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Performance Analysis of Adaptive Control Technique for Aircraft Gas Turbine Engine

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ABSTRACT:

This paper presents an adaptive control technique to compensate the thrust variation in an aircraft engine whose performance has been disturbed due to atmospheric conditions. The course of dysfunction appears when a large throttle transient is performed such that the engine switched from low to high speed mode. A relationship is observed between engine disturbance and the overshoot in engine shaft rpm or compressor discharge pressure or turbine temperature, which is determined to cause the thrust variation. This relationship is used to adapt a control. This method works very well up to the operability limit of an engine. Additionally, the type of disturbance identified from sensors data will be useful to implement the adaptive control in real time operation.

KEYWORDS:

Gas turbine engine; Full authority digital engine (or electronics) control; Adaptive control; Matlab

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1. Introduction

Aircraft engine performance varies from engine to engine due to manufacturing tolerances, ageing, atmospheric conditions and deterioration. Generally the control system developed for the engine is robust enough to keep it operating within acceptable boundaries for several thousand flight cycles, even though the degradation will eventually require the engine to be overhauled as limits are reached [1]. These limits include operability constraints such as maximum temperatures, and performance constraints such as FAA's rise time requirement for thrust in commercial engines. Generally, aircraft engines control Engine Pressure Ratio (EPR) or shaft speed to generate desired thrust, since thrust cannot be measured directly during flight. Although these regulated variables are maintained at their set points regardless of engine dysfunction, the non-regulated parameters shift from their nominal values with deterioration. Thus, in the degraded engine, the actual thrust output, which is indirectly controlled through the regulation of other variables, may be shifted from the expected value.

Undesirable thrust responses due to engine degradation and an adaptive scheme to recover the nominal thrust response are investigated in this paper using the engine simulation. Off-nominal values of specific internal engine parameters representing component efficiencies and flow capacities are often used to account for these performance variations. The equations which describe the degraded engines behaviour are:

$$X(t) = f(x(t), u(t), p)$$

$$Y(t) = g(x(t), u(t), p)$$

where p represents the vector of health parameters. When obtaining a standard linear point model of an engine, the health parameters are treated like inputs. Depending upon how they manifest themselves, the system dynamics may or may not vary with degradation. But the state equation clearly demonstrates that steady state is only obtained when the x(t) and u(t) vectors shift to compensate p and the output equation shows how non-zero values of p can produce additional steady state shifts in the output variables. These equations also imply that degradation causes shifts in the engines trim values and these shifts that can result in unacceptable operation.

2. Engine model

The engine models in SIMULINK are needed for control system analysis and design, because most of the controls vary with respect to engines. The engine GE T700 is a turbo shaft engine used in apache and black hawk. The engine has been rebuilt to a linear state for testing. When the internal state of an engine reaches a thermodynamic equilibrium, the engine is said to be in a steady state. Steady state models of jet engines are traditionally called cycle decks [2]. Cycle deck derives its name from the fact that it is a computer program to analyze the thermodynamic engine cycle and performance at any operating condition in the flight envelope. Hence, a cycle deck is the engine model that represents the steady state characteristics of each engine module over its entire range of operation. The industry practice is to use data or empirical-analytical correlations in the form of component maps to give greater accuracy. These maps are converted into a set of multivariate functions of corrected speed, corrected flow rate, pressure ratio and efficiency for each module. These functions are then implemented in the form of look up tables for efficient digital computation [3]. The map functions are commonly adjusted for Reynolds number effects and variable geometry settings. A cycle deck is also called a component level model and it is highly Fidel, physics based simulation of an engine's steady state performance.

3. Model based adaptive control

Models can be integrated into the control loop to identify the system's state and derive prognostic actions. This offers completely new possibilities in engine control. On-board models may be used to provide engine parameters, which cannot be measured directly due to sensor location or their physical property [4]. They may replace sensed parameters due to faults or low frequency response and can be used to predict upcoming events. Adaptive controller shown in Fig. 1.

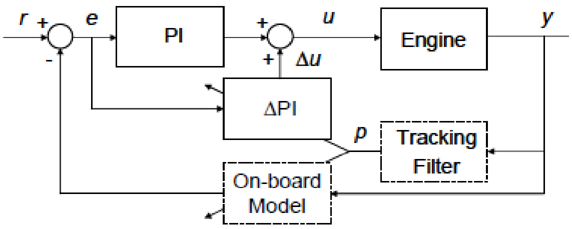

Fig. 1: Adaptive controller block diagram

Adaptive control refers to a self-adjusting controller that can modify the controller action depending on the transient external circumstance. An extra layer of control allows adjusting the closed loop filter in a way that the control action is optimized for all conditions. Typically, the parameter that requires a change in the controller setting varies much more slowly than the closed loop controller. A more extended view of an adaptive control system if that providing self-calibration. Even the most accurate mathematical model of a real system cannot be more than an approximation of its real dynamics. There are several sources of uncertainty that may unfavourably influence the stability and performance of the control system, which can be categorized as parametric and unknown uncertainties. The controller used here is a multi-mode, multi-variable PI controller. The performance modes are low and high speed modes. The safety modes are over speed mode and stall margin mode. Over speed mode prevents the engine from running too fast and stall margin mode takes over as the engine operation approaches the stall line to prevent the engine from stalling.

