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Numerical investigation on the assistant restarting method of variable geometry for high Mach number inlet

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ABSTRACT

To compromise the compression efficiency and the starting properties, the inner contraction ratio (ICR) of a general high Mach number inlet is usually designed in the range of dual solution area. When going into an unstarted status, the high Mach inlet needs an assistant method to restart. This work explores a variable geometry method to restart the inlet. The rotating cowl is adopted to a typical Mach 4 cruising inlet, and the unsteady computation method with a dynamic Chimera grid technique is applied to simulate the rotating process of the inlet cowl. The change characteristics of the restarted performance at different rotating angle amplitude of the inlet cowl are investigated systematically. The numerical results reveal that the unstarted status of this typical inlet induced by the effect of high backpressure failed to restart if the inlet cowl rotating angle amplitude is under a small critical value, which is called lower critical angle. The inlet could restart if the cowl rotating angle amplitude is a little larger than the lower critical angle, and the flow may rapidly go to a steady condition after the inlet cowl returns to the design position. However, the performance of the restarted inlet is still worse than the design condition, because of the existence of an stable separation bubble on the should, even if the inlet cowl stops rotating. The separation bubble becomes shrunk with an increasing the cowl rotating angle amplitude. When the inlet cowl rotating angle amplitude reaches a large critical value which is called upper critical angle, the separation bubble disappears, and all the separation is swallowed by the mean flow. Therefore the design performance of the inlet can be recovered, which means that the flow mass capture coefficient, total pressure recovery coefficient, drag and the outlet Mach number go back to the design level. It is also show that within the range of the lower and upper critical angles, the larger the rotating angle amplitude is, the more rapidly the separation bubble reaches stable state.

1. Introduction

As one of the key components of an air-breathing propulsion system for the high Mach number aircraft, the status of the inlet has significant influence on the engine and even the whole aircraft. If the inlet unstarts, the flow mass capture coefficient and total pressure recovery coefficient decreases drastically, which could result in a decline of the engine performance, and even flameout of the engine. Meanwhile, the spillage drag may increase significantly because of the overflow caused by the inlet unstarting [1–4]. Therefore, the flight performance and aircraft safety are impacted by starting properties directly. In the inlet design process, engineers should pay sufficient attention to the inlet unstart and its harmfulness, and one should also prepare some backup methods to assistant the inlet restart rapidly when it falls into the unstarted status.

Recently, a large number of investigations have shown that the inner contraction ratio (ICR) is one of the most significant factors affecting the high Mach inlet starting properties [5–7]. At the same time, to compromise the compression efficiency and starting properties, the ICR of a typical high Mach inlet is usually in the dual solution area [5,8–11], and most part of the working range is also located in this area. When the operating conditions of the inlet change, such as the incoming Mach number decrease or the inlet backpressure increases, etc., the inlet maybe goes to an unstarted status. So it is very important to develop a reliable assistant starting method to help an unstarted inlet restart.

Until now, the assistant method to restart the inlet mainly includes but not limited to bleeding [12,13], unsteady effects [14,15] and variable geometry [16–19], etc. Similar to the exit area enlargement, the mechanism for bleeding is to help flow spills

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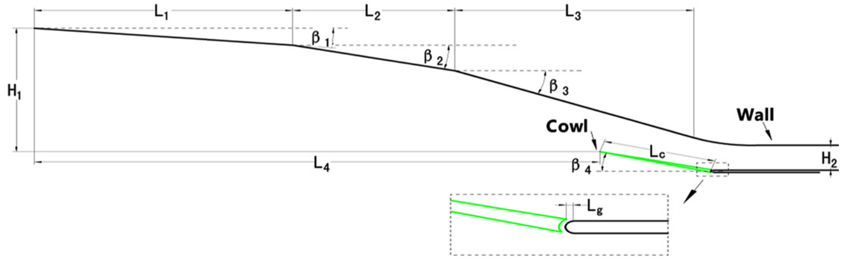

Fig. 1. The sketch of inlet model. (For interpretation of the colors in the figure(s), the reader is referred to the web version of this article.)

