Engine Maintenance Management

Managing Technical Aspects of Leased Assets

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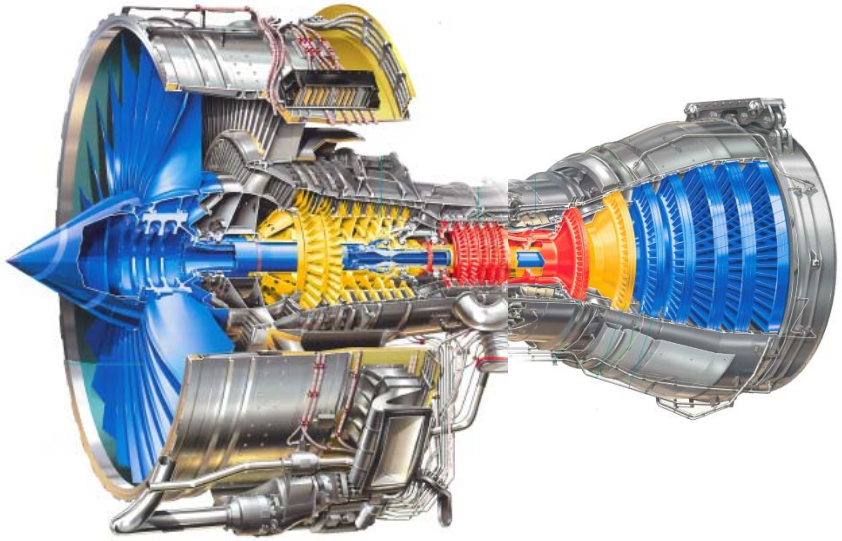
Agenda

- Technical Drivers of Off-Wing Maintenance
- Commercial Considerations of Off-Wing Maintenance
- Lessor & Lessee Considerations of Off-Wing Maintenance
- Flight Hour Agreement (FHA) Programs

Appendix A Engine Maintenance Costs & Reserve Rates

A modern 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**.



Technical Drivers of Off-Wing Maintenance

Technical Drivers of Off-Wing Maintenance

Technical drivers of off-wing engine maintenance can be broadly **categorized into four areas**:

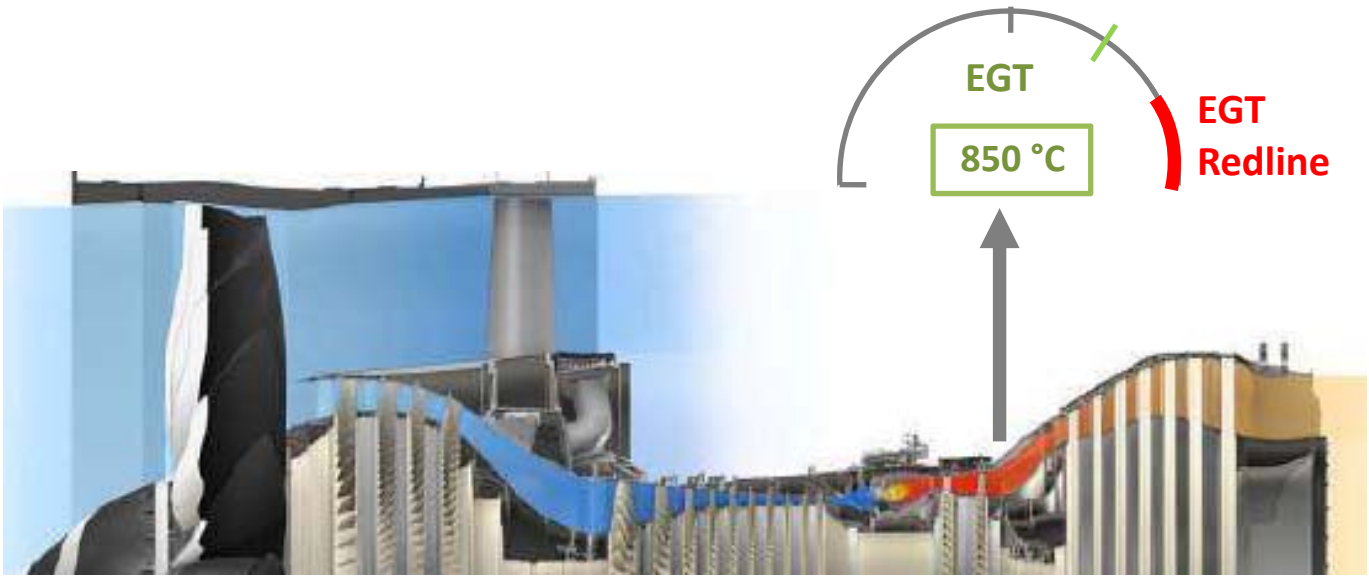
1. EGT Margin Deterioration
2. Expiry of Life-Limited Parts (LLPs)
3. Hardware Deterioration
4. Other Removal Causes

Technical Drivers of Off-Wing Maintenance

1. EGT Margin Deterioration

Exhaust Gas Temperature - EGT is **a measure of the temperature** of the gas as it leaves the turbine unit.

Engines are certified with temperature limits enforced via a limit on maximum take-off EGT, referred to as the **redline EGT**.

