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Matching mechanism analysis on an adaptive cycle engine

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Abstract As a novel aero-engine concept, adaptive cycle aero-engines (ACEs) are attracting wide attention in the international aviation industry due to their potential superior task adaptability along a wide flight regime. However, this superior task adaptability can only be demonstrated through proper combined engine control schedule design. It has resulted in an urgent need to investigate the effect of each variable geometry modulation on engine performance and stability. Thus, the aim of this paper is to predict and discuss the effect of each variable geometry modulation on the matching relationship between engine components as well as the overall engine performance at different operating modes, on the basis of a newly developed nonlinear component-based ACE performance model. Results show that at all four working modes, turning down the high pressure compressor variable stator vane, the low pressure turbine variable nozzle, the nozzle throat area, and turning up the core-driven fan stage variable stator vane, the high pressure turbine variable nozzle can increase the thrust at the expense of a higher high pressure turbine inlet total temperature. However, the influences of these adjustments on the trends of various engine components' working points and working lines as well as the ratio of the rotation speed difference are different from each other. The above results provide valuable guidance and advice for engine combined control schedule design.

1. Introduction

For the purpose of obvious reduction on R&D cost and cycle, design objectives include all-weather, long-range, multi-mission, and so on for next-generation affordable aircraft. These design objectives lead to new requirements on aircraft engine design. On one hand, a newly designed engine should have turbojet features such as higher specific thrust in order to qualify for thrust stringent missions such as non-augmented supersonic cruising and transonic climbing. On the other hand, it should also have the turbofan feature of

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lower specific fuel consumption to compete in fuel cost missions such as long-range reconnaissance. Clearly, to achieve these conflicting goals in an engine, a variable cycle engine[1] is undoubtedly an ideal propulsion device.

As a new concept of variable cycle engine, an ACE consists of a typical double-bypass VCE (variable cycle engine)[2] surrounded by a third bypass duct (shown in Fig. 1).[3] The third bypass duct contains a row of variable inlet guide vanes and a single compression stage through extending one row of main fan blades into the stream. In essence, it is a triple-bypass VCE. It contains four different operating modes through different combined modulations of several variable geometries while a VCE contains double modes.[4] When both the third bypass and the second bypass are open, it operates at a triple-bypass mode named Mode M3. When the third bypass is closed while the second bypass is open, it operates at a double-bypass mode named Mode M2. On the contrary, if the third bypass is open while the second bypass is closed, it operates at another different double-bypass mode named Mode M13. When neither the second bypass nor the third bypass is open, it is called one-bypass mode named Mode M1.[5] When an ACE operates at Mode M1 or Mode M13, the third bypass is just open a little which guarantees the flow compatibility and contributes little to the power-balance. The Flade (fan on blade) is regarded as being closed. The gas paths of an ACE at variable modes are shown in Fig. 2.

Owning to the complexity of an ACE which has three bypasses, the split ratio is more proper than the bypass ratio for their definitions.

The first bypass split ratio is defined as below:

$$B_1 = \frac{W_{a24}}{W_{a23}} \tag{1}$$

where B_1 is the first bypass split ratio, W_{a24} (kg/s) is the first bypass air flow, and W_{a23} (kg/s) is the HPC (high pressure compressor) air flow.

The second bypass split ratio is defined as below:

$$B_2 = \frac{W_{a22}}{W_{a21}} \tag{2}$$

where B_2 is the second bypass split ratio, W_{a22} (kg/s) is the second bypass air flow, and W_{a21} (kg/s) is the CDFS (core driven fan stage) air flow.

The third split bypass ratio is defined as below:

$$B_3 = \frac{W_{a12}}{W_{a2}} \tag{3}$$

where B_3 is the third bypass split ratio, W_{a12} is the third bypass air flow, and W_{a2} (kg/s) is the fan air flow.

Through the combined modulation of various variable geometries, an ACE has four different working modes alternatives to guarantee superior performance along a wide flight regime. The available variable geometries are shown in Fig. 3. It contains these variable geometries including the CDFS variable stator vane ($\mathrm{VSV_{CDFS}}$[6]), the Flade variable stator vane ($\mathrm{VSV_{Flade}}$[7]), the HPC variable stator vane ($\mathrm{VSV_{HPC}}$), the HPT (high pressure turbine) variable area nozzle ($\mathrm{VAN_{HPT}}$), the LPT (low pressure turbine) variable area nozzle ($\mathrm{VAN_{LPT}}$), the front VABI (variable area bypass injector (Pro-VABI), the rear VABI (Rear-VABI),[8] and the nozzle throat section (A_8).

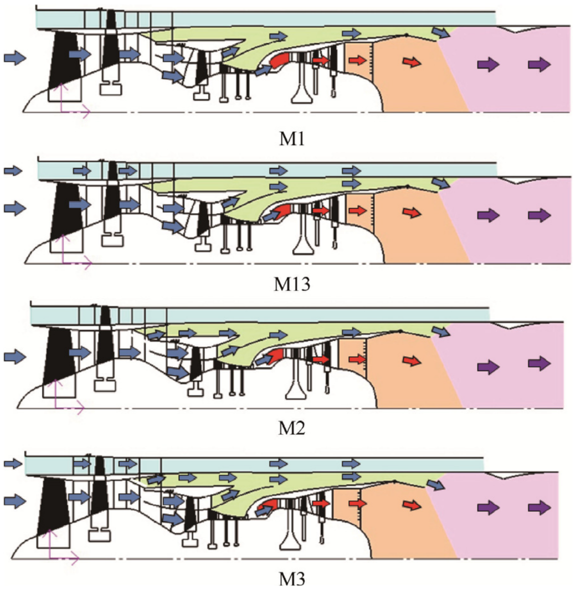
M1
M13
M2
M3

Fig. 2 Flow path characteristics of an ACE at variable modes.

With the support of the AETD (Adaptive Engine Technology Development) plan, ACEs have made great progress. The core engine of an ACE has been tested by GEAE (General Electric Aircraft Engine Group).[9] According to the public literature,[3] avoiding severe inlet spillage drag at a supersonic part-load operation and greater variable cycle characteristics are the two obvious advantages of ACEs compared to other traditional aero-engines. Specially, by allowing an engine to pass as much amount of air as possible at a part-load operation during supersonic cruise, an ACE can avoid severe inlet spillage drag compared to a typical VCE such as F120.[10] In addition, the alternatives of four different working modes can extend the range of engine bypass ratio variation enormously. These two advantages can only be demonstrated through proper combined variable geometries control schedule design. Thus, there is an urgent need to investigate the effect of each variable geometry modulation on engine performance

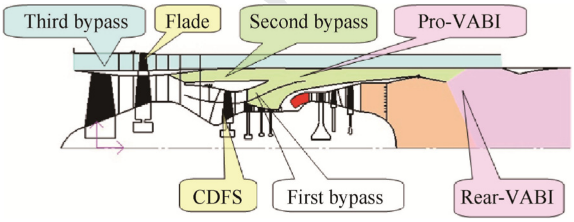

Fig. 1 Configuration of an adaptive cycle engine.

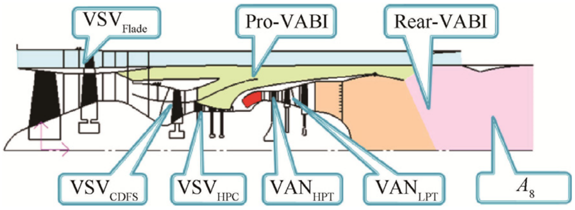

Fig. 3 Variable geometries of an ACE.

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