. DER Repair Standards, Applications
& Cost Savings

8.0 Designated Engineering Representative (DER) Repairs



- ❑ **Designated Engineering Representatives (DERs)** are private individuals (independent professionals or staff engineers in the repair center) designated by the FAA whom may approve or recommend approval of engineering technical data within the limits of their authority by means of Form 8110-3. A recommendation for approval of technical data for a finding of compliance to airworthiness standards can only be made by an authorized DER – **Figure 84.**



U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

National Policy

ORDER
8110.37E

Effective Date:
03/30/2011

SUBJ: Designated Engineering Representative (DER) Handbook

This order is a handbook of procedures, technical guidelines, limitations of authority, and tools and resources for designated engineering representatives (DERs). We wrote it for all DERs and the ACO staffs that manage them. We designed this handbook to give ACOs and DERs a better understanding of their individual and mutual responsibilities.

All users of this order will familiarize themselves with its contents and comply with the instructions and guidance contained herein.

Richard E. Jennings
Acting Manager, Aircraft Engineering Division
Aircraft Certification Service

Figure 84. FAA DER Authority

- ❑ A strategy available to airlines to reduce expenses for materials is to repair rather than replace parts that are worn or damaged. This is particularly applicable to expensive engine parts. Repairs approved under FAA regulations by airworthiness engineers who are delegated to approve repair and repair processes are referred to as **DER (Designated Engineering Representative) Repairs.**



I. Background

Traditionally, the engine OEMs have published “standard” repair schemes in the engine shop manuals. However, over the past 10-15 years, the OEMs’ strategy to profit from the aftermarket has resulted in fewer repairs being included in their manuals. Instead, repairs developed by OEMs have been provided to individual MROs only after license agreements have been completed and royalty payments agreed. OEMs may also recommend replacing parts rather than repairing because their cost to manufacture a new part is a small fraction of the catalogue list price of the part.

Today, operators have an array of choices when it comes to deciding what to do about worn or damaged parts. Among the options are:

- ▶ Buying a new part from an original equipment manufacturer (OEM), having the part repaired by an OEM-affiliated repair station,
- ▶ Buying a new Parts Manufacturer Approval (PMA) component from a non-OEM source, and
- ▶ Obtaining a Designated Engineering Representative (DER)- approved repair.

The choice depends on factors such as the age of the aircraft, the part’s warranty status, the cost of the various options, and the likely turnaround times for part delivery or repair approval.



II. DER Standards, Applications & Cost Savings

A DER repair is a repair process and configuration that has met all the specifications for development, performance, reliability, and safety, and has been validated and certified by an FAA-authorized DER.

DER repairs have to conform to the same airworthiness standards as new OEM parts or OEM manual repairs in order to maintain the same level of safety; the minimum requirement is to restore a part to its original function and level of safety. DER Repairs can range from equivalent OEM repairs to advanced repairs that often go beyond the basic repairs found in the OEM manual – example DER Repair in **Figure 85**.



Figure 85. DER Repaired Compressor Blades

DER repairs are most common in the engine area because these assemblies are high-cycle and under great service stress. Auxiliary power units (APUs) would be next, along with landing gears, which are subject to repetitive dynamic loads.

If a part can be repaired, the DER route may be the most cost-effective way to go, particularly if the airplane is out of warranty and the part is complex, costly, and difficult to obtain in a timely manner. The cost savings associated with DER repairs can be significant; ranging from 15 to 40 percent of the OEM part cost.