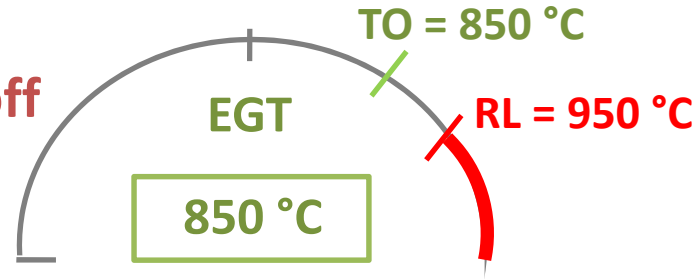


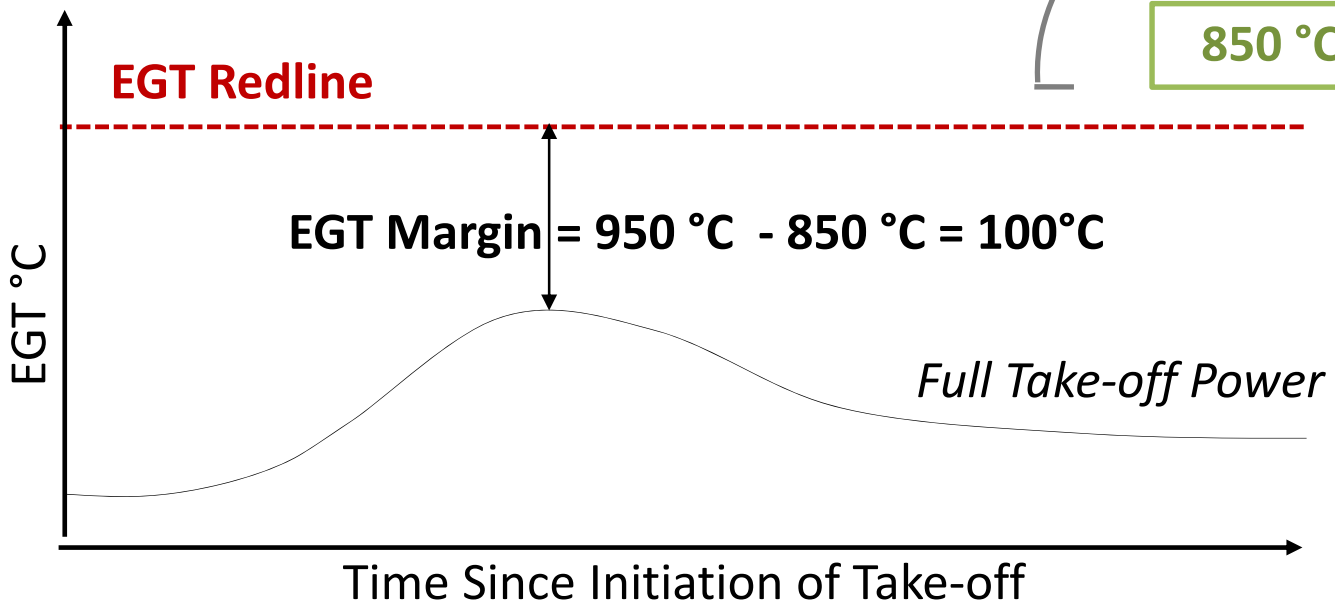
Technical Drivers of Off-Wing Maintenance

1. EGT Margin Deterioration

EGT Margin (EGTM) is the difference between the **peak EGT** incurred during take-off and the certified redline EGT. It is used to evaluate and track engine **time on-wing & health**.

EGT Margin °C = EGT Redline – EGT Take-off



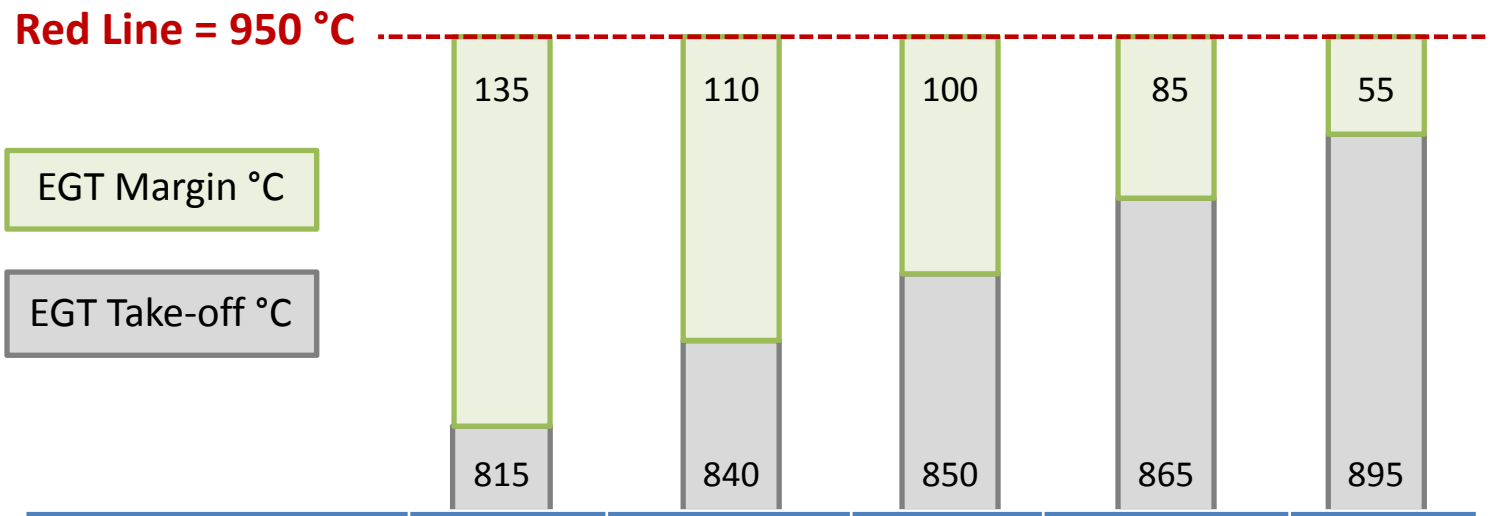


Technical Drivers of Off-Wing Maintenance

1. EGT Margin Deterioration

EGT margins (EGTM) are at their highest levels when the engines are new or just following refurbishment.

