Keeping Score: Analysis of an Engine's Shop Visit Rate

By: Shannon Ackert

Abstract

The commercial aviation industry applies a common set of ground rules and defined metrics that are used to monitor the operational reliability of their products. In the category of engine reliability, one of the primary parameters used to monitor operational performance is the shop visit rate (SVR). Observing the rate at which the SVR changes over a specified period is an effective process to measure the efficacy of an engine's inherent design, product upgrades, maintenance practices, and quality improvements.

While an engine's shop visit rate is a versatile and powerful performance measure, the parameter is often misunderstood and cited incorrectly as a time on-wing metric. A characteristic point about the SVR is that its primary purpose as a performance metric is to quantify the ***rate*** of engine removals within a specified period, generally quantified in events per 1,000 engine flight hours.

This report provides both a quantitative and qualitative analysis of an engine's Shop Visit Rate (SVR) and highlights why the parameter serves as a useful measure of overall reliability; its intended purpose being to measure levels of reliability inherent in the engine as designed and manufactured, and the reliability that is observable during operation.

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1. INTRODUCTION

A rate of change is a rate that describes how one quantity changes in relation to another quantity. Extending this definition to an engine's shop visit rate (SVR) enables one to measure changes in engine removals over corresponding changes in periods of time.

The rate at which the SVR changes over a specified period is a valuable index to gauge an engine's overall reliability. The SVR is especially practical since it measures the level of reliability inherent in the system as designed, and the reliability that is observable during operation. The index is particularly useful in qualifying the impact of product improvements.

The relative stability and accuracy of the shop visit rate improves as an engine model progresses through its economic life cycle. As an engine ages, and initial production issues are identified and addressed, its associated SVR begins to stabilize and eventually returns to a normal state. In this normalized state, the SVR is classified as "mature" during which time the index closely aligns with average time on-wing.

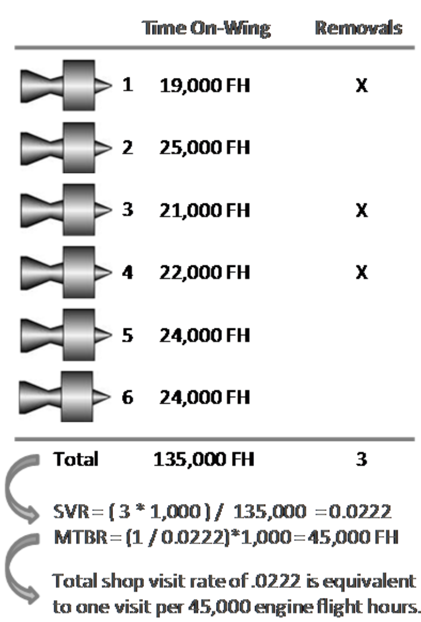
As a performance metric, the shop visit rate quantifies the ***rate*** of engine replacements, or the speed at which engine removals change over a specific period. (e.g. for every 50,000 hours of combined engine flight hours, 1 unit was replaced).

2. SHOP VISIT RATE CALCULATION

The shop visit rate is a parameter 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 1. 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.

The engine's Mean-Time-Between Removals MTBR, another widely used reliability metric, is the reciprocal of the total SVR. The MTBR can be calculated by dividing the total engine flying hours accrued in a period by the number of engine removals (scheduled & unscheduled) that occurred during the same period.

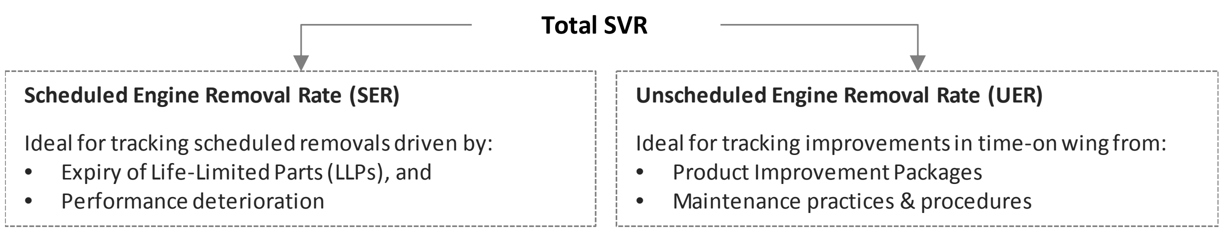
Figure 1 – Example Shop Visit Rate Calculation



3. SHOP VISIT RATE COMPONENTS

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 2. Each of these components provides further insight into engine reliability, most notably the UER given this parameter can help identify chronic problems. The following discusses each of these parameters in greater detail.

Figure 2 – Total Shop Visit Rate Constituents



Scheduled Engine Removal Rate - The SER measures how often a particular 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.