3.1. Performance due to usage and ageing

As the engine is used, wear occurs that affects the engines performance: turbine blades erode, clearances open up, etc. This result in component flows and efficiencies that are worse than in a new engine and the performance degrades. Also the erroneous output from sensors due to sensor ageing can leads to engine performance deterioration. In order to achieve the same level of thrust as in new engine, the deteriorated engine must run hotter and/or faster. This shift from nominal operation increases with use, and eventually reaches the point where performance cannot be maintained without compromising the safety of the engine or the life of its components. The health parameter represent shifts from the engine's nominal values and correspond to moderate to severe degradation which might occur when the engine is due for an overhaul based on flight cycles, or when the engine is used in a particular harsh environment such as a sandy desert or an area of volcanic activity.

3.2. Analysis of the degraded responses

Since the only structural difference between the active performance controllers as the engine moves through a large transient is the replacement of EPR control with ETR control, that is a likely cause of the disturbance in thrust. For the new engine, ETR is quickly brought under control with little overshoot. For the degraded cases, even though the initial (low speed) steady-state (uncontrolled) value of ETR is closer to the final (high-speed) set point as the mode switches than in the nominal case, significant overshoot seems to cause an upset in thrust due to the interaction of the variables. This disturbance in thrust will impact the information from sensors greatly. The engine control is designed to maintain thrust response even under degraded conditions. And the thrust curves in both low and high-speed mode are the rate of increase essentially matches the nominal response. It is only during the mode transition that the response curves are delayed. Thus an approach to minimize the variation in thrust response is to adapt the controller as a function of degradation to decrease the interaction between the controlled variables. Since the ETR overshoot of the degraded response is hypothesized to be the cause of the problem, we shall reduce its influence to level in the nominal response. This can be achieved by compensating the error with the scale factor. The scale factor is obtained as the difference in values by the comparison of model based system and the nominal system at the same state.

4. Results and discussion

To test the hypothesis, the scale factors calculated from the transient simulation of the degraded engine [9], different cases were tried with the errors of sensors [8] such as (i) no fault, (ii) drift bias fault, (iii) offset fault, (iv) pulse fault. Although there are various control variables such as temperature, pressure and fuel flow are available, here rpm has been taken for control. Fig. 2 depicts the condition of rpm at particular transient period with no fault. Fig. 3 shows the rpm vs. time at drift bias fault of degraded engine. The response of the PID control is fault, whereas the model based adaptive control is a controlled one.

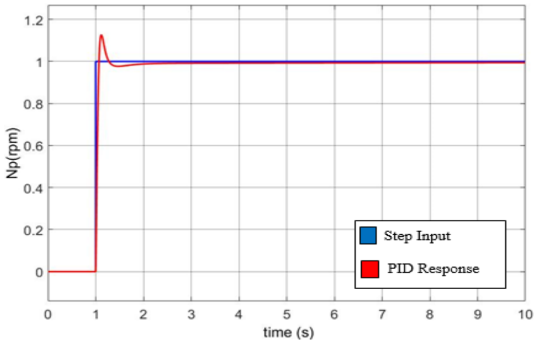

Fig. 2: Compensated Np response from a PLA step for a nominal condition engine

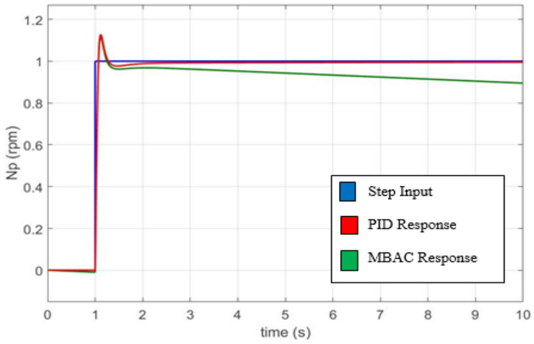

Fig. 3: Compensated Np response from a PLA step for a drift bias fault of degraded engine

The response of degraded engine during sensor offset condition is shown in Fig. 4. Here the response of PID control and model based adaptive control are observed when the rpm offset has taken place from one value to another. Fig. 5 shows the response of degraded engine during pulsated error signal obtained from sensor and PID response. Also, the response of model based adaptive control is obtained for the same error condition.

