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AIRCRAFT PERFORMANCE MONITORING FROM FLIGHT DATA

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Preliminary notes

To ensure timely maintenance and efficient aircraft operations, it is necessary to know and keep track of aircraft's actual performance. Flight performance is determined by aircraft's physical characteristics. Theoretical aircraft performance, obtained after manufacturing and flight testing, are described in flight manual. Transport aircraft in operation is usually exposed to standard operational conditions. Despite the standard operational conditions and regular aircraft maintenance, structure aging and high dynamic loads due to high subsonic Mach number could lead to changes of main physical factors that determine flight performance. For this reason actual aircraft performance often differs from theoretical. Commercial airlines monitor true performance of aircraft in operation. This paper presents an overview of existing performance monitoring methods as well as first indications for new research possibilities regarding physical characteristics determination for aircraft in operation using flight data.

Keywords: *aerodynamic coefficients; flight performance; flight testing; system identification*

Praćenje stvarnih performansi zrakoplova prema podacima iz leta

Prethodno priopćenje

Poznavanje stvarnih performansi zrakoplova bitno je za učinkovitu eksploataciju i pravovremeno održavanje. Performanse su određene fizikalnim karakteristikama zrakoplova. U Priručniku za letenje opisane su teorijske performanse određene od proizvođača nakon proizvodnje zrakoplova i testiranja u letu. Komercijalni zrakoplovi su tijekom svog operativnog ciklusa uglavnom izloženi predviđenim uvjetima eksploatacije. Unatoč predviđenim uvjetima eksploatacije i redovnom održavanju, starenje materijala i velika opterećenja na strukturu zrakoplova kod leta visokim podzvučnim Machovim brojem, mogu dovesti do promjene temeljnih fizikalnih faktora koji određuju performanse. Zbog toga se stvarne performanse zrakoplova nerijetko razlikuju od teorijskih. Zračni prijevoznici prate stanje zrakoplova i njegove stvarne performanse tijekom korištenja. U ovom radu prikazan je pregled dosadašnjih metoda praćenja performansi i mogućnosti istraživanja na području određivanja fizikalnih parametara zrakoplova u eksploataciji prema podacima iz leta.

Ključne riječi: *aerodinamički koeficijenti; identifikacija sustava; ispitivanje u letu; performanse leta*

1 Introduction

Aircraft in service is exposed to dynamic load that degrades its aerodynamic and flight characteristics. Flight performance is function of aircraft's physical characteristics which are changing due to degradation. Degradation of specific range, endurance and other flight performance could affect operational and aircraft maintenance procedures in future usage.

It is very important to monitor aircraft performance changes during operations. According to Airbus company's research, difference between aircraft specific range is −1,3 % per year when there is no engine replacement, and −0,3 % per year with engine replacement [1].

Problem of aircraft performance monitoring from flight data is explored from available literature [1÷13]. Aircraft degradation emerges as main topic of numerous research articles through different aspects.

The most common problems with aircraft degradation are due to aging of structures. Collection of methods for systematic aircraft structure condition and damage monitoring is known under a common name - SHM (Structural Health Monitoring) [2÷5]. Methods for structure aging monitoring include measuring of material vibration characteristics and their changes caused by strength variation in material and structure. Purpose of SHM is to get information about true structure condition (possible damage, fractures, etc.) to secure timely maintenance and efficient operations. Aeroelastic effects under high dynamic load can lead to structural changes of flight control surfaces and decrease its efficiency [2].

In the literature, the term aircraft degradation appears also in problems of identification and monitoring of engine health parameters [6÷8]. Engine performance monitoring of aircraft in service is known as Engine Health Monitoring (EHM). EHM methods are based on measuring the key "health" indicators of individual components such as engine rotation speed N_1 and N_2, fuel consumption, EGT (Exhaust Gas Temperature), etc. The measured "health" parameters can indicate engine thrust deviations compared to nominal thrust of new engine.