I. Typical Narrowbody Airframe Heavy Structural Check DMCs

Aircraft	Check	Interval	Initial Costs	Initial (\$ / Mo)	Ageing Costs	Ageing (\$ / Mo)
A319-100	6Y SC	72 Mo	\$775K - \$875K	\$10,800 - \$12,100	\$1.0M - \$1.1M	\$13,800 - \$15,200
A319-100	12Y SC	144 Mo	\$825K - \$925K	\$5,700 - \$6,400	\$1.1M - \$1.2M	\$7,600 - \$8,300
A320-200	6Y SC	72 Mo	\$800K - \$900K	\$11,100 - \$12,500	\$1.05M - \$1.15M	\$14,500 - \$15,900
A320-200	12Y SC	144 Mo	\$850K - \$950K	\$5,900 - \$6,600	\$1.15M - \$1.25M	\$7,900 - \$8,600
A321-200	6Y SC	72 Mo	\$825K - \$925K	\$11,500 - \$12,800	\$1.05M - \$1.15M	\$14,500 - \$15,900
A321-200	12Y SC	144 Mo	\$875K - \$975K	\$6,000 - \$6,800	\$1.2M - \$1.3M	\$8,300 - \$9,000
B737-700	8Y SC	96 Mo	\$625K - \$725K	\$6,500 - \$7,500	\$825K - \$925K	\$8,500 - \$9,600
B737-700	10Y SC	120 Mo	\$350K - \$450K	\$2,900 - \$3,750	\$500K - \$600K	\$4,100 - \$5,000
B737-700	12Y SC	144 Mo	\$850K - \$950K	\$5,900 - \$6,600	\$1.0M - \$1.2M	\$6,900 - \$8,300
B737-800	8Y SC	96 Mo	\$650K - \$750K	\$6,800 - \$7,800	\$850K - \$975K	\$8,800 - \$10,100
B737-800	10Y SC	120 Mo	\$375K - \$475K	\$3,100 - \$3,900	\$525K - \$625K	\$4,300 - \$5,200
B737-800	12Y SC	144 Mo	\$875K - \$975K	\$6,000 - \$6,800	\$1.05M - \$1.25M	\$7,200 - \$8,600
B737-900	8Y SC	96 Mo	\$675K - \$775K	\$7,000 - \$8,000	\$875K - \$1.0M	\$9,100 - \$10,400
B737-900	10Y SC	120 Mo	\$400K - \$500K	\$3,300 - \$4,100	\$550K - \$650K	\$4,500 - \$5,400
B737-900	12Y SC	144 Mo	\$925K - \$1.05M	\$6,400 - \$7,200	\$1.1M - \$1.3 M	\$7,600 - \$9,000

Assumptions:

- 2018 USD
- Includes labor & material for all routine and associated non-routine maintenance tasks
- Includes cost of interior refurbishment & upkeep
- A320 family 12Y SC costs excludes the costs affiliated with the 6Y SC
- Includes cost of strip & paint for 12Y structural checks



II. Typical Widebody Airframe Heavy Structural Check Reserves

Aircraft	Check	Interval	Initial Costs	Initial (\$ / Mo)	Ageing Costs	Ageing (\$ / Mo)
A330-200	6Y SI	72 Mo	\$1.55M - \$1.75M	\$21,500 - \$24,300	\$2.00M - \$2.30M	\$27,500 - \$31,500
A330-200	12Y SI	144 Mo	\$1.65M - \$1.85M	\$11,400 - \$12,800	\$2.10M - \$2.30M	\$14,500 - \$16,500
A333-300	6Y SI	72 Mo	\$1.60M - \$1.80M	\$22,200 - \$25,000	\$2.10M - \$2.40M	\$29,000 - \$33,000
A330-300	12Y SI	144 Mo	\$1.70M - \$1.90M	\$11,800 - \$13,100	\$2.20M - \$2.50M	\$15,200 - \$17,300
A350-900	12Y SI	144 Mo	\$2.70M - \$3.00M	\$18,750 - \$20,800	\$3.30M - \$3.60M	\$22,900 - \$25,000
B777-200	8Y SI	96 Mo	\$3.20M - \$3.60M	\$33,250 - \$37,500	\$3.70M - \$4.20M	\$38,500 - \$43,750
B777-300	8Y SI	96 Mo	\$3.40M - \$3.80M	\$35,500 - \$39,500	\$3.90M - \$4.40M	\$40,600 - \$45,800
B787-8	12Y SI	144 Mo	\$2.30M - \$2.60M	\$16,000 - \$18,000	\$2.90M - \$3.20M	\$20,000 - \$22,200
B787-9	12Y SI	144 Mo	\$2.40M - \$2.70M	\$16,700 - \$18,750	\$3.00M - \$3.30M	\$20,800 - \$22,900
B787-10	12Y SI	144 Mo	\$2.50M - \$2.80M	\$17,400 - \$19,400	\$3.10M - \$3.40M	\$21,500 - \$23,600