Example - EGT Margins for new CFM56-7B Engines



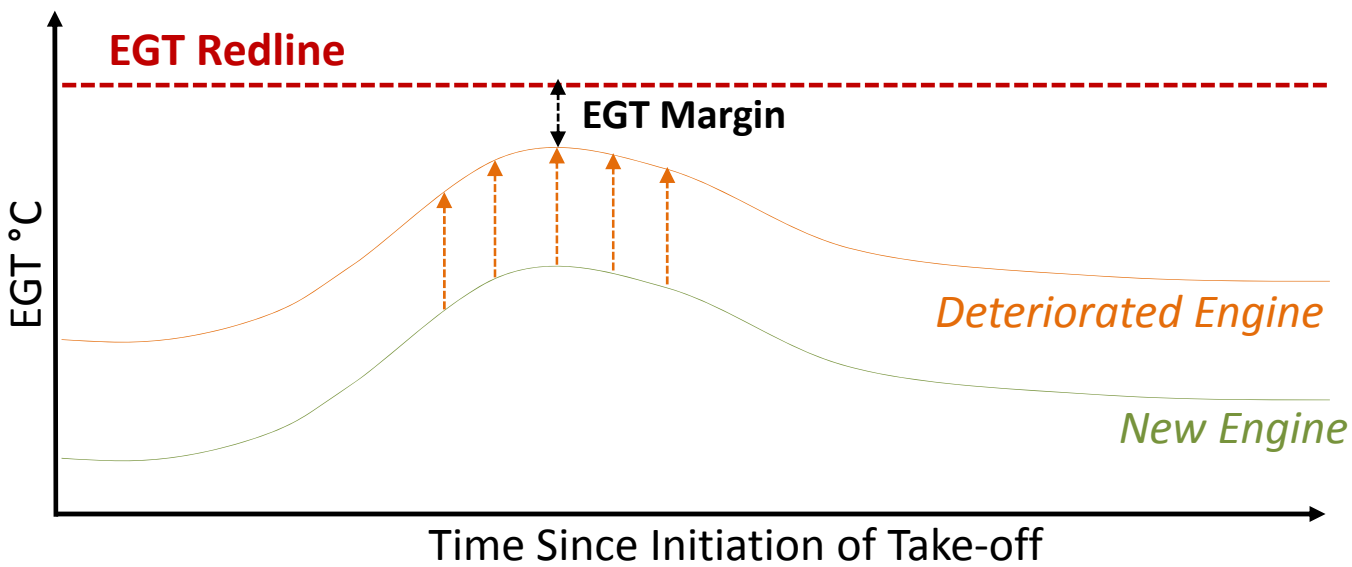
Engine Model	7B20	7B22	7B24	7B26	7B27
Takeoff Thrust	20,600	22,700	24,200	26,300	27,300

Technical Drivers of Off-Wing Maintenance

1. EGT Margin Deterioration

As the engine deteriorates, the EGT margin will rise until it reaches **Redline EGT**, or the absolute temperature limit which cannot be exceeded without damaging the engine

EGT Margin Deterioration

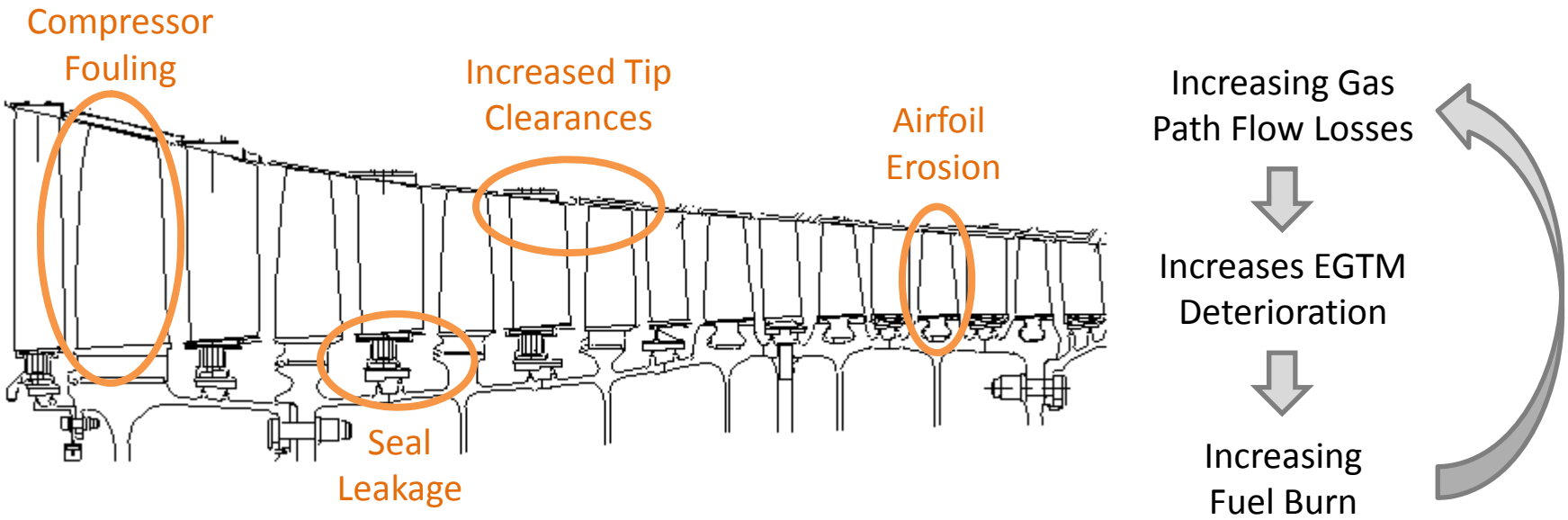


Technical Drivers of Off-Wing Maintenance

1. EGT Margin Deterioration

EGT Margin Deterioration largely results from **hardware distress** (e.g. gradual increase in clearance between turbine blade tips & surrounding static seals or shrouds, and combustor distress)