Aircraft degradation also includes the term aerodynamic deterioration [9÷13]. Major aircraft manufacturers, Airbus and Boeing, have developed flight performance monitoring systems that can measure level of aerodynamic deterioration but without capability for separating contribution of individual aerodynamic (physical) characteristics [1]. The total aerodynamic degradation manifests itself purely through an increase in aircraft drag. Aircraft performance monitoring methods use data registered during regular (scheduled) flights [1]. Research paper [11] studies correlation between fuel consumption and exterior cleaning of aircraft. Surface roughness caused by accumulation of impurities increases skin friction drag and reduces aerodynamic effectiveness.

There is no research paper about monitoring the individual aerodynamic coefficients for commercial aircraft in operation. Short overview of flight testing methods that could be used for individual aerodynamic coefficients monitoring is given in this paper. Also, basic principles of current performance monitoring methods for transport aircraft equipped with automatic light data recording devices (FDR) within Flight Operation Quality Assurance (FOQA) programme is explained.

2 Flight testing methods

Flight testing includes a set of numerous methods described in [14÷19] that are used for determination of:
- aircraft performance,
- stability and control derivatives,
- handling quality indicators,
- flight envelope.

Flight test methods are usually categorized according to different measurement principles and theories into two basic groups:
1) Performance evaluation (certification) methods,
2) System identification methods.

2.1 Performance evaluation methods

The basic objective of performance evaluation methods is "to fulfil the mission in terms of range, fuel consumption, achievable maximum speed, rate of climb, altitude, and so on" [14, pp. 27].

After production, various flight tests help determine aircraft's final performance parameters. These performance parameters are nominal values presented in the form of diagrams and tables and are included in flight manual or computer programme. However, over time, certain changes occur that lead to nominal performance deviation.

According to Boeing study, changes in total drag for well-maintained aircraft is not greater than 0,5 % during in-service period [9].

For Boeing and Airbus aircraft, there is continuous performance tracking established through Aircraft Performance Monitoring programme (APM) [1]. APM programme is used by airliners to monitor the trend of fuel consumption and specific air range (SR) during time in service. Main method for SR determination is the method for cruise flight drag estimation [15, 16]. More details of cruise performance monitoring method are given in the third part of this paper.

2.2 System identification methods

Aircraft system identification is a process for finding mathematical model of black box system from input-output data using statistical methods. Figure 1 presents relations between system identification, control and simulation.

Simulation: $\boldsymbol{y} = (\boldsymbol{u}, \boldsymbol{S})$

Control: $\boldsymbol{u} = (\boldsymbol{y}, \boldsymbol{S})$

System identification: $\boldsymbol{S} = (\boldsymbol{u}, \boldsymbol{y})$

Figure 1 Dynamic system identification compared to simulation and control

This part of the paper will describe basic flight testing methodology and give short overview of most used methods for aircraft identification purposes.

System identification methods are used for:
- aerodynamic gradients or derivatives determination,
- enhancement and validation of simulation models,
- synthesis and validation of control laws and
- handling quality.

Aircraft modelling through system identification is always necessary when producing a new aircraft in order to validate aerodynamic coefficient gradients determined from analytical or numerical methods and wind tunnel measurements.

Aerodynamic coefficient gradients identified from flight test are used for loading comprehensive aerodynamic database into flight simulators. There are many research studies addressing these problems [20÷27]. Accuracy of identified aerodynamic coefficient gradients depends on collected data quality. Required data usually include:
- control surface deflection,
- linear accelerations,
- angular accelerations,
- Euler angles,
- airflow data,
- engine operation parameters.

Control surface deflections are input data for aircraft model whose parameters are being estimated. Any error in their determination directly affects the error in determined parameters.

Linear and angular accelerations give indication about aerodynamic effects. For measuring accelerations, triple axis accelerometer is used or raw data from inertial navigation system (INS).

Euler angles are also available from INS. Euler angles are not of primary importance since aerodynamic effects do not depend on aircraft attitude, but they are used for kinematic data compatibility analysis.

Angle of attack, aerodynamic slip angle and air speed are provided by airflow measurements. Most often, airflow measurements contain errors and noise which is why they must be adjusted during kinematic or data compatibility analysis considering aircraft Euler angles and kinematic equations.