III. Typical Widebody Thrust Reverser Overhaul Reserves (*per reverser, 2 per aircraft*)

Aircraft	Interval (Months)	Initial Costs (\$/Unit)	Initial (\$/Mo)	Ageing Costs (\$/Unit)	Ageing (\$/Mo)
A330	96 – 120	\$500K - \$600K	\$9,200 - \$11,600	\$600K - \$700K	\$11,600 - \$13,500
A350	96 – 120	\$750K - \$850K	\$14,000 - \$16,600	\$850K - \$950K	\$15,000 - \$18,750
777	96 – 120	\$800K - \$900K	\$15,000 - \$17,700	\$900K - \$1.0M	\$15,800 - \$19,700
787	96 – 120	\$750K - \$850K	\$14,000 - \$16,600	\$850K - \$950K	\$15,000 - \$18,750

Assumptions:

- 2018 USD
- Includes labor & material for all routine and associated non-routine maintenance tasks
- Includes cost of interior refurbishment & upkeep
- Includes cost of strip & paint for 8Y (B777) and 12Y (A330, A350, & 787) structural checks
- A330 family 12Y SC costs excludes the costs affiliated with the 6Y SC



IV. Typical Landing Gear Overhaul Reserves

Aircraft	Intervals	Initial Costs	Initial (\$ / Mo)	Ageing Costs	Ageing (\$ / Mo)
A320	120 Mo / 20,000 FC	\$440K - \$480K	\$3,600 - \$4,000	\$500K - \$540K	\$4,100 - \$4,500
A320 NEO	144 Mo / 20,000 FC	\$450K - \$490K	\$3,125 - \$3,400	\$510K - \$550K	\$3,500 - \$3,800
A330	120 Mo / 20,000 FC	\$850K - \$950K	\$7,000 - \$7,900	\$950K - \$1.05M	\$7,900 - \$8,750
A350	144 Mo / 16,700 FC	\$1.05M - \$1.15M	\$7,300 - \$8,000	\$1.15M - \$1.35M	\$8,000 - \$9,400
737NG	120 Mo / 20,000 FC	\$400K - \$440K	\$3,300 - \$3,700	\$460K - \$500K	\$3,800 - \$4,100
777	120 Mo / 20,000 FC	\$1.00M - \$1.20M	\$8,300 - \$10,000	\$1.10M - \$1.30M	\$9,100 - \$10,800
787	144 Mo / 21,000 FC	\$850K - \$950K	\$5,900 - \$6,600	\$950K - \$1.15M	\$6,600 - \$8,000

V. Typical APU Heavy Repair Reserves

Aircraft	Interval (APU FH)	Initial Costs	Initial (\$/APU FH)	Ageing Costs	Ageing (\$/APU FH)
A320	7,000 – 9,000	\$320K - \$360K	\$38.00 - \$44.00	\$350K - \$400K	\$40.00 - \$46.00
A330	5,000 – 7,000	\$450K - \$550K	\$70.00 - \$80.00	\$480K - \$580K	\$75.00 - \$85.00
A350	5,000 – 7,000	\$450K - \$550K	\$70.00 - \$80.00	\$480K - \$580K	\$75.00 - \$85.00
737NG	7,000 – 9,000	\$320K - \$360K	\$38.00 - \$44.00	\$350K - \$400K	\$40.00 - \$46.00
777	5,000 – 7,000	\$550K - \$650K	\$85.00 - \$95.00	\$580K - \$680K	\$90.00 - \$100.00
787	5,000 – 7,000	\$450K - \$550K	\$70.00 - \$80.00	\$480K - \$580K	\$75.00 - \$85.00

