TITLE OF THE INVENTION

An optimization model for forecasting the shop visit build goals and prediction of optimal cost for an aero-engine maintenance and a method thereof.

TECHNICAL FIELD OF THE INVENTION

[001] The present invention relates to Maintenance, Repair and Overhaul (MRO) of an aircraft.

[002] Particularly, the present invention relates to maintenance of an aircraft engine.

[003] More particularly, the present invention relates to forecasting of shop visit behaviour and setting build goals for an aircraft engine based on user-defined operational parameters.

[004] More particularly, the present invention relates to forecasting of costs associated with multiple shop visits for engine maintenance.

[005] More particularly, the present invention monitors the deterioration of operating parameters such as Exhaust Gas Temperature (EGT) and the condition of Life Limited Parts (LLPs) and forecast an optimized maintenance schedule that minimizes the total Direct Maintenance Cost (DMC) of an engine.

BACKGROUND OF THE INVENTION

[006] Aircraft engines require excellent care and routine maintenance to ensure safe operations during flight. When an engine is sent to a shop for a form of maintenance, it is called shop visit. The engine will continue in operation, until a functional failure is detected in case of failure-based monitoring. However, predictive monitoring is focused on scheduling the maintenance before any expensive damage occurs by monitoring the trend of operational parameters like Exhaust Gas Temperature (EGT) and the remaining useful life of LLPs; they are specific components or parts of an engine that have a predetermined operating life or usage limit. These components need particular attention when it comes to maintenance, inspections, and replacement because they are essential to the aircraft's safe operation.

During a routine shop visit, the engine is overhauled regarding components & parts for different reasons such as LLP (Life Limited Part) thresholds being reached, or engine may have worn beyond limits or have suffered damages.

[007] One of the significant measures of engine performance is the Exhaust Gas Temperature (EGT). The EGT is a measure of the temperature leaving the exhaust of the turbine. An engine's EGT Margin is the difference between the peak EGT incurred during a take-off and the certified redline. EGT Margin is a parameter used to evaluate and track engine time on-wing and health. Engines with high EGT margins remain on on-wing longer and thus tend to have lower shop visit rates.

[008] The EGT margin consumption depends on the performance degradation characteristics of the engine components. The component performance parameters are the efficiency and mass flow, influencing the thrust. Irrespective of the component degradation, the thrust level needs to be maintained that leads to increasing fuel flow and rise in exhaust gas temperature. Hence the EGT margin, specified by the engine manufacturers for reliable and efficient engine operation is continuously reduced with engine flight hours, due to degradation.

[009] In the aviation industry, a commercial aircraft must undergo regular maintenance to prevent component and system failures during operations. Many of the aircraft maintenance activities take place after an aircraft has been operating for certain flight hours, flight cycles, or calendar days. The level of maintenance depends on the level of deterioration of the engine, and it is directly related to the cost required for the maintenance.

[0010] The operational cost of an aircraft can be broadly attributed to the airframe and the engine. The direct operational cost is associated with the engine maintenance. The engine maintenance cost, a part of the operational cost, is characterized by MROs, defining the standards for maintenance cost estimation. Engine maintenance costs are influenced by its associated shop visit rate. An engine with a higher shop visit rate will incur higher life cycle maintenance costs.

[0011] Precisely predicting the future shop visits is always challenging, especially when it is affected by many operational and external factors. Therefore, the engine must go for the shop visit when any of these operational parameters reaches its threshold, or any expensive damage occurs due to some external factors.

[0012] The present invention provides a new approach for the prediction of shop visit build goals. The main factor that decides the time of the shop visit is the life remaining in LLPs. Based on LLP management, the shop visit forecasting can be done in two ways. One is to run the LLPs to their limits and schedule the shop visit (Optimized for maximum usage of LLP) and the other is to minimize the number of shop visits by replacing some LLPs before it run till its limit (Optimized for minimum number of shop visits). The first one saves cost by increasing the efficiency of LLPs and the second one saves on the downtime of engines by not allowing frequent shop visits to happen.

[0013] There are several cases that decide the level of work scope to be performed when an engine is sent to shop. Some of them are, (1) engine performance, (2) observed hardware conditions, (3) time accumulated on-wing for various engine modules and (4) business goals. Therefore, forecasting shop visits according to various operating conditions will help the lessors/engine owners to analyze their contracts and thus consider the decision to improve their profits.