Engine operational parameters provide thrust force. Any error in thrust force calculation directly affects aircraft total drag value. Usually engine thrust model is known ahead, validated and taken as known input value.

The choice of aircraft identification method is made with regard to the model being tested. In general, the aircraft model may be parametric or non-parametric. The non-parametric model is estimated from input-output dynamics of the aircraft, but without considering the nature of equations of motion, which means that it is not necessary to know the aircraft dynamic model structure. Parametric models require certain assumptions about dynamic model structure, representing a problem for completely new aircraft concepts such as unmanned airborne vehicles.

System identification methodology allows dynamic system structure and parameters determination based on registered aircraft response to given inputs. Once the dynamic model structure is defined, problem of aircraft identification is reduced to parameter estimation. Parameter estimation means finding the parameters that best describe the system by current input variables and measured dynamic outputs.

2.2.1 Parametric aircraft model

Aircraft performance results from the combination of gravitational, inertial, aerodynamic and propulsive force. To estimate flight performance, aircraft motion is described with a set of nonlinear differential equations for rigid body with six degrees of freedom. The aerodynamic force is predetermined by the aircraft physical characteristics.

Aircraft performance degradation can be due to unwanted changes in the aircraft physical characteristics. The unwanted changes of aircraft physical characteristics may include: aerodynamic surface misrigging, seals missing or damaged, doors not flush or leaking, rough or deformed surfaces due to bird strike or repair patches, chipped paint, dirty aircraft, etc. [1, 9].

Direct measuring of aerodynamic and propulsive force during aircraft flight is not possible. To determine the size and effect of aerodynamic and propulsive force they must be modelled and calculated based on recorded flight data.

Aerodynamic model of rigid aircraft with six degrees of freedom can be written in the form of three equations for aerodynamic force and three equations for aerodynamic moment. The six aerodynamic equations are nonlinear and their form and structure will depend on the observed problem. Aircraft aerodynamic during standard operating flight regimes can be shaped as:

$$C_X = C_{X0} + C_{X\alpha}\alpha + C_{X\alpha^2}\alpha^2 + C_{XT}C_T,$$

$$C_Y = C_{Y\beta}\beta + C_{Yp}p^* + C_{Yr}r^* + C_{Y\delta_n}\delta_n,$$

$$C_Z = C_{Z0} + C_{Z\alpha}\alpha + C_{Z\dot{\alpha}}\dot{\alpha}^* + C_{Zq}q^* + C_{Z\delta}\delta_m + C_{Zih}i_h,$$

$$C_\ell = C_{\ell\beta}\beta + C_{\ell p}p^* + C_{\ell r}r^* + C_{\ell\delta_\ell}\delta_\ell + C_{\ell\delta_n}\delta_n,$$

$$C_m = C_{m0} + C_{m\alpha}\alpha + C_{m\dot{\alpha}}\dot{\alpha}^* + C_{mq}q^* + C_{m\delta}\delta_m + C_{mih}i_h,$$

$$C_n = C_{n\beta}\beta + C_{np}p^* + C_{nr}r^* + C_{n\delta_\ell}\delta_\ell + C_{n\delta_n}\delta_n.$$

where are:
C_X, C_Y and C_Z – total aerodynamic force coefficients,
C_l, C_m and C_n –total aerodynamic moment coefficients,
C_T– thrust in dimensionless form,
α, β – angle of attack and sideslip angle,
δ_l, δ_m and δ_n – control surface deflection angles,
i_h– horizontal stabiliser angle setting,
$\dot{\alpha}^*$ – angle of attack rate in dimensionless form,
p^*, q^*, r^* –angular rates in dimensionless form.
C_{X0}, $C_{X\alpha}$, $C_{X\alpha}^2$, C_{XT}, $C_{Y\beta}$, etc. – aerodynamic coefficient gradients.

Presented aerodynamic coefficient gradients represent aircraft's actual physical characteristics. For example, the aerodynamic gradient C_{X0} represents the aircraft's parasite drag due to the surface friction and shape. $C_{X\alpha}$ represents a change of aircraft's parasite drag due to changes of angle of attack. $C_{X\alpha 2}$ takes into account the non-linearity of increased drag with a change in angle of attack. By changing aerodynamic or engine parameters, actual performance of aircraft is also being affected.