Assumptions:

- 2018 USD
- Cost of landing gear overhaul includes cost of exchange Fee
- APU - Excludes Life-Limited Parts (LLPs)



VI. Typical Narrowbody Engine First-Run Performance Restoration Reserves

Engine	Thrust	Phase	Fl Leg	Time On-Wing (FC)	Costs	Rate (\$ / FH)
CFM56-5B6/3	23,500	First-Run	2.0	16,500 - 17,500	\$3.30M - \$3.50M	\$90- \$105
CFM56-5B4/3	27,000	First-Run	2.0	14,500 - 15,500	\$3.25M - \$3.45M	\$110 - \$125
CFM56-5B3/3	33,000	First-Run	2.0	11,000 - 12,000	\$3.25M - \$3.45M	\$135 - \$150
V2524-A5 S1	24,000	First-Run	2.0	15,000 - 16,000	\$3.20M - \$3.40M	\$100 - \$115
V2527-A5 S1	27,000	First-Run	2.0	12,000 - 13,000	\$3.20M - \$3.40M	\$115 - \$130
V2533-A5 S1	33,000	First-Run	2.0	9,500 - 10,500	\$3.20M - \$3.40M	\$160 - \$175
LEAP-1A24	24,400	First-Run	2.0	16,500 - 17,500	\$3.30M - \$3.60M	\$105 - \$120
LEAP-1A26	26,600	First-Run	2.0	12,000 - 13,000	\$3.30M - \$3.60M	\$125 - \$140
LEAP-1A33	32,900	First-Run	2.0	9,500 - 10,500	\$3.30M - \$3.60M	\$165 - \$180
PW1124G	24,490	First-Run	2.0	16,500 - 17,500	\$3.20M - \$3.50M	\$100 - \$115
PW1127G	26,650	First-Run	2.0	12,000 - 13,000	\$3.20M - \$3.50M	\$120 - \$135
PW1133G	33,000	First-Run	2.0	9,500 - 10,500	\$3.20M - \$3.50M	\$160 - \$175
CFM56-7B24E	24,000	First-Run	2.0	16,500 - 17,500	\$3.30M - \$3.50M	\$90 - \$105
CFM56-7B26E	26,300	First-Run	2.0	14,500 - 15,500	\$3.20M - \$3.40M	\$100 - \$115
CFM56-7B27E	27,300	First-Run	2.0	13,000 - 14,000	\$3.20M - \$3.40M	\$115 - \$130
LEAP-1B25	25,000	First-Run	2.0	14,500 - 15,500	\$3.30M - \$3.60M	\$105 - \$120
LEAP-1B27	26,400	First-Run	2.0	12,000 - 13,000	\$3.30M - \$3.60M	\$125 - \$140
LEAP-1B28	27,900	First-Run	2.0	11,500 - 12,500	\$3.30M - \$3.60M	\$130 - \$145

Assumptions:

- 2018 USD
- Repair, overhaul or replacement of thrust reversers and non-modular components, such as QEC, LRU or accessory units is not included
- Excludes Life-Limited Parts (LLPs)
- Temperate environment
- 10% Derate