4. SHOP VISIT RATE APPLICATIONS

The SVR, along with the In-Flight Shut-Down rate (IFSD) and Aborted Take-Off rate (ATO), is one of numerous reliability metrics used by decision makers to track an engine's operational performance. The metric is calculated monthly as a fleet average, and their absolute levels are 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 improvement initiatives, and
- Useful in determining spare engine requirements

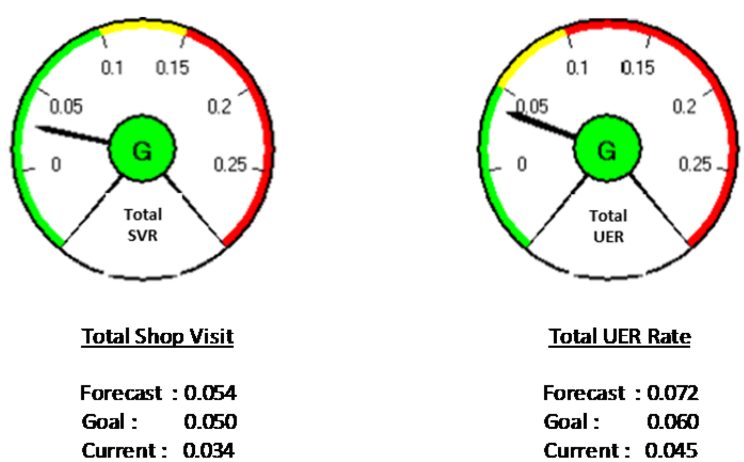
There are **two popular methods** of tracking SVRs that have been especially useful in monitoring reliability performance of engine fleets. These methods consist of the: 1.) Scorecard method and 2.) Time-series method. The following discusses the attributes of each.

4.1 Scorecard Method

The scorecard method gives managers an all-inclusive summary view of their SVR performance – see Figure 3. If the rate is 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.

The scorecard method can serve as an effective 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.

Figure 3 – Example SVR Scorecard Chart



4.2 Time-series Method

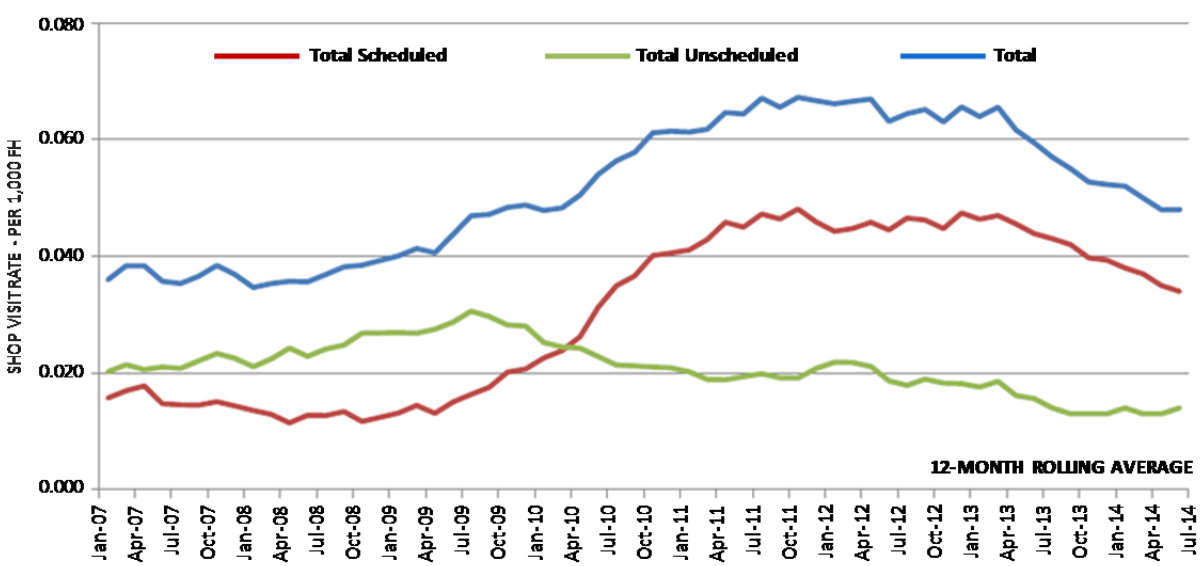
The time-series method is used when observations are made on a repeated basis and serves as an effective means to monitor an engine's SVR as a **trending metric**. Shop visit rate trends are plotted against time intervals to measure shifts in this parameter that results from unknown deficiencies (e.g. 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. The charts are also ideal for analyzing comparable engine fleets - those having similar models, age & operation – to determine differences, if any, in levels of operational reliability.

Figure 4 illustrates a long-term trend report highlighting movements in engine total, scheduled, and unscheduled removal rates. In the example illustrated, the UER is trending lower over time, implying effectiveness in product improvements, maintenance practices, or a combination of both.

Time series analysis plots are a useful tool for providing easy visibility to SVR shifts and assessing if there are any observable trends over long periods of time. SVR trend data is commonly plotted on a 12-month rolling average basis to smooth out irregularities.