Aircraft turbo fan engine model can be similarly defined with thrust force as an output variable for given Mach number, atmospheric conditions at altitude and compressor rotation speeds.

Airlines operation experience indicates that accumulated dirt on aircraft exterior surface increases the skin surface roughness. Surface roughness, according to Boeing research cited in [11], makes 0,4 % of the total drag. The authors of [11] found correlation between fuel consumption and the frequency of exterior cleaning. The results showed that increase of 10 % of the aircraft surface roughness is causing additional fuel consumption of 500US gal per year for specific Boeing aircraft.

The authors of [12] are estimating degraded aircraft's performance and pilot handling quality as a part of Icing Contamination Envelope Protection System.

2.2.2 Aircraft parameter estimation methods

Different methods considering sensor accuracy and measuring conditions are used for aircraft parameter estimation. Most usual classification based on [14] is:

1) Regression methods (multiple, linear, nonlinear) within equation error method (EEM),
2) Recursive regression methods (least squares, Fourier, etc.),
3) Neural network methods,
4) Maximum likelihood methods within output error method (OEM), and
5) Filtration methods (Kalman filter, Extended Kalman filter, etc.) within filter error method (FEM).

Most used parameter estimation methods are: regression analysis (least squares method, LSMortotal least squares method, TLSM) and maximum likelihood method (MLE) [14, 17, 19].

MLE method is used when input data has an error and measurement noise of deterministic nature. For measurements made in turbulent atmosphere (stochastic process) filtering methods are used with Kalman or extended Kalman filter depending on the linearity or nonlinearity of model.

3 Flight performance monitoring methods

Aircraft manufacturing companies, Airbus and Boeing, give Aircraft Performance Monitoring (APM) programme for monitoring cruise flight performance. The APM programme compares the actual aircraft cruise performance with theoretical one contained in the flight manual or In-Flight Performance (IFP) calculation software. According to [1], aerodynamic and engine performance database inside IFP software is valid for "cruise analysis in the expected usual operational conditions". In order to compare theoretical and actual performance of the aircraft, Airbus recommends using of three different methods depending on the aircraft type and installed equipment [1]:

1) Fuel used method,
2) Trip fuel burn-off method, and
3) Specific range method.

The basic idea of the first method can be reduced to comparison of fuel used only in the cruise flight phase with the forecasted fuel consumption according to flight manual or IFP software.

The second method analyses the difference between the actual overall fuel consumption and fuel needed for the same flight route according to flight planning software. Fuel calculated with flight planning software is adjusted considering the difference between the true and predicted flight profile.

The third method, specific range, is more accurate since it uses mathematical methods and flight mechanic equations from data collected in stabilized conditions during cruise.

These data contain airflow data (angle of attack α, airspeed V, pressure altitude p and temperature T), linear accelerations (a_x, a_y and a_z), engine thrust performance parameters such as fuel flow (FF), engine rotation speed (N), bleed flow, etc. The registered flight data are then used to calculate actual performance of airframe-engine combination. The flight data are used for specific air range calculation as distance covered per unit of fuel burnt. Most useful way of flight data collecting is through automatic system for flight data recording in Digital Standard Interface Record Format (DSIRF). These data could be accessed from Quick Access Recorder (QAR) immediately after landing. After analysis they are used to show specific air range performance deviations from theoretical or book level. Example of recorded linear accelerations during flight in clean configuration from QAR device of A320 aircraft is shown in Fig. 2. It is visible from Fig. 2 that aircraft during standard commercial flight mostly has zero lateral acceleration which corresponds to flight without sideslip angle β.