EGT Margin Deterioration Cycle

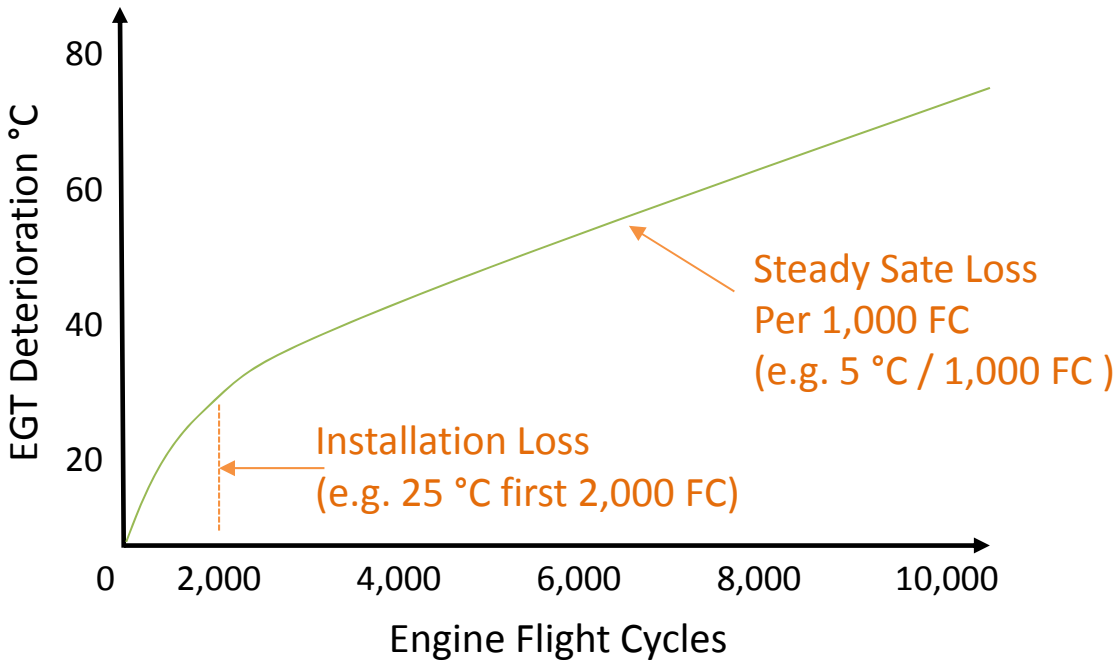


Technical Drivers of Off-Wing Maintenance

1. EGT Margin Deterioration

Rates of EGTM deterioration are highest during initial operation & subsequently **stabilize to reach a steady state level.**

Relationship Between EGTM Deterioration & Engine FC



Technical Drivers of Off-Wing Maintenance

1. EGT Margin Deterioration

Rate of EGTM deterioration is influenced by:

Flight Operations - rate of EGTM deterioration increases as:

- Engine thrust rating increases
- Engine derate decreases
- Average flight leg decreases
- Operating environment becomes more severe

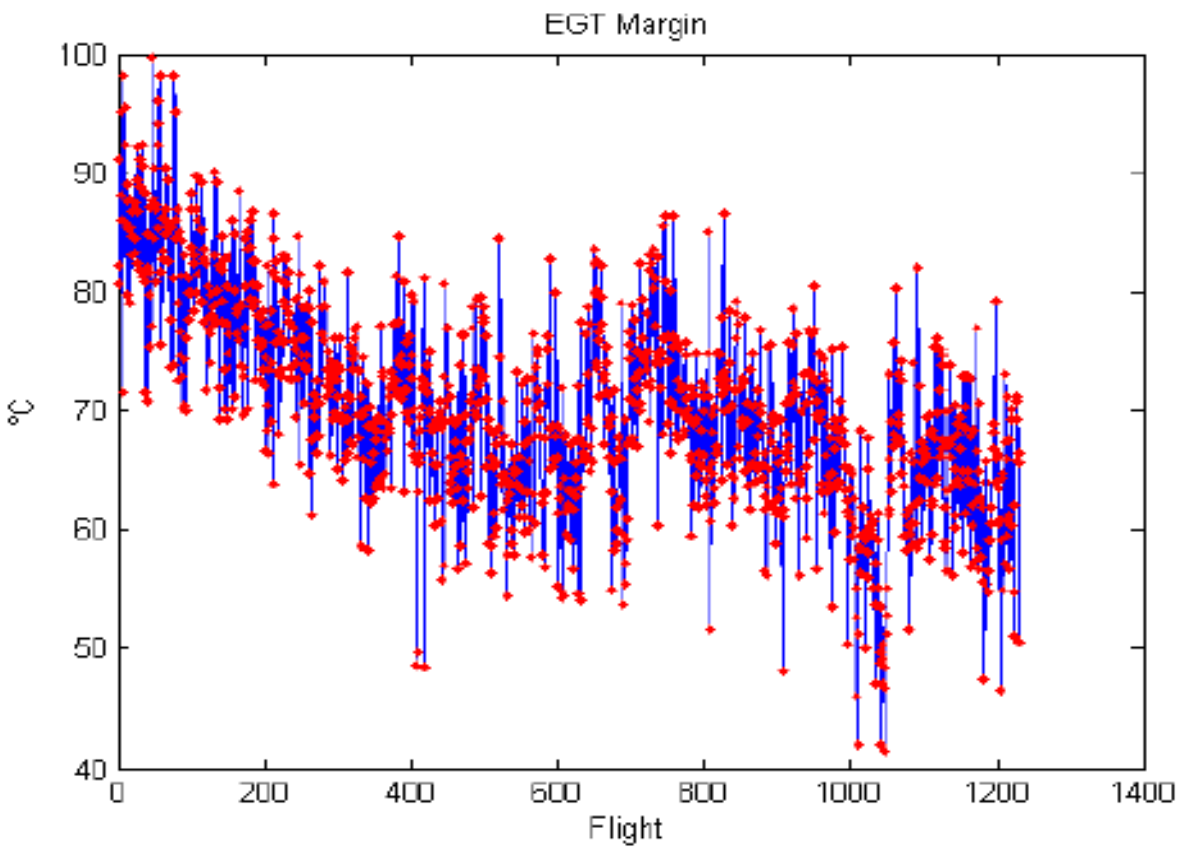
Engine Age (Maturity)

- **First-run** engines traditionally have higher EGTM and lower EGTM deterioration rates relative to mature engines

Technical Drivers of Off-Wing Maintenance

1. EGT Margin Deterioration

EGTM trend monitoring - trend monitoring of EGTM looks at successive snapshots to help analyze the wear trend of engines.