Figure 4 – Example SVR Time-series Chart



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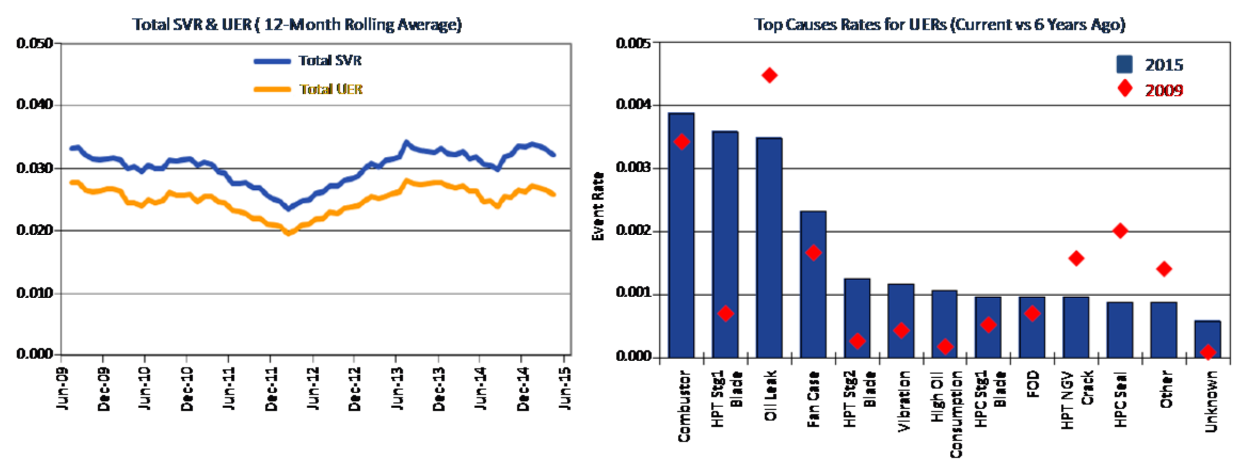
Although removal rates are effective at measuring in-service performance, the parameters cannot identify the dominant causes that induce unscheduled engine removals. Given that unscheduled engine removals have severe operational consequences then it becomes imperative to identify those factors (e.g. component failure trends) that are contributing to these removal rates. Once identified, engine OEMs rank these failure trends according to their "cause rates."

Figure 5 illustrates the time-series SVR and UER removal rate trend representative of a widebody engine, as well as the ranking of the top causes contributing to unscheduled removals.

Figure 5 – SVR & UER Time-series Chart, and Associated Actuarial Analysis



The results of the failure analysis will determine the degree of priority over how to address reliability shortcomings. Those causes having a direct effect on safety will receive immediate priority while those having a direct effect on operational reliability will undergo a product improvement trade-off study – Appendix A illustrates a decision diagram that is relevant in determining whether a proposed product improvement is likely to be accomplished.

Engine SVR Perspective

The SVR measures the operational performance of an engine mainly on the basis that it is considered to be a single component. Therefore, the metric plays a role in validating overall engine reliability. The SVR is not ideally suited for evaluating the reliability of individual components and subassemblies affecting the engine.

5. FACTORS INFLUENCING THE SHOP VISIT RATE

Several factors combine to influence the rate of engine removals. These factors consist of 1.) Inherent design reliability, 2.) Operational reliability, and 3.) Maintenance practices. The following examines the impact these factors impose on an engine's shop visit rate.

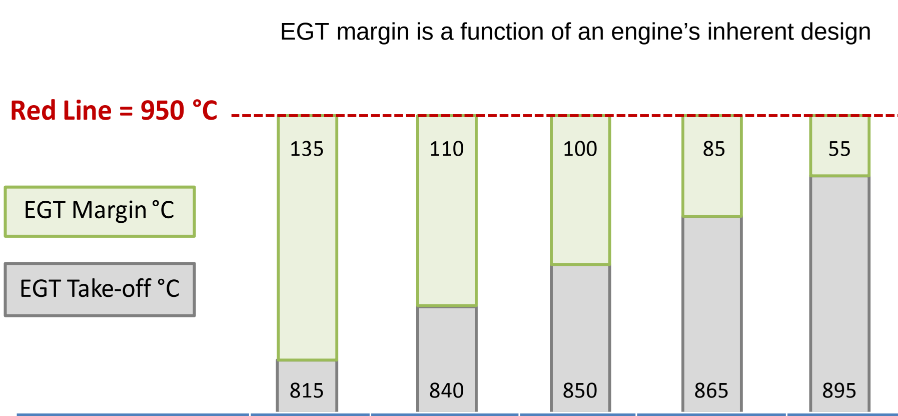
5.1 Inherent Design Reliability

Inherent design reliability is the level of reliability inherent in the system as designed and manufactured. Factors influencing propulsion system design are many and varied but mainly consist of a.) methods of construction, b.) level of technology, c.) use of advanced materials (e.g. lightweight aluminum, titanium & composites), c.) blade and rotor design (e.g. two vs. three-shaft configuration), and d.) level of bypass ratio. The integration of these mechanical design features facilitates the objective of optimizing both thermodynamic & propulsive efficiency while also achieving low shop visit rates through:

- ✓ High EGT margin, and
- ✓ High LLP stub lives

EGT Margin is a parameter used to evaluate and track engine time on-wing and health. An engine's EGT Margin is the difference between the peak EGT incurred during a take-off and the certified redline. The level of EGT margin of an engine **is a function of an engine's inherent design**. Engines with high EGT margins remain on on-wing longer and thus tend to have lower shop visit rates. Figure 6 illustrates the available EGT Margins for new CFM56-7B engines.

Figure 6 – CFM56-7B EGT Margins



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

Source : CFMI

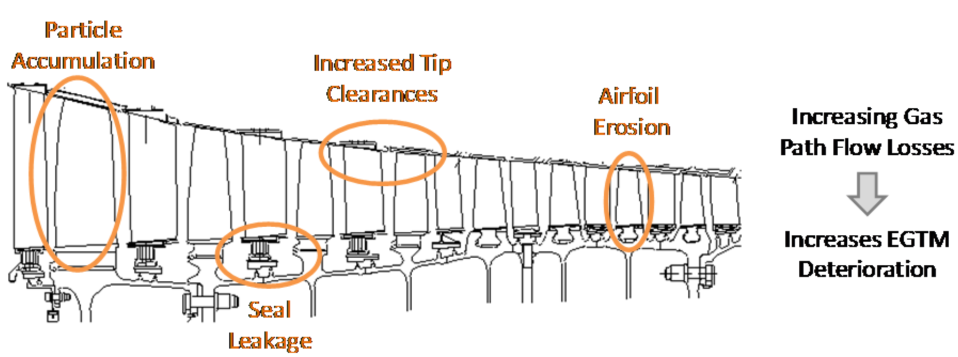
The term LLP stub-life is used to represent the shortest life remaining of all LLPs installed in an engine. Engines whose inherent design includes LLPs with high stub-lives will tend to experience lower rates of engine removals compared to engines with lower LLP stub-lives. Engines designed with high LLP stub-lives have overall operational advantages, but particularly if operating on short-haul routes.

5.2 Operational Reliability

Operational reliability is the reliability that is observable during operation. An engine's SVR is largely influenced by the severity of its operation; defined by the average flight leg flown, operating environment, and engine thrust & derate. More demanding operating conditions will impose greater stress on engine parts and components, resulting in higher removal rates driven by increasing rates of EGT margin deterioration.

EGT margin deterioration largely results from a.) hardware distress as a result of the gradual increase in clearance between the turbine blade tips & surrounding static seals or shrouds, and b.) combustor distress – Figure 7. As the gas path of an engine deteriorates, it becomes necessary to adjust the engine power to a higher setting to obtain the required thrust. Higher power settings contribute to increased fuel flow that creates higher EGT and reduced EGT margins. EGT margin deterioration is often the primary driver of engine removals, particularly for engines operating on short-haul missions.

Figure 7 – Causes of EGT Margin Deterioration



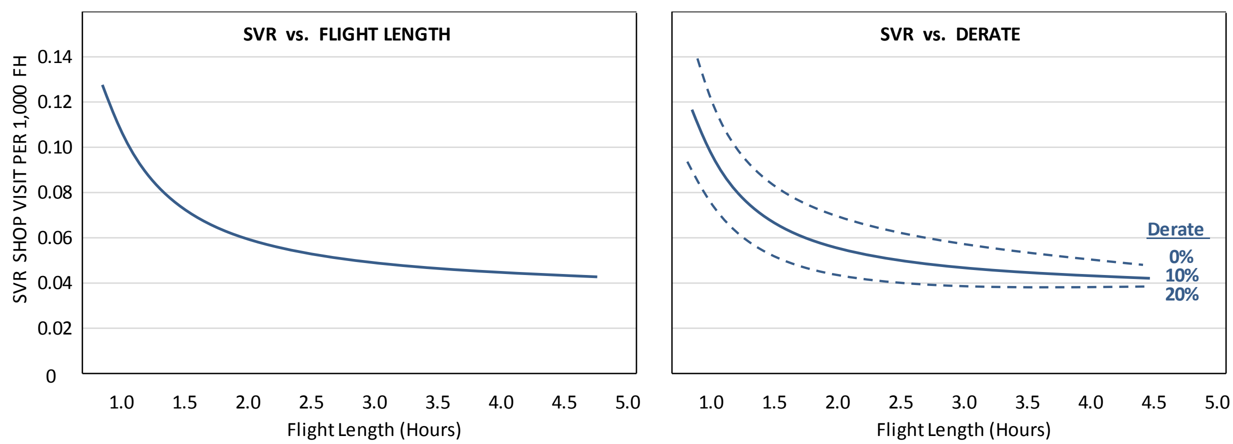
The rate of EGT margin deterioration is affected by how an engine is operated. For a particular engine, actual rates of deterioration will vary with operational factors, such as engine derate and average flight length flown. Engines operating on short flight legs experience higher rates of deterioration than those operating higher flight legs. Additionally, engines operating in hot & dusty environments experience greater EGT margin deterioration rates than those operating in cool & temperate environments. A brief discussion of each of these influencing factors follows.