[0014] The level of work scope performed is related to the shop visit cost of the engine. This includes all the cost for scheduled and unscheduled labor and material.

OBJECTS OF THE INVENTION

[0015] It is an object of the present invention to forecast the shop visits and set the build goals for an aircraft engine maintenance based on the user-defined operational parameters.

[0016] It is another object of the present invention to monitor the deterioration trend of EGTM and LLP remaining life and schedule maintenance before expensive damage occurs.

[0017] It is yet another object of the present invention to forecast the maintenance costs corresponding to the forecasted shop visits.

[0018] It is still another object of the present invention to assist lessors/ engine owners to analyze the possibility of reducing engine Direct Maintenance Cost (DMC) and to propose the various ways to improve their profits.

[0019] It is still another object of the present invention to assist the asset owners to take accurate decisions related to their lease contract based on the maintenance profile of the corresponding asset.

SUMMARY OF THE INVENTION

[0020] The present invention discloses an optimization model for forecasting the shop visit build goals and prediction of optimal cost for an aero-engine maintenance and a method thereof. The forecasting of shop visit build goals is done by 2 approaches - one is by optimizing the maximum usage of LLP that means LLPs are run to their limits and other is by optimizing for the number of shop visits that means minimizing the number of shop visits by replacing some LLPs before they run till their limits. The first approach saves the cost by increasing the efficiency of LLPs while the second approach saves on the downtime of engines by avoiding frequent shop visits happening. The present invention assists lessors/ engine owners to analyze the possibility of reducing engine Direct Maintenance Cost (DMC) and to propose various ways to improve their profits. It further assists the asset owners to take accurate decisions related to their lease contract based on the maintenance profile of the corresponding asset.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] Further features and advantages of the present invention will become apparent from the following detailed description, taken in combination with the appended drawings, in which:

[0022] Fig. 1 depicts a flowchart explaining the shop visit forecast scenario optimized over maximum usage of LLPs.

[0023] Fig. 2 depicts a flowchart explaining the shop visit forecast scenario optimized over minimum number of shop visits.

[0024] Fig. 3 depicts an overview of shop visit forecast optimization algorithm used in the model.

[0025] Fig. 4 depicts a flowchart explaining the shop visit forecast optimization method that finds the trade-off between utilizing the LLPs to their limit and minimizing the number of shop visits with an affordable LLP residual value.

[0026] Fig. 5 depicts the flowchart explaining the calculation of direct maintenance cost LLP cost.

[0027] Fig. 6 depicts synthetic generation of EGTM data using the stochastic model.

[0028] Fig. 7 depicts estimation of shape and scale parameters of Weibull distribution using Regression.

DETAILED DESCRPITION OF THE DRAWINGS

[0029] The present invention discloses an optimization model for forecasting of the shop visit build goals and prediction of the optimal cost for an aircraft engine maintenance and a method thereof. A model of the present invention aids in assisting the lessors/ engine owners to analyze the possibility of reducing engine direct maintenance costs (DMC) and further proposes various options to improve their profits.

[0030] There are two different ways to forecast the shop visit build goals. The first one is based on considering the maximum usage of Life Limited Parts (LLP's) and second one is focused on minimizing the number of shop visits. Examples of these two scenarios are shown in figures 1 and 2.

[0031] The scenario A as depicted in figure 1, where the LLPs run to their limit before sending the system to shop visit. On the other hand, scenario B as depicted in figure 2, which has one less shop visit than scenario A by investing more on LLP cost. However, the total cost for scenario B is way less than scenario A. Therefore, the optimal solution for reducing the cost is to find a trade-off between both these scenarios.

[0032] It is important to consider the EGTM degradation trend along with the LLP usage while deciding a shop visit build goal. A shop visit can happen either the EGTM reaches its threshold or when the LLP runs to their limit.

[0033] The parameters being considered for forecasting the shop visits are but not limited to Engine Thrust Rating, Derate, EGT Margin, LLP rules, Stage Length, Environment - Temperate, Hot / Dry, Erosive / Corrosive (in addition to severity matrix, use historic utilization, routes & projected utilization, routes data to split % across environments into data model). Build Goals are either manually provided by user or auto suggested through simulation comparison by the system.

[0034] Fig. 3 gives an overview of shop visit forecast optimization algorithm used in the optimization model to find the optimal combination of build goals (BG) in which the total shop visit cost (SVC) using these build goal set should be minimum.