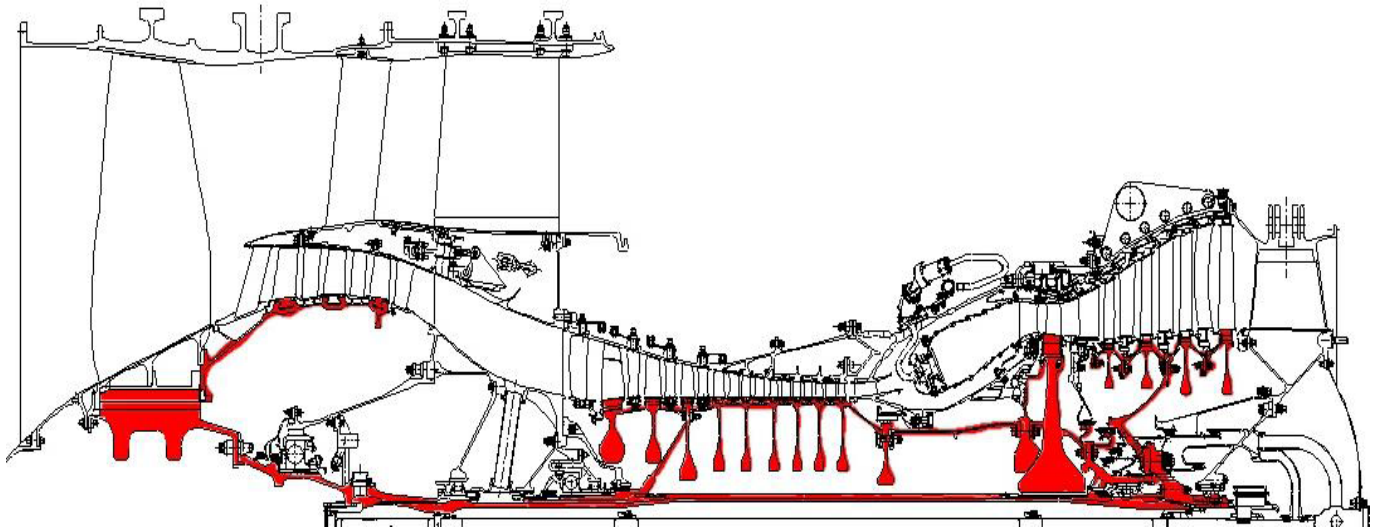


Technical Drivers of Off-Wing Maintenance

2. Expiry of Life-Limited Parts (LLPs)

Within engine modules are certain **parts that cannot be contained** if they fail, and as such are governed by the number of flight cycles operated.

These parts are known as **Life-Limited Parts (LLP)** and generally consist of disks, seals, spools, and shafts. **LLPs are discarded** once their useful lives are reached.



Technical Drivers of Off-Wing Maintenance

2. Expiry of Life-Limited Parts (LLPs)

LLPs account for a **high proportion** of mx costs on **short-haul missions** due to lower avg. flight legs & higher cycle accumulation

CFM567B - SHOP VISIT FORECASTER		SHOP VISIT 1		SHOP VISIT 2		SHOP VISIT 3	
RATING	-7B26/E	TOW (FH)	25,495	TOW (FH)	12,600	TOW (FH)	16,200
FLIGHT LEG	1.80	TOW (FC)	14,164	TOW (FC)	7,000	TOW (FC)	9,000
DERATE	10%	BUILD GOAL (FC)	7,000	BUILD GOAL (FC)	9,000	BUILD GOAL (FC)	9,000
REGION	Temperate	WORKSCOPE LEVEL	PR	WORKSCOPE LEVEL	PR+	WORKSCOPE LEVEL	PR
SUMMARY DATA							
SUMMARY	PR : $10.26 M LLP : $4.87 M **SV : $15.13 M** PR ($/FH) : 145.60 Stub Loss : 10.9%	PR : $2.53 M LLP : $1.40 M **SV : $3.93 M** PR ($/FH) : 99.20 Stub Loss : 15.1%	36% 64%	PR : $2.60 M LLP : $1.31 M **SV : $3.91 M** PR ($/FH) : 206.30 Stub Loss : 10.3%	33% 67%	PR : $2.54 M LLP : $1.40 M **SV : $3.94 M** PR ($/FH) : 156.50 Stub Loss : 10.3%	36% 64%

LLPs account for a **low proportion** of mx costs on **long-haul missions** due to higher avg. flight legs & lower cycle accumulation

GE90 - SHOP VISIT FORECASTER		SHOP VISIT 1		SHOP VISIT 2		SHOP VISIT 3	
RATING	-115B	TOW (FH)	18,868	TOW (FH)	16,000	TOW (FH)	16,000
FLIGHT LEG	8.00	TOW (FC)	2,358	TOW (FC)	2,000	TOW (FC)	2,000
DERATE	10%	BUILD GOAL (FC)	2,000	BUILD GOAL (FC)	2,000	BUILD GOAL (FC)	2,000
SUMMARY DATA							
SUMMARY	**PR : $26.25 M** **LLP : $3.01 M** **SV : $29.26 M** PR ($/FH) : 392.60 Stub Loss : 1.3%	PR : $5.25 M LLP : $ M **SV : $5.25 M** PR ($/FH) : 278.30 Stub Loss : 0.0%	0% 100%	PR : $7.00 M LLP : $0.00 M **SV : $7.00 M** PR ($/FH) : 437.50 Stub Loss : 0.0%	0% 100%	PR : $7.00 M LLP : $1.26 M **SV : $8.26 M** PR ($/FH) : 437.50 Stub Loss : 2.7%	15% 85%