Flight Leg – Shorter flight segments force engines to spend a larger proportion of total flight time using take-off and climb power settings resulting in more rapid EGT margin deterioration rates, which translates into higher SVRs and lower time on-wing. Figure 8 shows the relationship between an engine's SVR and flight length. The shape of the curves implies that short flight length (reflective of a higher cyclic operation) has a significant impact on trending the engine shop visit rates higher.

Thrust & Derate Level - Higher thrust generates higher core temperatures, which exposes constituent parts in the engine to greater thermal stress resulting in higher EGT margin deterioration, higher SVRs, and lower time on-wing.

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. Lower derate translates into higher take-off thrust, resulting in higher deterioration rates. It further suggests that thrust derate imposes a larger impact on reducing shop visit rates for short flight lengths versus longer flight lengths – Figure 8.

Figure 8 – Total SVR Constituents



Operating Environment - Engines operated in hot-dry and erosive-corrosive environments are exposed to greater hardware deterioration leading to accelerated EGT margin deterioration and higher shop visit rates.

5.3 Maintenance Practices

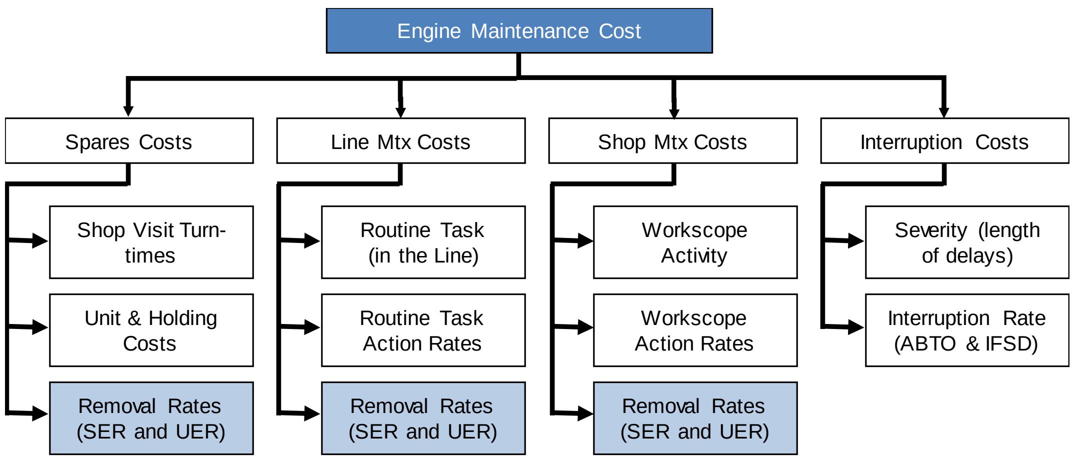
Notwithstanding the maximum limits of operational performance established by an engine's design, it is obvious that following good maintenance practices also minimizes shop visit rates. Techniques such as effective management of life limited parts, workscope optimization, incorporation of reliability improvement modifications, and good engine health monitoring; all contribute to improving an engine's shop visit rate.

6. SHOP VISIT RATE & IT'S INFLUENCE ON ENGINE MAINTENANCE COSTS

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 9 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 9 –Drivers of Engine Maintenance Costs



Engine spares cost are the costs of provisioning for a fleet of engines and is dependent on replenishment of rotable spares (shop turn-time), holding costs of rotable engines in stock, spares unit cost, and removal rates (SERs and UERs). From an airline's perspective, the SVR is the dominant factor in the determination of required engine spare levels. The rate becomes a factor, in combination with the shop repair turn-time and available spares required to support the operation, to arrive at an optimal spares level.

An engine with a higher shop visit rate often requires a higher number of spare engines available for a given fleet size and utilization. Thus, the failure to keep the SVR under control drives an operational requirement for more spare engines.

Engine Performance Guarantee Perspective

Engine manufacturers traditionally offer levels of operational performance (reliability) guarantees to aircraft operators. Performance guarantees will take into consideration that an engine's cumulative shop visit rate will not exceed a guaranteed rate. Example wording:

"OEM assures operator that by the end of warranty period commencing with the first commercial operation of aircraft powered by OEM engines, the cumulative engine Shop Visit Rate will not exceed a guaranteed rate of [****] per 1000 eligible engine flight hours. Under this guarantee, if the cumulative engine Shop Visit Rate exceeds the guaranteed rate, the engine OEM will credit operators account an amount of [****] U.S. Dollars for each Eligible Engine Shop Visit determined to have been more than the guaranteed rate."