[0035] According to an embodiment of the disclosure, an optimization method of forecasting the shop visit build goals and predicting optimal cost for an engine maintenance, comprising steps of:
a prediction of the shop visit build goals for an aero-engine maintenance based on user-defined operational parameters;
a prediction of the required work scope being performed;
a forecasting and computing the costs associated with the respective forecasted shop visit;

an optimization and determination of an aero-engine maintenance schedule based on the optimization of the shop visit cost required over the forecasted maintenance time period.

[0036] In one of the embodiments, the operational parameters used for the prediction of the shop visit build goals for an aero-engine maintenance are EGTM degradation and LLP remaining cycles.

[0037] In one of the embodiments, the method of forecasting the shop visit build goals for an aero-engine maintenance further comprising:
a monitoring of EGTM profile and predicting the Remaining Useful Life (RUL) based on the degradation trend of EGTM;
a monitoring of LLP remaining life and determining a trade-off between utilizing the LLPs to their limit and minimizing the number of shop visits with an affordable LLP residual value;
a prediction of the time required for maintenance based on EGTM degradation and LLP remaining cycle;
a forecasting of shop visits by optimizing the time required for a trade-off between maximum LLP usage, minimum number of shop visits and cycles remaining till the EGTM reaches the threshold set by the airline operators.
Here, the residual value is the dollar value that an LLP can incur if it is replaced before utilizing to its maximum limit.

[0038] In one of the embodiments, as shown in Figure 6, the EGTM data is generated synthetically using the stochastic model (combining all the aspects mentioned herein), where the EGTM profile is built by simulating the EGTM data by the Non-linear Weiner process, which is used for modeling the aero-engine performance degradation using time series data and can be defined as:

$$y_t = a\tau(t,\theta) + b\mathcal{W}(t) + \varepsilon_t$$

where y_t is the observed EGTM value at time t, a is the drift coefficient and satisfies $a \sim \mathbb{N}(\mu_a, \sigma_a^2)$, $\tau(t,\theta)$ (θ is a parameter) is a nonlinear function of time t to reflect the nonlinear features of degradation process, $\mathcal{W}(t)$ is the standard Brownian motion

($\mathcal{W}(t) \sim \mathbb{N}(0, t)$), b is the diffusion coefficient that characterizes the time-varying uncertainty of the degradation process and ε_t is the observation noise and has Gaussian distribution, i.e., $\varepsilon_t \sim \mathbb{N}(0, \sigma_\varepsilon^2)$.

Once the data simulation is over, that data is used to perform Weibull analysis to find the remaining useful life (RUL) or reliability. The reliability in Weibull distribution can be defined as

$$R(t) = \boldsymbol{e}^{-(t/\eta)^{\beta}}$$

where η is the scale parameter and β is the shape parameter.

Figure 7 depicts estimation of shape and scale parameters of Weibull distribution using a plot technique called regression.

[0039] Other parameters that need to be considered which influence the degradation of EGTM include but not limited to environment, severity, derate, stage length, thrust rate, etc. Then the new formulation of reliability can be written as

$$R(t) = \boldsymbol{e}^{-(t(\sum_{i=1}^{n}(w_i s_i)/\eta)^{\beta}}$$

where n is the total factors, w_i is the weight and s_i is each factor values. Then the remaining cycle can be calculated by substituting R(t)=0.1 and solving for time t. The above equation to find t can be rearranged as follows:

$$t = \frac{e^{\left(\frac{\ln\left(\ln\left(\frac{1}{R(t)}\right)\right)+\beta\ln(\eta)}{\beta}\right)}}{\sum_{i=1}^{n}(w_i s_i)}$$

This equation is to estimate the time (t) at which the next shop visit is due.

[0040] The above-mentioned RUL based on EGTM is compared with LLP remaining cycle and an optimization algorithm is defined with objective function as total shop visit cost. As explained by the flowchart in fig. 4, the shop visit forecast optimization

method finds the trade-off between utilizing the LLPs to their limit and minimizing the number of shop visits with an affordable LLP residual value.

[0041] The Engine Maintenance Cost consists of three primary clusters i.e.
Material Costs (LLP & Components) - ~65%
Labor Costs - ~ 15% (depending on where the maintenance is being done)
Repair Costs - ~20%.