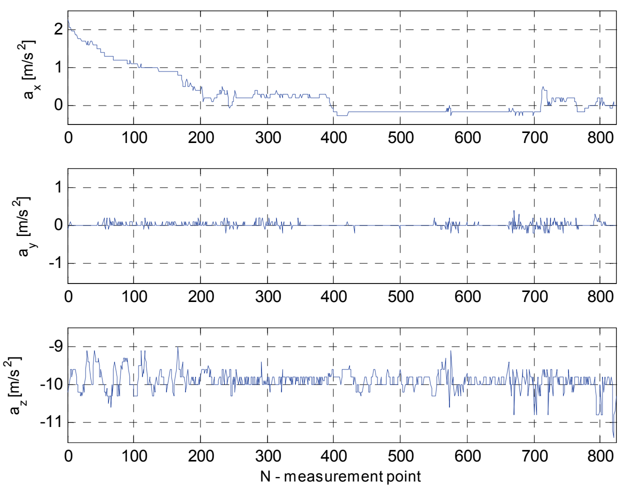

Figure 2 Example of linear accelerations during regular flight of Airbus A320 aircraft

The most important aerodynamic factor in cruise performance analysis is total drag (D) of airframe–engine combination. Aircraft performance is calculated from equations of longitudinal motion for aircraft as a point mass model (PMM) [28]:

$$m\frac{\mathrm{d}V}{\mathrm{d}t} = F_T - D - W\sin\gamma, \qquad (1)$$

$$mV\frac{\mathrm{d}\gamma}{\mathrm{d}t} = L\cos\phi - W\cos\gamma, \qquad (2)$$

$$mV\cos\gamma\frac{\mathrm{d}\chi}{\mathrm{d}t} = L\sin\phi. \qquad (3)$$

In these equations, m is aircraft mass, F_T is thrust, W is aircraft weight and L is aerodynamic lift. Lift and total drag are proportional to aerodynamic coefficients (C_L or C_D), dynamic pressure q and reference area S_{ref} as shown in Eq. (4) and (5):

$$L = C_L \cdot q \cdot S_{\mathrm{ref}}, \qquad (4)$$

$$D = C_D \cdot q \cdot S_{\mathrm{ref}}, \qquad (5)$$

where for small α,

$$C_L = \alpha C_X - C_Z,$$
$$C_D = -C_X - \alpha C_Z.$$

For straight flight ($\dot{\chi} = 0$, climb angle γ = const.) aircraft bank angle must be $\phi = 0$ from which follows:

$$\frac{V}{\mathrm{g}}\cdot\frac{\mathrm{d}V}{\mathrm{d}t} = \frac{F_T - D}{W}\cdot V - V\sin\gamma, \qquad (6)$$

$$L = W\cos\gamma. \qquad (7)$$

From Eq. (6) follows:

$$\frac{F_T - D}{W}\cdot V = \frac{\mathrm{d}h}{\mathrm{d}t} + \frac{V}{g}\frac{\mathrm{d}V}{\mathrm{d}t}, \qquad (8)$$

$$P_S = \frac{\mathrm{d}h}{\mathrm{d}t} + \frac{V}{g}\frac{\mathrm{d}V}{\mathrm{d}t}. \qquad (9)$$

During steady level flight specific excess power is $P_S = 0$. When stabilized cruise flight is not established, it is necessary to correct the calculated deviations. The stabilization criteria for steady-state level flight are:

$$|\Delta h| < 6{,}1\ \mathrm{m}\ (20\ \mathrm{ft}),$$
$$|\Delta T| < 1\ ^\circ\mathrm{C},$$
$$|\dot{V}_k| < 0{,}00857\ \mathrm{m/s^2}\ (1\ \mathrm{kn/min}),$$
$$|\Delta Ma| < 0{,}003,$$
$$DA < 5^\circ.$$

where:
$\dot{V}_K$ – aircraft acceleration along the flight path,
DA – drift angle ($DA = \chi - \chi_A$) is an angle between aerodynamic and flight speed, or angle between heading and track in navigation.

The criteria for stabilized cruise flight is very important with respect to flight path acceleration since the amount of $\dot{V}_k$ = 0,00857 m/s^2 (1 kn/min), leads to calculated drag deviation of about 1,3 % [1].