Technical Drivers of Off-Wing Maintenance

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,
- Erosion / Corrosion / Oxidation

4. Other Removal Causes

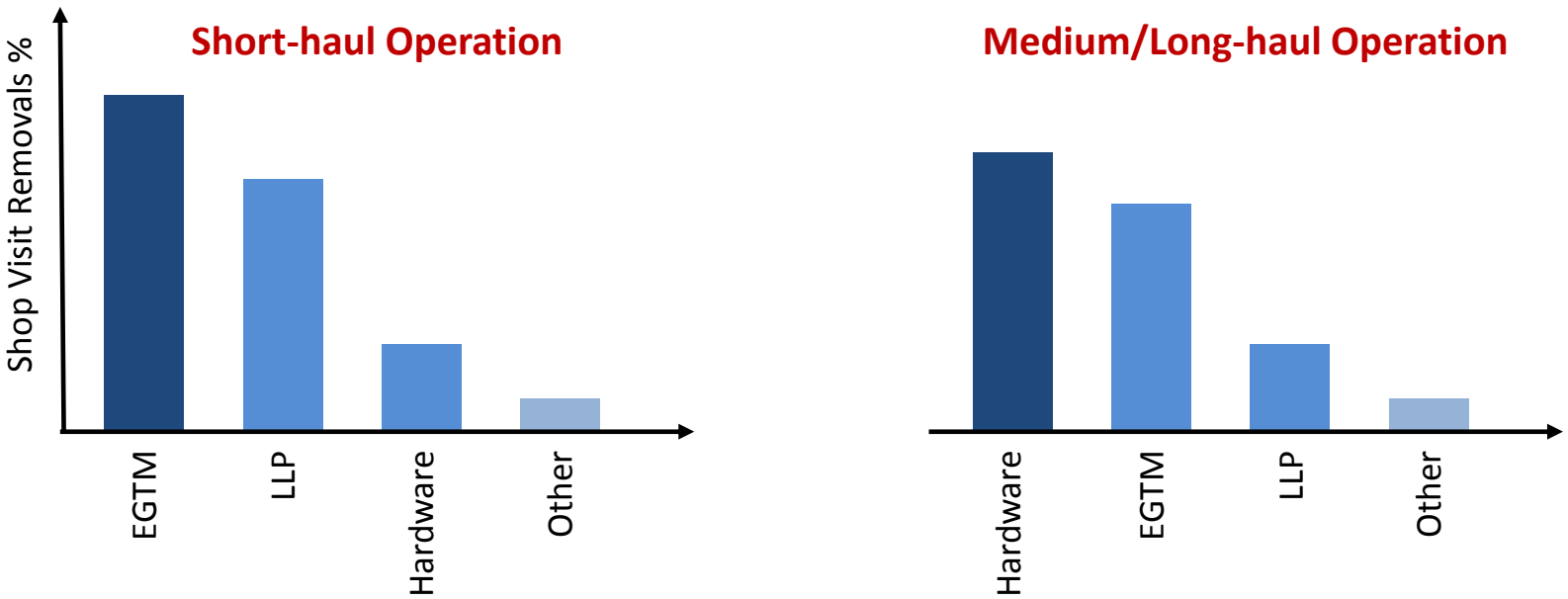
Other removal causes include amongst others:

- Foreign Object Damage (FOD),
- Oil Leak / High Oil Consumption,
- Vibration,
- Airworthiness Directives

Technical Drivers of Off-Wing Maintenance

- Engines operating on **short-haul flights** experience higher removals due to: a.) EGTM deterioration & b.) LLP expiry.
- Engines operating on **medium-to-long haul flights** experience higher removals due to deteriorating: a.) hardware & b.) EGTM.

Technical Drivers of Engine Removals by Operation



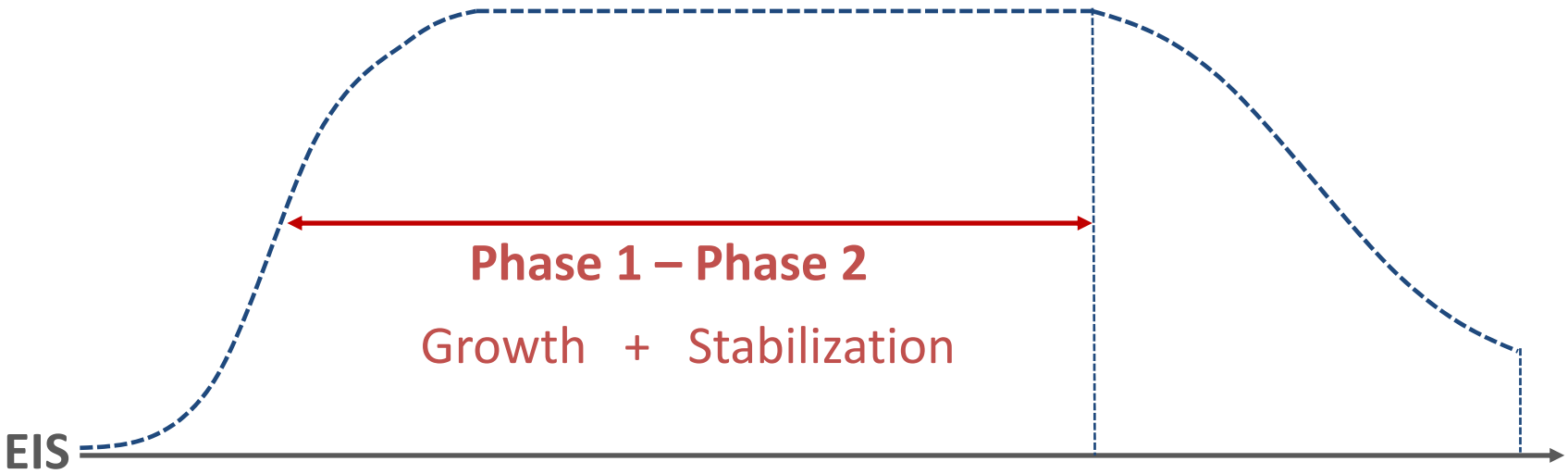
Commercial Considerations of Off-Wing Maintenance