[0042] In one of the embodiments, the shop visit costs predicted by the model of the present invention include both Direct Maintenance Cost and LLP cost (refer to fig. 5). These costs depend on the type of shop visit and the level of work scope being performed against an engine. For example, the HSR or CPR against a V2500 would consume more resources compared to a PV or a Miscellaneous visit. Therefore, once the shop visit build goals are forecasted, the required work scope being performed needs to be predicted.

[0043] In one of the embodiments, the Labor cost is computed as:

$$Total\ Man\ hour\ cost = Man\ hour\ routine\ cost * (R\&I_{hrs} + Man_{hrs} + Inspection_{hrs})$$

[0044] Depending on the predicted levels of work scope being performed against an engine, the manhour calculation is a factor of work man hours plus inspection hours. For each module, the R&I cost is taken as constant and relevant man-hours and inspection hours are added depending on the additional work scope levels that need to be done. These modules are nothing but the Engine Modules which include parts or collection of parts of the engine like the FAN, Low Pressure Compressor, HP System (High Pressure Compressor and High-Pressure Turbine), and Low Pressure-Turbine.

[0045] In still another embodiment of the disclosure, the Material cost is computed as:

$$C_{material} = \sum \begin{cases} C_{unit} * QPA & \text{if } s_{prob} = 100\% \\ C_{unit} * QPA & \text{if } C_{repair} > 0.65 * C_{unit} \\ C_{repair} * QPA & \text{if } C_{repair} < 0.65 * C_{unit} \end{cases}$$

Where, s_{prob} is scrap probability; QPA is quantity per assembly; C_{unit} is unit price of the part; $C_{material}$ is material cost.
Thus, Material Cost is dependent on the scrap probability predicted for each part as part of the incoming shop visit.

[0046] During shop visits, each module should undergo some level of work scope based on the condition of that module. There are four different types of shop visits namely, Hot Section Refurbishment (HSR), Miscellaneous Repair (Misc. Repair), Project Visit (PV) and Core Performance Restoration (CPR). The level of work scope of each module may vary according to the shop visit types. The predictions are made as the level of work need e.g.: L1, L2.1, L2.3, L2.9 and L3.

[0047] In one of the embodiments, after predicting the work scope for each module, the remaining cycles of LLP's associated with each module are compared with the predicted build goals by the shop visit forecast. The LLP cost is calculated based on three cases:
1) If all the LLP's remaining cycle corresponding to a module are greater than the build goal, sum of cleaning and inspection cost for each LLP's are added to the LLP cost;
2) If all the LLP's remaining cycle corresponding to a module are less than the build goal, sum of replacement cost for each LLP are added to the LLP cost;
3) If some LLP's remaining cycle are less than build goal, replacement cost of those LLP's and repair cost of other LLP's (remaining cycle are greater than build goal) are added to the LLP cost;
then total LLP cost will be the summation of all modules LLP cost (modules without LLP's are ignored) averaged over total forecasted cycles.

[0040] In one of the embodiments, an optimization model of the present invention further assists in forecasting the future value of the final DMC and LLP cost based on the economy and currency inflation rate; the yearly inflation rates being forecasted from the historic data using Dynamic Mode Decomposition (DOI: 10.1109/ICCCNT54827.2022.9984629). Using the forecasted rates, monthly rate can be calculated as:

$$1 + \mathrm{r}_{\mathrm{annual}} = \left(1 + \mathrm{r}_{\mathrm{monthly}}\right)^{12}$$

$$\mathrm{r}_{\mathrm{monthly}} = (1 + \mathrm{r}_{\mathrm{annual}})^{\frac{1}{12}} - 1$$

and future value is calculated by the formula:

$$future\ value = current\ value\left(1 + \frac{r_{month}}{100}\right)$$

CLAIMS

I/ We claim,

1. An optimization method for forecasting the shop visit build goals and prediction of optimal cost for an aero-engine maintenance, the method comprising the steps of:
   a prediction of the shop visit build goals for an aero-engine maintenance based on user-defined operational parameters;
   a prediction of the required work scope being performed;
   a forecasting and computation of the costs associated with the respective forecasted shop visit;
   an optimization and determination of an aero-engine maintenance schedule based on the optimal/ minimum shop visit cost required over the forecasted maintenance time period.

2. The method as claimed in claim 1, wherein the operational parameters used for the prediction of the shop visit build goals for an aero-engine maintenance are EGTM degradation and LLP remaining cycles.