VI. Typical Narrowbody Engine Mature-Run Performance Restoration Reserves

Engine	Thrust	Phase	Fl Leg	Time On-Wing (FC)	Costs	Rate (\$ / FH)
CFM56-5B6/3	23,500	Mature-Run	2.0	10,500 - 11,500	\$3.30M - \$3.60M	\$140- \$165
CFM56-5B4/3	27,000	Mature-Run	2.0	9,000 – 10,000	\$3.30M - \$3.60M	\$155 - \$180
CFM56-5B3/3	33,000	Mature-Run	2.0	8,000 – 9,000	\$3.30M - \$3.60M	\$180 - \$205
V2524-A5 S1	24,000	Mature-Run	2.0	11,000 - 12,000	\$3.40M - \$3.70M	\$135 - \$160
V2527-A5 S1	27,000	Mature-Run	2.0	9,000 - 10,000	\$3.40M - \$3.70M	\$160 - \$185
V2533-A5 S1	33,000	Mature-Run	2.0	8,000 – 9,000	\$3.40M - \$3.70M	\$185 - \$210
LEAP-1A24	24,400	Mature-Run	2.0	10,500 - 11,500	\$4.00M - \$4.40M	\$160 - \$185
LEAP-1A26	26,600	Mature-Run	2.0	9,500 – 10,500	\$4.00M - \$4.40M	\$190 - \$215
LEAP-1A33	32,900	Mature-Run	2.0	7,500 – 8,500	\$4.00M - \$4.40M	\$255 - \$280
PW1124G	24,490	Mature-Run	2.0	10,500 - 11,500	\$3.90M - \$4.30M	\$155 - \$180
PW1127G	26,650	Mature-Run	2.0	9,500 – 10,500	\$3.90M - \$4.30M	\$185 - \$210
PW1133G	33,000	Mature-Run	2.0	7,500 – 8,500	\$3.90M - \$4.30M	\$250 - \$275
CFM56-7B24E	24,000	Mature-Run	2.0	11,000 - 12,000	\$3.40M - \$3.60M	\$135- \$160
CFM56-7B26E	26,300	Mature-Run	2.0	9,500 - 10,500	\$3.40M - \$3.60M	\$155- \$180
CFM56-7B27E	27,300	Mature-Run	2.0	9,000 – 10,000	\$3.40M - \$3.60M	\$160 - \$185
LEAP-1B25	25,000	Mature-Run	2.0	10,000 – 11,000	\$4.00M - \$4.40M	\$165 - \$190
LEAP-1B27	26,400	Mature-Run	2.0	9,000 – 10,000	\$4.00M - \$4.40M	\$195 - \$220
LEAP-1B28	27,900	Mature-Run	2.0	8,000 – 9,000	\$4.00M - \$4.40M	\$225 - \$250

Assumptions:

- 2018 USD
- Repair, overhaul or replacement of thrust reversers and non-modular components, such as QEC, LRU or accessory units is not included
- Excludes Life-Limited Parts (LLPs)
- Temperate environment
- 10% Derate



VII. Typical Widebody Engine First-Run Performance Restoration Reserves

Engine	Thrust	Phase	Fl Leg	Time On-Wing (FC)	Costs	Rate (\$ / FH)
CF6-80E1A4	70,000	First-Run	5.0	4,600 – 5,000	\$6.20M - \$6.60M	\$240 - \$270
CF6-80E1A4B	72,000	First-Run	5.0	4,200 – 4,600	\$6.20M - \$6.60M	\$250 - \$280
PW4168	68,000	First-Run	5.0	4,700 – 5,100	\$6.20M - \$6.60M	\$245 - \$275
PW4170	70,000	First-Run	5.0	4,300 – 4,700	\$6.20M - \$6.60M	\$260 - \$290
Trent 768	67,500	First-Run	5.0	5,200 – 5,600	\$6.60M - \$7.00M	\$235 - \$265
Trent 772	71,200	First-Run	5.0	5,000 – 5,400	\$6.60M - \$7.00M	\$245 - \$275
GEnx-1B67	67,000	First-Run	7.0	3,800 – 4,200	\$6.10M - \$6.50M	\$215 - \$245
GEnx-1B70	70,000	First-Run	7.0	3,600 – 4,000	\$6.10M - \$6.50M	\$225 - \$255
GEnx-1B74	74,500	First-Run	7.0	3,400 – 3,800	\$6.10M - \$6.50M	\$240 - \$270
GEnx-1B76	76,100	First-Run	7.0	3,200 – 3,600	\$6.10M - \$6.50M	\$255 - \$285
Trent 1000-67	67,300	First-Run	7.0	3,600 – 4,000	\$6.20M - \$6.60M	\$225 - \$255
Trent 1000-70	70,100	First-Run	7.0	3,400 – 3,800	\$6.20M - \$6.60M	\$240 - \$270
Trent 1000-74	74,400	First-Run	7.0	3,200 – 3,600	\$6.20M - \$6.60M	\$255 - \$285
Trent 1000-76	76,000	First-Run	7.0	3,000 – 3,400	\$6.20M - \$6.60M	\$270 - \$300
GE90-110B	110,000	First-Run	7.0	3,200 – 3,600	\$9.50M - \$10.5M	\$420 - \$460
GE90-115B	115,000	First-Run	7.0	3,000 – 3,400	\$9.50M - \$10.5M	\$440 - \$480
Trent XWB-84	84,000	First-Run	7.0	3,300 – 3,700	\$6.40M - \$6.80M	\$260 - \$290