Commercial Considerations of Off-Wing Maintenance

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

- **Entry Into Service (EIS)** - engine first enters into service.
- **Growth** – engine gaining acceptance & orders are increasing,
- **Stabilization** – engine sales are at a consistent, steady level.
- **Dispersion** - engine sales drop to a low level & are being sold for spare parts or scrap.

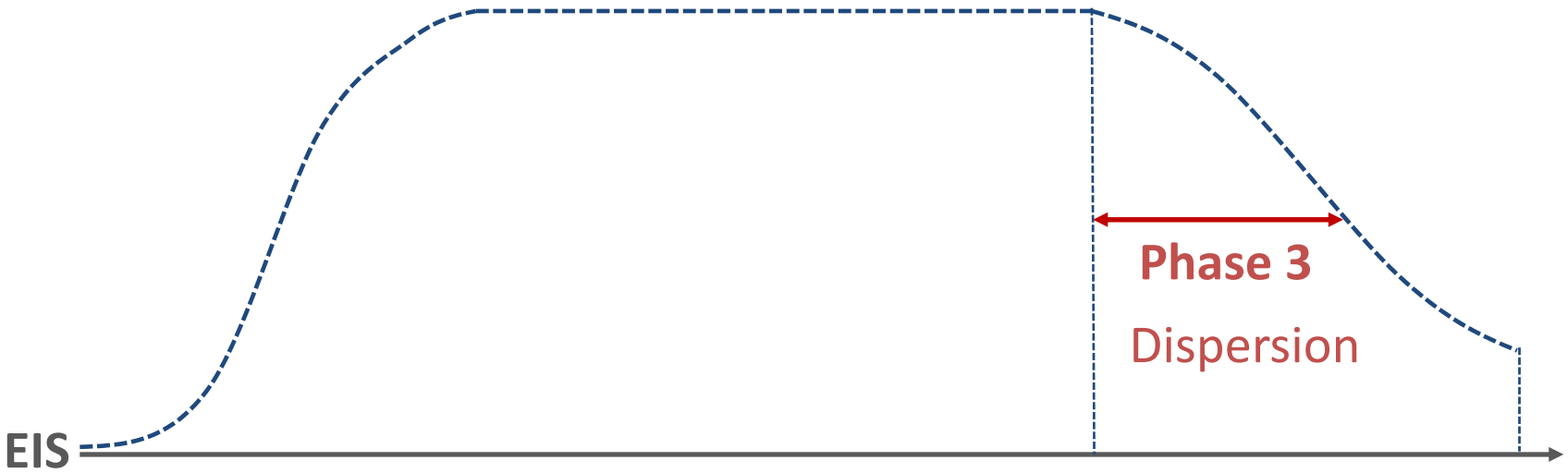
Commercial Considerations of Off-Wing Maintenance



Workscope Considerations : Phase 1–2 (Growth + Stabilization)

- Build for minimum number of SVs, which allows one to achieve lower shop DMC ($ / FH) but higher SV costs.
- Use OEM parts & repairs,
- Invest / Benefit from latest SB modifications & technology
- Build to maximize EGTM recovery and time on-wing

Commercial Considerations of Off-Wing Maintenance



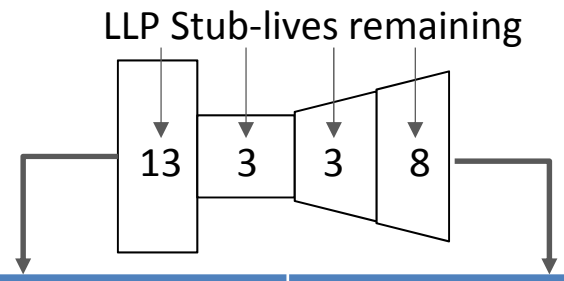
Workscope Considerations : Phase 3 (Dispersion)

- Maximizing usage of LLPs, which often leads to lower SV costs but higher DMC ($ / FH)
- Weigh benefits of purchasing replacement engine in lieu of performing a shop visit
- Weigh benefits of PMA parts and DER repairs

Commercial Considerations of Off-Wing Maintenance

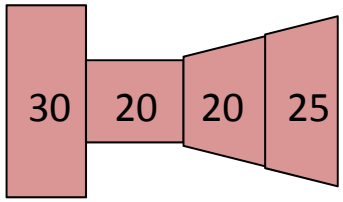
Example Workscope Consideration:

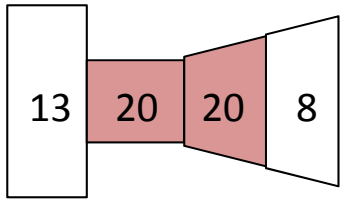
Engine Enters Shop →



	Growth & Stabilization	Dispersion
Workscope	Full Overhaul	Core Restoration
LLP Replacement	Fan + Core + LPT	Core Modules
Build-Goal	20,000 FC	8,000 FC
Restoration Cost $	$2.50M	$2.0M
LLP Cost $	$2.50M	$1.5M
Total Shop Visit Cost $	$5.0M	$3.5M
Restoration $ / FH @ 1.5 FL	$83.33 / FH	$102.50 / FH

Engine Exits Shop →





Lessor & Lessee Considerations of Off-Wing Maintenance

Lessor & Lessee Considerations of Off-Wing Maintenance

Engines installed on leased aircraft often times **have more constraints** and will depend on the:

- Delivery conditions
- Term of the lease
- Redelivery conditions

Commercial considerations within a lease **factor the mirror-in-mirror-out philosophy** whereby the status of engine redelivery conditions are used to establish delivery conditions.