3. The method as claimed in claim 1, wherein the method of predicting the shop visit build goals for an aero-engine maintenance further comprising:
   a monitoring of EGTM profile and predicting the Remaining Useful Life (RUL) based on the degradation trend of EGTM;
   a monitoring of LLP remaining life and determining a trade-off between utilizing the LLPs to their limit and minimizing the number of shop visits with an affordable LLP residual value;
   a prediction of the time required for maintenance based on EGTM degradation and LLP remaining cycle;
   a forecasting of shop visits by optimizing the time required for a trade-off between maximum LLP usage, minimum number of shop visits and cycles remaining till the EGTM reaches the threshold set by the airline operators.

4. The method as claimed in claim 1, wherein the EGTM profile is built by simulating the EGTM data by the Non-linear Weiner process, which is used for modeling the aero-engine performance degradation using time series data and can be defined as:

$$y_t = a\tau(t,\theta) + b\mathcal{W}(t) + \varepsilon_t$$

5. The method as claimed in claim 3, wherein the Remaining Useful Life (RUL)/ Reliability being determined by Weibull analysis based on simulated data; the RUL/ Reliability being calculated by the formula:

$$R(t) = \boldsymbol{e}^{-(\boldsymbol{t}/\boldsymbol{\eta})^{\boldsymbol{\beta}}}$$

6. The method as claimed in claim 3, wherein the RUL/ Reliability based on other operational parameters that influence being calculated by the formula:

$$R(t) = \boldsymbol{e}^{-(\boldsymbol{t}(\sum_{\boldsymbol{i=1}}^{\boldsymbol{n}}(\boldsymbol{w_i s_i})/\boldsymbol{\eta})^{\boldsymbol{\beta}}}$$

7. The method as claimed in claim 3, wherein the time period required for the EGTM degradation being calculated by:

$$t = \frac{e^{\left(\frac{\ln\left(\ln\left(\frac{1}{R(t)}\right)\right)+\beta\ln(\eta)}{\beta}\right)}}{\sum_{i=1}^{n}(w_i s_i)}$$

8. The method as claimed in claim 1, wherein the shop visit cost associated with a forecasted maintenance schedule includes Direct Maintenance Cost and LLP cost.

9. The method as claimed in claim 8, wherein Labor Cost (total man hour cost) is calculated by the formula:

$$Total\ Man\ hour\ cost = Man\ hour\ routine\ cost * (R\&I_{hrs} + Man_{hrs} + Inspection_{hrs})$$

10. The method as claimed in claim 8, wherein the material cost is calculated by the formula:

$$C_{material} = \sum \begin{cases} C_{unit} * QPA & if\ s_{prob} = 100\% \\ C_{unit} * QPA & if\ C_{repair} > 0.65 * C_{unit} \\ C_{repair} * QPA & if\ C_{repair} < 0.65 * C_{unit} \end{cases}$$

Where, $C_{material}$ = material cost, s_{prob} = scrap probability, QPA = quantity per assembly, C_{unit} = unit price of the part, C_{repair} = repair price.

11. The method as claimed in claim 1 & 8, wherein after predicting work scope for each module, LLP cost is being calculated by comparing LLP remaining cycles associated with the module and the predicted build goals for the shop visit.

12. The method as claimed in claim 1, wherein the future value of the final DMC and LLP cost being forecasted based on the economy and currency inflation rate; the yearly inflation rates being forecasted from the historic data using Dynamic Mode Decomposition (DOI: 10.1109/ICCCNT54827.2022.9984629).

13. The method as claimed in claim 12, wherein using the forecasted rates, monthly rate can be calculated as:

$$1 + r_{annual} = (1 + r_{monthly})^{12}$$

$$r_{monthly} = (1 + r_{annual})^{\frac{1}{12}} - 1$$

and future value is calculated by -

$$\text{future value} = \text{current value}\left(1 + \frac{r_{monthly}}{100}\right)$$

14. An optimization model for forecasting the shop visit build goals and prediction of optimal cost for an aero-engine maintenance, the model comprising:

a processor coupled to the memory; and

at least one application stored in the memory and executable by the processor for:

a prediction of the shop visit build goals for an aero-engine maintenance based on user-defined operational parameters;

a prediction of the required work scope being performed;

a forecasting and computation of the costs associated with the respective forecasted shop visit;

an optimization and determination of an aero-engine maintenance schedule based on the optimal/ minimum shop visit cost required over the forecasted maintenance time period.