Stabilized conditions of measurement are the main criteria in selecting the relevant parameters for specific air range determination. SR is measure of aircraft cruise efficiency and is defined as range per weight of used fuel ($SR = V / FF$). The method assumes known aircraft weight. The passengers mass is calculated according to the standard values defined by EU-OPS 1.620 [29].

For given aircraft weight, Mach number Ma and air pressur ep, the lift coefficient C_L for cruise flight can be calculated as: $C_L = f\left(W/\delta, Ma\right)$, where: $\delta = p/p_0$.

For a determined lift coefficient value and known drag polar, associated drag coefficient C_D can be determined as function of C_L and Mach number: $C_D = f\left(C_L, Ma\right)$.

The value of the drag coefficient is used to calculate the required thrust force for steady and straight level flight in these conditions according to Fig. 3.

Thrust force is expressed through engine rotation speed N_1 or engine total pressure ratio EPR.

For increase in C_D due to changes in aerodynamics aircraft should use more thrust for the same "optimal speed". Greater thrust means higher fuel consumption, and decrease in specific air range.

To calculate drag deviations from flight data it is necessary to determine the achieved engine's thrust force. Any errors in the engines thrust determination are transferred to error in drag model. Accuracy of identified drag model depends on accurate knowledge of aircraft weight and engine thrust.

APM method is also used for "apparent" distinction of engine and aerodynamic performance influence. Fig. 4 shows schematic operating principle of APM method. Orange boxes present theoretical model and blue boxes true aircraft flight data.

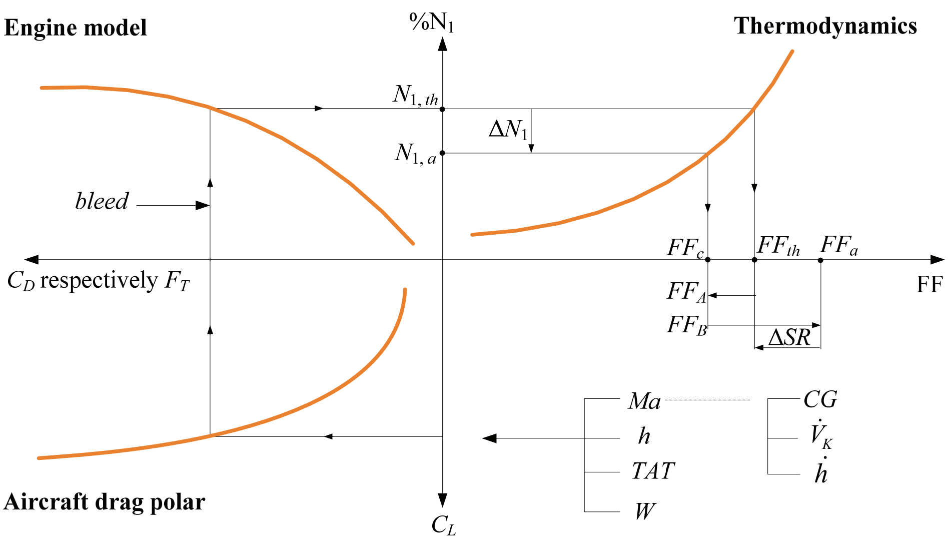

Figure 3 The main operating principle of APM program [1]

Flight variables are registered during at least fifteen minutes long time period. An average value of variables during best 60 s time period is used for cruise point performance calculation (Tab. 1).

Measured flight variables are used as an input data in IFP software that gives theoretical aircraft performance, or theoretical engine rotation speed $N_{1,th}$ and theoretical fuel flow FF_{th}.

Apparent aerodynamic degradation is calculated for a chosen cruise point data for measured actual engine rotation speed $N_{1,a}$ and theoretical engine rotation speed $N_{1,th}$ (see Figs. 3 and 4).