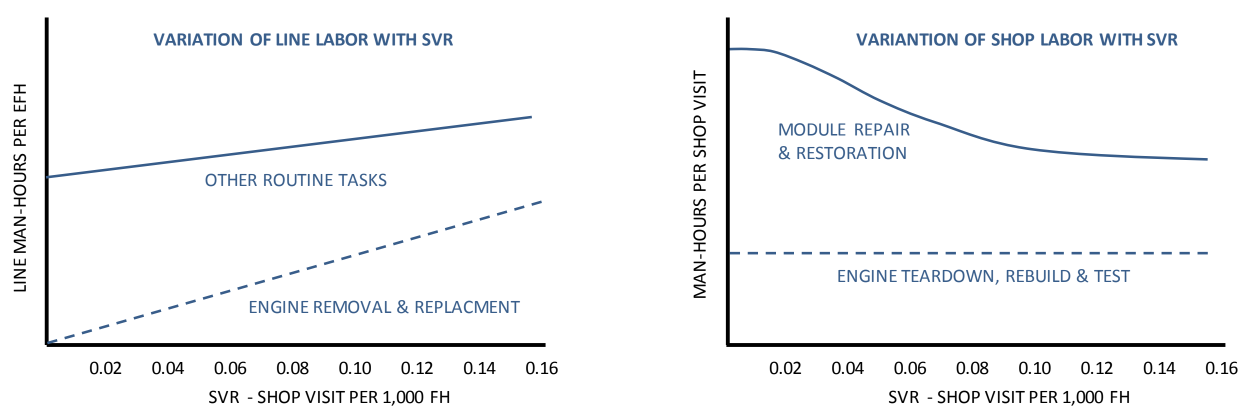
Under **line maintenance cost,** the first parameter is the routine task, or labor hours and piece-part material consumed to perform routine line tasks. These include items such as oil replacement, filter replacement, borescope inspections, etc.

The next factor is the routine task action rate, which is the **frequency** that both line labor hours and piece-part material is consumed. And the last item is the removal rate (SERs and UERs), which are maintenance actions that resulted when an engine is being removed & replaced on the line. As illustrated in Figure 10, this activity is heavily influenced by the shop visit rate.

Under shop maintenance costs, the first parameter is the workscope activities, which consist of labor hours and associated piece-part material used in restoring an engine. The next is the workscope action rate, which is the frequency that both shop labor and piece part material is consumed. And the last item is the removal rate (SERs and UERs), which are workscope actions that result when an engine is being restored in the shop.

As illustrated in Figure 10, the dominant factor that determines the shop labor expenditure is the SVR. Note, however; the amount of required work at each shop visit itself varies with the SVR, reducing as the visit rate increases. The reason for differences in required work is because, under a modular design, not all modules will require teardown at each shop visit. The figure also includes the standard (constant) man-hours required to perform each module teardown and rebuild plus an allowance for testing.

Figure 10 – Variation of Shop & Line Labor With SVR



The last economic factor is **interruption costs.** Schedule interruptions result from Aborted Take-off Rates (ABTO) and In-Flight Shutdown Rates (IFSD), both which cause adverse financial penalties resulting from delays, cancelations, and air turn-backs. Schedule interruptions are the only economic driver that is not influenced by the shop visit rate.

7. THE FALLACY OF THE SHOP VISIT RATE

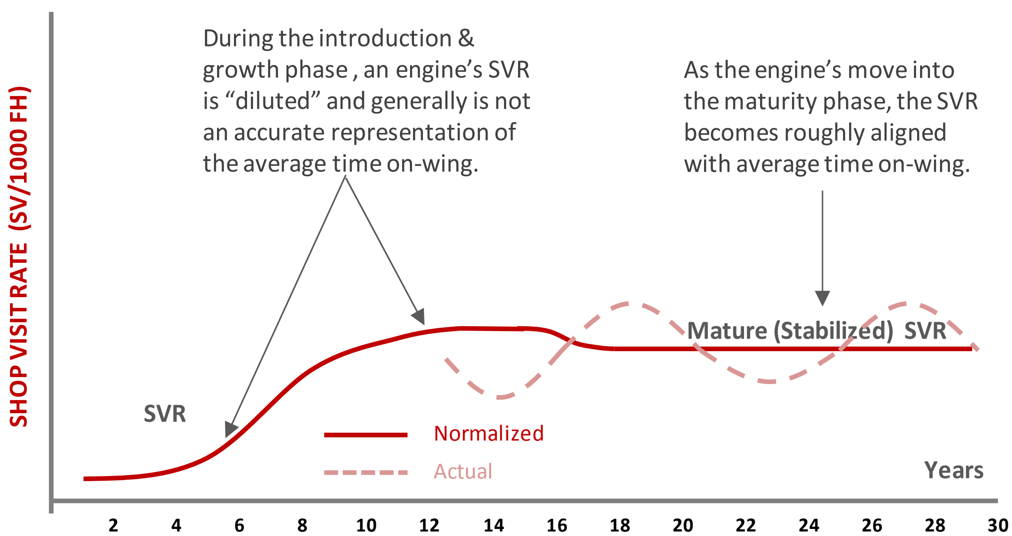
Although the shop visit rate is an effective parameter used to track operational performance, the index can often be a misleading indicator of average time on-wing, particularly during an engine's growth phase. During the period an engine enters into service and grows its population base, the SVR becomes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