15. The model as claimed in claim 14, wherein the operational parameters used for the prediction of the shop visit build goals for an aero-engine maintenance are EGTM degradation and LLP remaining cycles.

16. The model as claimed in claim 14, wherein the prediction of the shop visit build goals for an aero-engine maintenance further comprising:

a monitoring of EGTM profile and predicting the Remaining Useful Life (RUL) based on the degradation trend of EGTM;

a monitoring of LLP remaining life and determining a trade-off between utilizing the LLPs to their limit and minimizing the number of shop visits with an affordable LLP residual value;

a prediction of the time required for maintenance based on EGTM degradation and LLP remaining cycle;

a forecasting of shop visits by optimizing the time required for a trade-off between maximum LLP usage, minimum number of shop visits and cycles remaining till the EGTM reaches the threshold set by the airline operators.

17. The model as claimed in claim 14, wherein the EGTM profile is built by simulating the EGTM data by the Non-linear Weiner process, which is used for modeling the aero-engine performance degradation using time series data and can be defined as:

$$y_t = a\tau(t, \theta) + b\mathcal{W}(t) + \varepsilon_t$$

18. The model as claimed in claim 16, wherein the Remaining Useful Life (RUL)/ Reliability being determined by Weibull analysis based on simulated data; the RUL/ Reliability being calculated by the formula:

$$R(t) = \boldsymbol{e}^{-(\boldsymbol{t}/\boldsymbol{\eta})^{\boldsymbol{\beta}}}$$

19. The model as claimed in claim 16, wherein the RUL/ Reliability based on other operational parameters that influence being calculated by the formula:

$$R(t) = \boldsymbol{e}^{-(\boldsymbol{t}(\sum_{\boldsymbol{i}=\boldsymbol{1}}^{\boldsymbol{n}}(\boldsymbol{w_i s_i})/\boldsymbol{\eta})^{\boldsymbol{\beta}}}$$

20. The model as claimed in claim 16, wherein the time period required for the EGTM degradation being calculated by:

$$t = \frac{e^{\left(\frac{\ln\left(\ln\left(\frac{1}{R(t)}\right)\right)+\beta\ln(\eta)}{\beta}\right)}}{\sum_{i=1}^{n}(w_i s_i)}$$

21. The model as claimed in claim 16, wherein the shop visit cost associated with a forecasted maintenance schedule includes Direct Maintenance Cost and LLP cost.

22. The model as claimed in claim 21, wherein Labor Cost (total man hour cost) is calculated by the formula:

$$Total\ Man\ hour\ cost = Man\ hour\ routine\ cost * (R\&I_{hrs} + Man_{hrs} + Inspection_{hrs})$$

23. The model as claimed in claim 21, wherein the material cost is calculated by the formula:

$$C_{material} = \sum \begin{cases} C_{unit} * QPA & if\ s_{prob} = 100\% \\ C_{unit} * QPA & if\ C_{repair} > 0.65 * C_{unit} \\ C_{repair} * QPA & if\ C_{repair} < 0.65 * C_{unit} \end{cases}$$

Where, $C_{material}$ = material cost, s_{prob} = scrap probability, QPA = quantity per assembly, C_{unit} = unit price of the part, C_{repair} = repair price.

24. The model as claimed in claim 14 & 21, wherein after predicting work scope for each module, LLP cost is being calculated by comparing LLP remaining cycles associated with the module and the predicted build goals for the shop visit.

25. The model as claimed in claim 14, wherein the future value of the final DMC and LLP cost being forecasted based on the economy and currency inflation rate; the yearly inflation rates being forecasted from the historic data using Dynamic Mode Decomposition (DOI: 10.1109/ICCCNT54827.2022.9984629).

26. The model as claimed in claim 25, wherein using the forecasted rates, monthly rate can be calculated as:

$$1 + \mathrm{r}_{\mathrm{annual}} = \left(1 + \mathrm{r}_{\mathrm{monthly}}\right)^{12}$$

$$\mathrm{r}_{\mathrm{monthly}} = (1 + \mathrm{r}_{\mathrm{annual}})^{\frac{1}{12}} - 1$$

and future value is calculated by -

$$future\ value = current\ value\left(1 + \frac{r_{monthly}}{100}\right)$$