Lessor & Lessee Considerations of Off-Wing Maintenance

Mirror-in-Mirror-out Philosophy:

Lessee 1 **returns & lessor accepts engines** meeting defined minimums per the lease (e.g. 6,000 FH / 4,000 FC)

Lessor **delivers & lessee 2 accepts engines** meeting defined minimums per the lease (e.g. 6,000 FH / 4,000 FC)

Lessor & Lessee Considerations of Off-Wing Maintenance

Lessors depend on **transferability & liquidity**, and **residual value protection** of their engines.

So parts and repairs installed during maintenance events have to be acceptable to all operators and regulatory jurisdictions.

That is why most lessors do not allow for:

- PMA parts to be installed , &
- DER repairs

Flight Hour Agreement (FHA) Programs

Flight Hour Agreement (FHA) Programs

Under an 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.

Advantages

- **Cost Visibility** - Smoothing of expenditure designed principally to address the cost and timing uncertainties inherent in traditional time and material contracts
- **Greater Value** - Overhauled to the latest standards; all ADs and target Service Bulletins (SBs) issued for the life of the program are incorporated at shop visit at OEM's expense
- **Reduced Infrastructure** - Relieves the operator of the need to purchase stocks of engines and accessories

Flight Hour Agreement (FHA) Programs

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 a situation where there is no aftermarket competition on any level ; where the OEM controls all commercial aspects – spares, materials, repairs, etc.

Flight Hour Agreement (FHA) Programs

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.

Term Options

1. **Per Fleet Cumulative Term** - Fixed period of time for the fleet: e.g. 12 years from entry into service of first aircraft,
2. **Per Engine Term** - Fixed period of time for each engine: e.g. 12 years from EIS of each engine.
3. **Per Shop Visit Term** - Fixed number of Restoration Shop Visits per engine, e.g. term finishes for each engine after 1st SV.

Appendix A - Maintenance Costs & Reserve Rates

Engine	Thrust	Phase	Fl Leg	Time On-Wing (FC)	Costs 2015 $	Rate ($ / FH)
CFM56-5B6/3	23,500	First-Run	1.7	16,000 - 17,000	$2.25M - $2.5M	$80- $88
CFM56-5B4/3	27,000	First-Run	2.0	11,500 - 12,500	$2.25M - $2.5M	$95 - $105
CFM56-5B3/3	33,000	First-Run	2.0	8,000 - 9,000	$2.25M - $2.5M	$140 - $155
CFM56-7B24E	24,000	First-Run	1.7	16,000 - 17,000	$2.25M - $2.5M	$80- $88
CFM56-7B26E	26,300	First-Run	2.0	12,500 - 13,500	$2.25M - $2.5M	$90- $100
CFM56-7B27E	27,300	First-Run	2.0	11,000 - 12,000	$2.25M - $2.5M	$105 - $115
V2524-A5 S1	24,000	First-Run	1.7	15,500 - 16,500	$2.25M - $2.5M	$80 - $88
V2527-A5 S1	27,000	First-Run	2.0	11,000 - 12,000	$2.25M - $2.5M	$105 - $115
V2533-A5 S1	33,000	First-Run	2.0	8,500 - 9,500	$2.25M - $2.5M	$140 - $150
Trent 772	71,200	First-Run	6.0	3,500 - 4,000	$5.5M - $6.0M	$230 - $250
PW4068	68,000	First-Run	6.0	3,250 - 3,750	$5.0M - $5.5M	$230 - $250
CF6-80E1A4	70,000	First-Run	6.0	3,250 - 3,750	$4.5M - $5.5M	$230 - $250
GE90-115B	115,000	First-Run	8.0	2,500 – 3,000	$6.5 - $7.5M	$280 - $300

Appendix A - Maintenance Costs & Reserve Rates

Engine	Thrust	Phase	Fl Leg	Time On-Wing (FC)	Costs 2015 $	Rate ($ / FH)
CFM56-5B6/3	23,500	Mature-Run	1.7	12,800 - 13,800	$2.5M - $3.0M	$125- $145
CFM56-5B4/3	27,000	Mature-Run	2.0	9,500 - 10,500	$2.5M - $3.0M	$135 - $155
CFM56-5B3/3	33,000	Mature-Run	2.0	6,500 - 7,500	$2.5M - $3.0M	$190 - $210
CFM56-7B24E	24,000	Mature-Run	1.7	12,800 - 13,800	$2.5M - $3.0M	$125 - $145
CFM56-7B26E	26,300	Mature-Run	2.0	10,000 - 11,000	$2.5M - $3.0M	$130 - $150
CFM56-7B27E	27,300	Mature-Run	2.0	8,800 - 9,800	$2.5M - $3.0M	$135 - $155
V2524-A5 S1	24,000	Mature-Run	1.7	12,500 - 13,500	$2.5M - $3.0M	$125 - $145
V2527-A5 S1	27,000	Mature-Run	2.0	8,800 - 9,800	$2.5M - $3.0M	$135 - $155
V2533-A5 S1	33,000	Mature-Run	2.0	7,000 - 8,000	$2.5M - $3.0M	$190 - $210
Trent 772	71,200	Mature-Run	6.0	2,500 - 3,000	$7.0M - $8.0M	$380 - $440
PW4068	68,000	Mature-Run	6.0	2,500 - 3,000	$6.5M - $7.5M	$360 - $420
CF6-80E1A4	70,000	Mature-Run	6.0	2,500 – 3,000	$7.0M - $8.0M	$380 - $440
GE90-115B	115,000	Mature-Run	8.0	1,800 - 2,200	$10.5 - $11.5M	$480 - $560