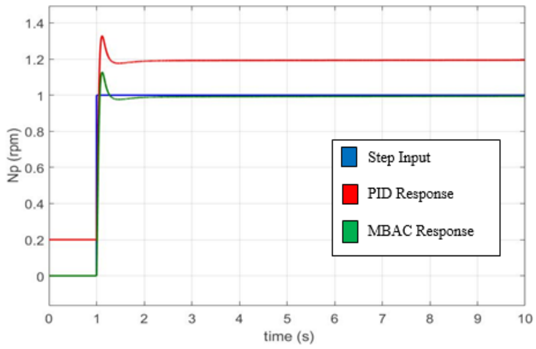

Fig. 4: Compensated Np response from a PLA step for a offset fault of degraded engine

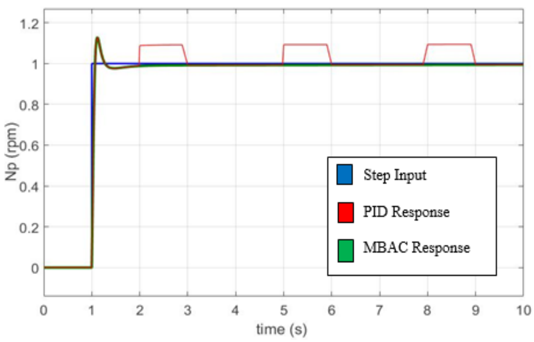

Fig. 5: Compensated Np response from a PLA step for a pulse fault of degraded engine

5. Conclusion

The proposed adaptive rule works very well for thrust response recovery of the GE T700 engine, degraded along with expected altitude at the given operating conditions. More work still needs to be done to evaluate the robustness of the scheme to off-nominal degradation and to identify those health parameters that have the most impact on the degraded response, since the technique may be very robust to variations in some parameters but not others. Additionally, the technique was tested for various error conditions of sensors, even though the transient response covered most of the PLA range at that point. It must still to be tested at other operating points. Tuning of the controller gains could improve the responses further, for instance by eliminating the slight overshoot in the compensated thrust curves. The objective of this work, however, was to develop a general strategy for adapting the controller for applicability to other engine/controller pairs. This method is general for a class of engines and controllers demonstrating the same type of thrust response as a result of degradation. Finally, although the approach for smoothing thrust response presented here works well, it only addresses a symptom of the real problem associated with engine degradation: the tendency of some variables to shift toward operability limits.

REFERENCES:

[1] G.P. Sallee. 1978. *Performance Deterioration based on Existing (Historical) Data; JT9D Jet Engine Diagnostics Program*, NASA Contractor Report 135448.

[2] J.D. Mattingly, W.H. Heiser and D.T. Pratt. 2002. *Aircraft Engine Design*, 2nd Edition, AIAA.

[3] K.I. Parker and T.H. Guo. 2002. Development of a turbofan engine simulation in a graphical simulation environment, *JANNAF 26th Aero-Propulsion Subcommittee, 2nd Modeling and Simulation Subcommittee Joint Meeting*, Destin, FL.

[4] T. Kobayashi and D.L. Simon. 2001. A hybrid neural network-genetic algorithm technique for aircraft engine performance diagnostics, *37th Joint Propulsion Conf. and Exhibit*, Salt Lake City, UT. https://doi.org/10.2514/6.2001-3763.

[5] H.H. Lambert. 1991. *A Simulation Study of Turbofan Engine Deterioration Estimation using Kalman Filtering Techniques*, NASA Technical Memorandum 104233.

[6] D.L. Simon. 2003. Aircraft turbofan engine health estimation using constrained Kalman filtering, *Proc. Int. Gas Turbine and Aero engine Congress and Exposition*, Atlanta, GA.

[7] S. Ganesan and G.M. Priyadharshini. 2016. Theoretical analysis on aircraft gas turbine engine's control unit, *IOSR-JMCE*, 13(6). https://doi.org/10.9790/1684-1306050105.

[8] F. Lu, J. Huang and Y. Xing. 2012. Fault diagnostics for turbo shaft engine sensors based on a simplified on-board model, *Sensors*, 12(8), 11061-11076. https://doi.org/10.3390/s120811061.

[9] M.G. Ballin. 1988. *A High Fidelity Real Time Simulation of a Small Turboshaft Engine*, NASA Technical Memorandum 100991.