- An operator puts ten aircraft (20 engines) in service January 1st of Year 1
- Each aircraft operates 3,000 FH per year or 9,000 FH by December 31st of Year 3.
- Four engines were removed during the 3-year period: 2 with 6,000 FH, and 2 with 8,000 FH
- The total engine operating hours = 172,000 FH [(16 x 9,000) + (2 x 6,000) + (2 x 8,000)]
- The SVR equal .0233 per 1,000 FH [(4 x 1,000)/172,000], and MTBR equal to 43,000 FH
- The average time on-wing for engines removed is 7,000 FH (28,000 FH / 4)

It is not possible that the MTBR can represent average time on-wing of 43,000 FH when the most any engine operated during the three-year period is 9,000 FH. And the reason for this is because both the SVR and MTBR are measuring rates of replacement (i.e. for every 43,000 hours of **combined** engine flight hours, one engine was replaced).

As the engine ages, a disproportionate amount of parts experiences higher deterioration rates, higher scrap rates, and correspondingly higher shop visit rates. As illustrated in Figure 11 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 11 – Effects of Dilution on Engine SVR



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The MSVR is a reliable index to calculate engine time on-wing **once the population has attained mature level status**. Following is an example calculation of time-on wing using an engine's MSVR:

- ✓ Time On-Wing = 1 / (MSVR /1,000), where the MSVR = 0.075 per 1,000 FH
- ✓ Time On-Wing = 1 / (0.075 / 1,000) = 13,333 FH

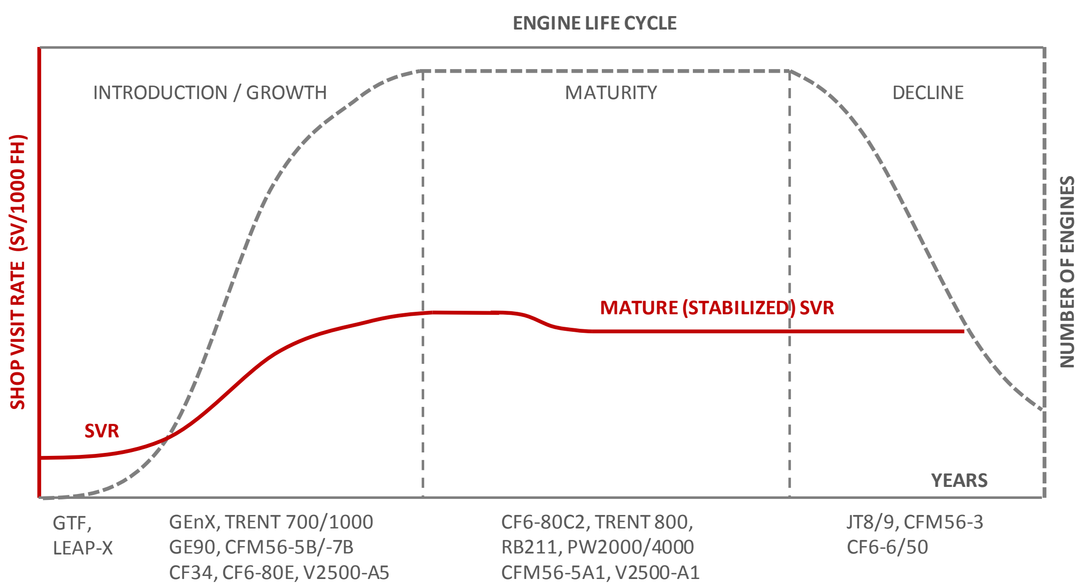
Both engine and aircraft manufacturers report shop visit rates that are adjusted to a mature level to make comparisons of engine time on-wing. This policy also enables equipment manufacturers to make a fair comparison of stabilized maintenance costs. The MSVR can also be used to calculate an engine's mature direct maintenance cost (DMC). Mature shop DMC is a function of the MSVR and the mature shop visit cost (MSVC):

Mature Shop DMC = MSVC x MSVR measured in $ / EFH

If we apply the example engine MSVR above, and apply it to a MSVC equal to $2.8M, then the mature shop DMC would equal $210/FH (0.075/1,000 FH * $2,800,000).