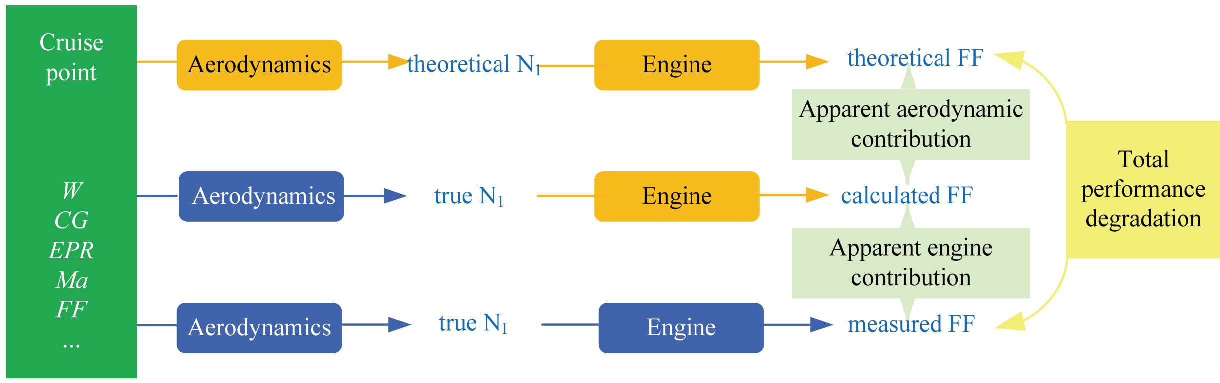

Figure 4 Schematic APM cruise performance method representation [1]

For measured cruise flight data aircraft performance software will give $N_{1,th}$ and related FF_{th}. If $N_{1,a}$ is taken as an input variable into theoretical engine performance model, it will give calculated fuel flow, FF_c.

Difference between values of calculated and theoretical fuel flow represents deviation of fuel flow due to apparent aircraft airframe degradation ΔFF_A, calculated from Eq. (10).

$$\Delta FF_A = \frac{FF_c - FF_{th}}{FF_{th}} \cdot 100(\%). \tag{10}$$

If engine performance is also degraded, calculated fuel flow for $N_{1,a}$ will differ from actual (measured) fuel flow, FF_a. The difference between the FF_a and FF_c will give fuel flow deviation due to engine performance degradation ΔFF_B, from Eq. (11).

$$\Delta FF_B = \frac{FF_a - FF_c}{FF_c} \cdot 100(\%). \tag{11}$$

Difference between actual specific air range $SR_{a,}$ (considering FF_a) and theoretical, SR_{th} (considering FF_{th}) in equal flight conditions (h, W, TAT, Ma, etc.) is indicated as specific range deviation ΔSR (or DSR, Deviated Specific Range) following Eq. (12) and (13).

$$\Delta SR = \frac{SR_a - SR_{th}}{SR_{th}} \cdot 100(\%). \tag{12}$$

$$\Delta SR = \frac{FF_{th} - FF_a}{FF_a} \cdot 100(\%) \tag{13}$$

Total specific air range deviation is equal to sum of specific range deviation due to engine performance degradation and specific range deviations due to air frame deterioration.

Engine thrust force is calculated indirectly from measured flight variables such as engine rotation speed, Mach flight number and outside air temperature. $N_1$is most effective indicator of thrust but because of mechanical engine wear out, it changes its significance during time. Another reason is variations in function that connect $N_1$and thrust from one engine to another [29].

The observed ΔN_1 or ΔEPR deviations do not necessarily indicate the aerodynamic airframe degradation. The most commonly observed deviation results from altered N_1/F_T or EPR/F_T ratio values with respect to the nominal ratio values for the same engine.

Even completely new engines can have different function between engine rotation speed or pressure ratio and resulting thrust F_T. The data obtained by testing the engine on test bench, cannot be sufficiently reliable to transfer the case to aircraft high Mach number and altitude flight (the one in the Flight Manual) [1].