through the wall perforations. Since the 1950s, the bleeding technique has been extensively studied and widely used. However, the development and application of this method is constrained by the excessive flow loss. The idea of using unsteady effects is proposed to assist the inlet start in recent years, including over speeding, diaphragm rupture and some other methods. By increasing relative incoming Mach number of the inlet, overspeeding helps the inlet switch from the self-start area to the dual solution area to assist the inlet start. However, for a high Mach number inlet with the large contraction ratio, the flight Mach required for inlet starting is out of reach practically, thus overspeeding is only of theoretical significance for the high Mach number inlet at current time. Similar to the rapid cowl separation, using the unsteady effect of the large pressure gradient before and after diaphragm rupture, the large inner contraction ratio inlet will be assisted to start. Although the mechanism of this method is relatively simple, the manufacture of diaphragm materials and how to break the diaphragm are difficult for engineering application. Variable geometry is the method to assist the inlet start by changing the inlet inner contraction ratio (reduces capture area or increases throat area). By assisting the inlet switch between the self-start area and the dual solution area in real time and efficiently, variable geometry can improve inlet starting performance at different flight conditions, and meanwhile to compromise compression efficiency. Therefore, in the above methods, variable geometry is an attractive method in terms of compromising the compression efficiency and the starting performance.

In the present work, the variable geometric rotating cowl is adopted to assist the inlet restart. Based on a typical Mach 4 cruising over-under type Turbine-Based Combined Cycle (TBCC) inlet, we focus on the unsteady aerodynamic characteristics during the movement of the cowl and the properties of the unstarted inlet caused by the excessive high back pressure from the combustor. The unsteady computation method with dynamic Chimera grid technique is employed to simulate the rotating process of the inlet cowl. By investigating the final working state of the inlet with different cowl rotating angle amplitude, the effectiveness of this method to the inlet and the performance of the inlet are analyzed and compared. The present research work is of great significance for the design of the inlet assistant starting device.

2. Variable geometry assistant starting technique and the inlet configuration

2.1. The variable geometry assistant starting technique

The variable geometry assistant starting technique can improve the inlet starting performance by changing the inner contraction ratio. When the inlet falls into an unstarted status, even if the unstarting triggering factors are removed, the inlet may still remain unstarted. There is a large separation region, strong shock and overflow in the vicinity of the cowl. After applying the variable geometric assistant starting technique, namely rotating the cowl to reduce the inner contraction ratio, the separation region will be gradually reduced and even disappeared. Meanwhile the strong shock is swallowed into the inlet, and the blockage flow is significantly reduced. Finally the inlet restarts. After the cowl turns back to the original position, the inlet can still be in starting state.

The specific variable geometry assistant starting method used in the paper is as follows. When the inlet unstarts induced by some excessive high back pressure, the inlet will still be unable to restart even though the back pressure reduces to the original normal condition. To restart the inlet, the inlet inner contraction ratio can be reduced by rotating the cowl. In this work we will show that when the cowl rotating angle amplitude reaches a large critical value which is called upper critical angle, the inlet can restart completely. Then rotate the cowl back to the original position, the performance of the inlet will recover to the original design condition. Finally, the inlet restores the initial compression performance.

Table 1
Parameters of the model.

L_1 (mm)	L_2 (mm)	L_3 (mm)	L_4 (mm)	L_c (mm)	L_g (mm)
236.559	144.99	227.933	509.867	108.001	0.5
H_1 (mm)	H_2 (mm)	β_1 (°)	β_2 (°)	β_3 (°)	β_4 (°)
173.689	34.359	5.794	14.102	23.888	14.1

2.2. The inlet configuration

In this paper, a typical mixed compression inlet scaled for wind tunnel test is considered, and the design point is Mach 4. Considering the pre-compression of aircraft forebody and other factors, the outer compression shock waves just intersect at the lip of the inlet cowl. To save the computational time, the model is simplified into two-dimensional (2-D) model neglecting the effect of the side walls.

The inlet model sketch is shown in Fig. 1, where the black line represents the inlet wall, and the blue line represents the cowl, which can rotate around the hinge axis. The inlet throat height is 34.359 mm after the boundary layer correction and the inner contraction ratio is 1.5, which is located in the dual solution area for starting. There is a 0.5 mm gap between the cowl and the inlet lower wall so that the cowl can rotate. The specific parameters of the inlet geometry are given in Table 1.

3. Numerical methods and validation

The numerical simulations in this paper are all performed using the ARI-OVERSET in-house code [20,21]. ARI-OVERSET code, developed by AVIC Aerodynamics Research Institute, is an advanced numerical platform for aeronautical engineering applications, and has been widely used in aircraft design. Especially, the Chimera grid technique in this code has provided a lot of reliable numerical results for the multi-body relative motion problems [22,23], such as store separation, variable geometry engine intake/exhaust systems and et al. A brief introduction and validation of this code have been shown in this section.

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