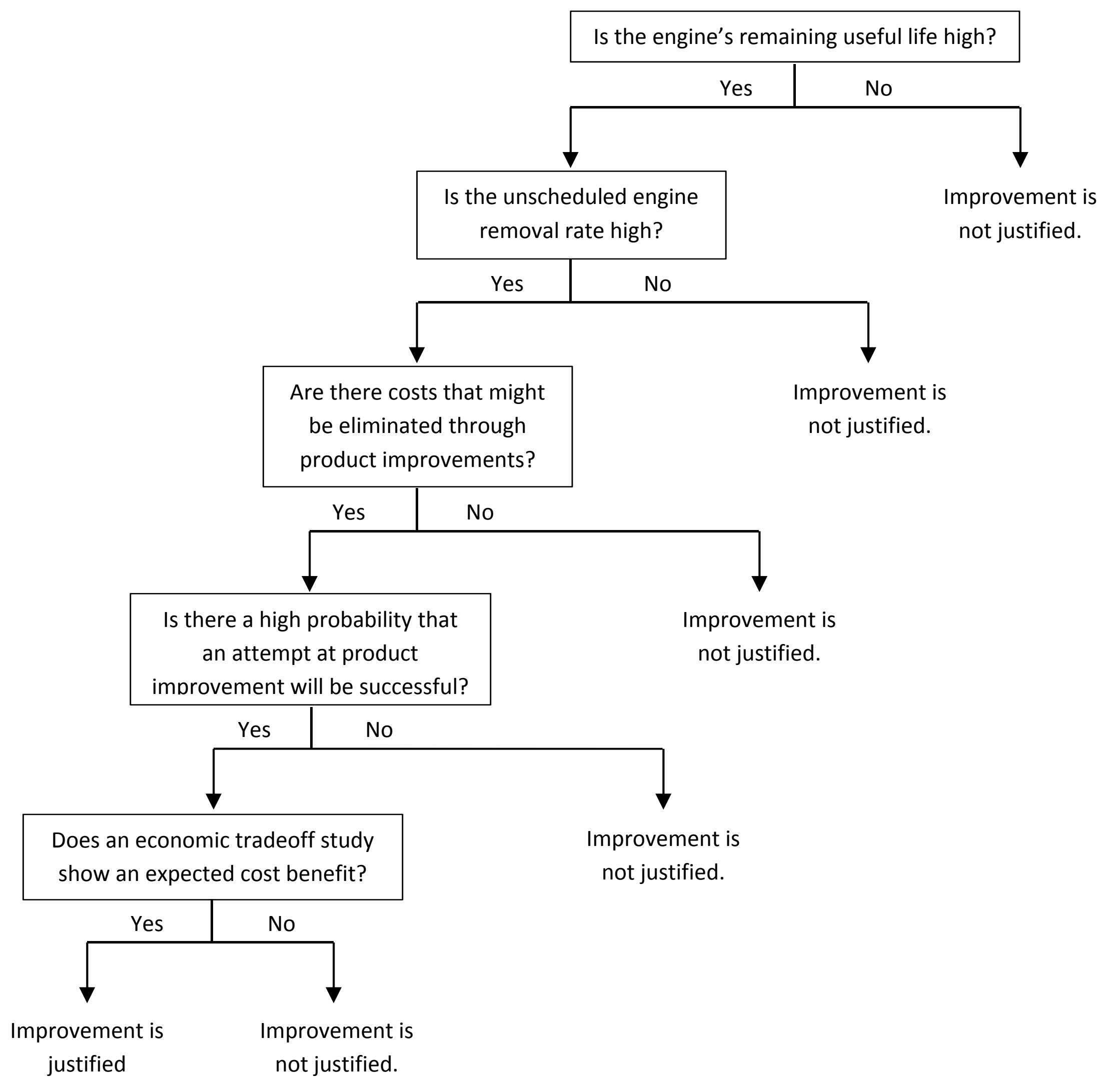
Once engines achieve a mature level status, most operators manage them with an alternating pattern of performance restoration and overhaul shop visit workscopes. Some engines may go through shop visit patterns that follow an alternating sequence of light and heavy visits or two light visits followed by a third heavy visit or an overhaul. Regardless of the pattern followed, the level of work specified achieves a targeted EGT margin coming out of the shop visit; this explains why the MSVR has a tendency to normalize over time. Figure 12 below highlights the SVR "maturity status" of current in-production and out-of-production engines relative to the engine life cycle phases.

Figure 12 – SVR Status of Current In-Production & Out-of-Production Engines



APPENDIX A – ENGINE PRODUCT IMPROVEMENT DECISION DIAGRAM

No engine manufacturer has unlimited resources for product improvements. The OEM needs to know which modifications are necessary and which are sufficiently desirable for him to risk the cost of developing them. The following decision diagram serves as a guide to assess the probable cost effectiveness of engine product improvements.



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