Table 1 Most important input variables for SR method in APM programme

Variable	Description
Ma	Mach flight number from Air Data Computer (ADC)
h	Pressure altitude from ADC (ft)
TAT	Total Air Temperature from ADC (°C)
W	Aircraft weight from *load and trim* sheet and fuel consumption (lb)
CG	Centre of gravity in % of mean aerodynamic chord (MAC)
$\dot{V}_K$	Aircraft acceleration along the flight path horizontal acceleration (in g's)
$\dot{h}$	Rate of climb from aircraft vertical acceleration (ft/min)
N_1	Engine rotation speed (%) for specific power setting of GE and CFM engines
EPR	Engine pressure ratio for specific power setting of IAE, RR and P&W engines
FF_n	True fuel consumption for engine *n* (kg/h)
EGT	Exhaust gas temperature
$(\dot{m}_a)_n$	Air mass flow through engine *n* (kg/h)
LHV	Lower heat value of fuel (J/kg)
Latitude and heading	For possible Coriolis/centrifugal and local gravitational acceleration effects

Engine performance is also affected by level of degradation described with immeasurable health parameters. Values of these health parameters affect exact calculation of thrust [13].

Based on specific range method results aircraft operator may take the necessary measure such as repair of structures, adjustment of engine settings, or correction of aircraft performance index (PI). PI is a number used for correction of true fuel consumption with respect to actual fuel consumption. It is used for synchronization of theoretical performance database with true situation inside of Flight Management System (FMS). Airbus recommends that the correction of performance index entries when fuel consumption deviations are at least ±0,5 % [1].

The disadvantages of Airbus specific range method are:

- requires at least fifteen minute period of steady cruise flight,
- not adjusted for the short flight destinations,
- it is not possible to estimate deviation of the specific physical factors from their theoretical (baseline) values,
- does not take into account all engine parameters in calculating thrust force.

4 Discussion

APM program is used for aircraft performance monitoring in cruise flight with capability to make distinction between aerodynamic and engine degradation level. The total aerodynamic degradation is completely attributed to drag changes. The APM method cannot determine specific physical parameters that led to drag changes. Only with later aircraft analysis, visual inspections of airframe and control surfaces, details about damage can be defined.

Therefore, continued research is planned to focus on application of system identification methods for QAR flight data analysis of transport aircraft in operation. The aim is to use data from entire flight path and to obtain more complete information about the aerodynamic degradation.

This will lead to setting the framework for different method of performance monitoring by aerodynamic parameters estimation. The method will enable monitoring aerodynamic coefficient deviations from baseline values.

To investigate method's ability for aerodynamic coefficient identification from steady flight, model of rigid transport aircraft will be used.

Aircraft flight simulation model will contain aerodynamic coefficients estimated with ESDU (*Engineering Design Software and Methods Tools*) method as described in [28] and engine off-design performance based on [31]. This aircraft flight model will then be used for steady flight simulation that will give input variables for aerodynamic coefficients estimation method.

Simulation model will have control surface deflection and engine rotation speed for its input parameters. Output variables will include linear and angular accelerations, Euler angles, aerodynamic speed components, angle of attack, sideslip angle, etc. Simulation variables will be compared with true data from aircraft QAR unit to evaluate simulation reality.

Next, input-output data from flight simulation will then be used for aerodynamic coefficient determination.

These aerodynamic coefficients can be used for estimation of different aircraft performance characteristics and for monitoring aerodynamic deterioration level.

Main purpose will be to determine capability of chosen parameter estimation method in aerodynamic coefficient monitoring from regular flight data for more efficient maintenance and flight planning operations.

5 Conclusion

Knowledge of true aircraft performance is necessary for safe flight planning of aircraft operations. Current and active methods for aircraft performance monitoring are based on measuring and calculating fuel consumption from cruise flight data. Deviation of aircraft performance from theoretical data or measured baseline can be evaluated only as specific air range deviation in current methods.

Stabilized cruise flight data cannot be used for other aircraft performance determination, such as: maximum rate of climb, maximum service ceiling or climb angle.

Aircraft flight performance results from airframe-engine combination of physical characteristics.

System identification methods can be used for monitoring of physical parameter changes. The input variables for system identification methods are registered in QAR unit during flight. Depending on the flight dynamics and the quality of recorded data, it is possible to estimate aerodynamic coefficients values.

Determined aerodynamic coefficients have physical meanings that can be associated with actual aircraft airframe changes.

New system for aerodynamic characteristics monitoring could give more substantial information about type of degradation and more accurate and complete actual aircraft performance.

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