Assumptions:

- 2018 USD
- Repair, overhaul or replacement of thrust reversers and non-modular components, such as QEC, LRU or accessory units is not included
- Excludes Life-Limited Parts (LLPs)
- Temperate environment
- 10% Derate



VII. Typical Widebody Engine Mature-Run Performance Restoration Reserves

Engine	Thrust	Phase	Fl Leg	Time On-Wing (FC)	Costs	Rate (\$ / FH)
CF6-80E1A4	70,000	Mature-Run	5.0	3,700 – 4,100	\$8.20M - \$8.60M	\$420 - \$450
CF6-80E1A4B	72,000	Mature-Run	5.0	3,500 – 3,900	\$8.20M - \$8.60M	\$440 - \$470
PW4168	68,000	Mature-Run	5.0	3,700 – 4,100	\$8.20M - \$8.60M	\$425 - \$455
PW4170	70,000	Mature-Run	5.0	3,500 – 3,900	\$8.20M - \$8.60M	\$445 - \$475
Trent 768	67,500	Mature-Run	5.0	3,900 – 4,400	\$8.20M - \$8.60M	\$400 - \$430
Trent 772	71,200	Mature-Run	5.0	3,700 – 4,100	\$8.20M - \$8.60M	\$425 - \$455
GEnx-1B67	67,000	Mature-Run	7.0	3,200 – 3,600	\$7.50M - \$8.00M	\$315 - \$345
GEnx-1B70	70,000	Mature-Run	7.0	3,000 – 3,400	\$7.50M - \$8.00M	\$330 - \$360
GEnx-1B74	74,500	Mature-Run	7.0	2,800 – 3,200	\$7.50M - \$8.00M	\$355 - \$385
GEnx-1B76	76,100	Mature-Run	7.0	2,700 – 3,100	\$7.50M - \$8.00M	\$365 - \$395
Trent 1000-67	67,300	Mature-Run	7.0	3,100 – 3,500	\$7.50M - \$8.00M	\$325 - \$355
Trent 1000-70	70,100	Mature-Run	7.0	2,900 – 3,300	\$7.50M - \$8.00M	\$340 - \$370
Trent 1000-74	74,400	Mature-Run	7.0	2,700 – 3,100	\$7.50M - \$8.00M	\$365 - \$395
Trent 1000-76	76,000	Mature-Run	7.0	2,600 – 3,000	\$7.50M - \$8.00M	\$380 - \$410
GE90-110B	110,000	Mature-Run	7.0	2,500 – 2,800	\$11.0M - \$12.0M	\$600 - \$640
GE90-115B	115,000	Mature-Run	7.0	2,400 – 2,700	\$11.0M - \$12.0M	\$620 - \$660
Trent XWB-84	84,000	Mature-Run	7.0	2,800 – 3,200	\$7.70M - \$8.20M	\$365 - \$395

Assumptions:

- 2018 USD
- Repair, overhaul or replacement of thrust reversers and non-modular components, such as QEC, LRU or accessory units is not included
- Excludes Life-Limited Parts (LLPs)
- Temperate environment
- 10% Derate



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