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Performance Analysis of Turbine-Based Combined Cycle Engine Inlet at Mach 5 and Mach 3.5 Condition using a Blowdown Wind Tunnel

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Abstract

An integrated inlet for a Turbine-Based Combined Cycle (TBCC) engine capable of taking off from the ground and cruising at Mach 6 was designed. The integrated inlet was designed to operate at subsonic to hypersonic speeds, and this was verified by numerical analysis. In order to verify the performance of the designed integrated inlet, a ground test was performed using the Scramjet Engine Test Facility (SETF), a blowdown wind tunnel at the Korea Aerospace Research Institute. The test was performed under Mach 5 conditions, and this paper summarizes the performance test results of the integrated inlet under Mach 5 conditions. In addition, for the Mach 3.5 condition experiment where the engine transition mode is executed, a Mach 3.5 nozzle of SETF was designed, and the applicability of the nozzle and the integrated inlet was examined by numerical analysis, and the results are also introduced in this paper.

Keywords: *Turbined-Based Combined Cycle Engine, Integrated Inlet, Blow-down type Wind Tunnel*

1. Introduction

The Korea Aerospace Research Institute (KARI) has been conducting various studies to develop key technologies for hypersonic air-breathing propulsion systems for reusable launch vehicle. We have been designing and analyzing hypersonic air-breathing engine such as scramjet engines, and have built a blowdown wind tunnel (Scramjet Engine Test Facility) and direct-connected test facility for combustor. In 2022, KARI began research on TBCC engine with the goal of securing core technologies for hypersonic aircraft and their propulsion systems that can take off from a ground stationary state and operate at hypersonic speeds. (Mach 5) This project aims to secure design-based technologies in the field of hypersonic aircraft(aerodynamics/structure/control).

TBCC engine consists of a turbine engine and a dual-mode scramjet engine, so it has two flow paths. Depending on the flight trajectory, the flow enters the turbine engine side in the subsonic and supersonic transition modes, and flow toward the dual-mode scramjet engine side in the supersonic and hypersonic regions. Therefore, the inlet of the TBCC engine must be variable so the flow path can be changed according to the operating region.

2. Integrated inlet for TBCC Engine

The transition point from the turbine engine to the dual-mode scramjet engine of the TBCC engine was selected as Mach 3.5. The integrated inlet has a two-dimensional shape and is designed for Mach 6 as the operating point. The integrated inlet has a total of four compression surfaces, and it is designed to undergo two external compressions and two internal compressions. Among these, the variable surfaces are the second ramp and the cowl, and their actuators are designed to be located on the sidewall. If the angle of the second ramp and the cowl is lowered, the flow path can be changed to a turbine engine. A constant area isolator is mounted behind the compression surfaces of the integrated inlet.

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Information on the inlet ramp angle design, self-start check, and isolator length design are summarized in Reference 1. The shape of the integrated inlet and the shock structure distribution at the operating point are shown in Fig. 1[1].

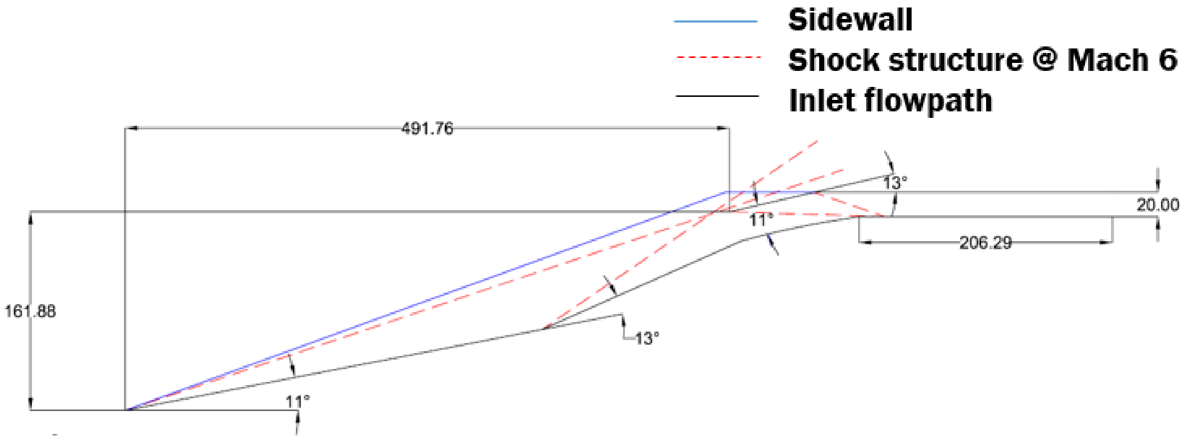

Fig 1. The integrated inlet conceptual design

3. Mach 5 and Mach 3.5 test with Scramjet Engine Test Facility

In order to verify the performance of the designed integrated inlet, a ground test was performed using the Scramjet Engine Test Facility (SETF), a blowdown-type wind tunnel at the Korea Aerospace Research Institute.[2] The test was performed under Mach 5 conditions of the SETF. Fig. 2 shows a photo of the inlet mounted on the SETF. A rake is installed at the rear of the isolator section to measure the pressure recovery rate and air capture ratio of the inflow. The rake consists of nine probes measuring pitot pressure and static pressure and three stagnation probes.

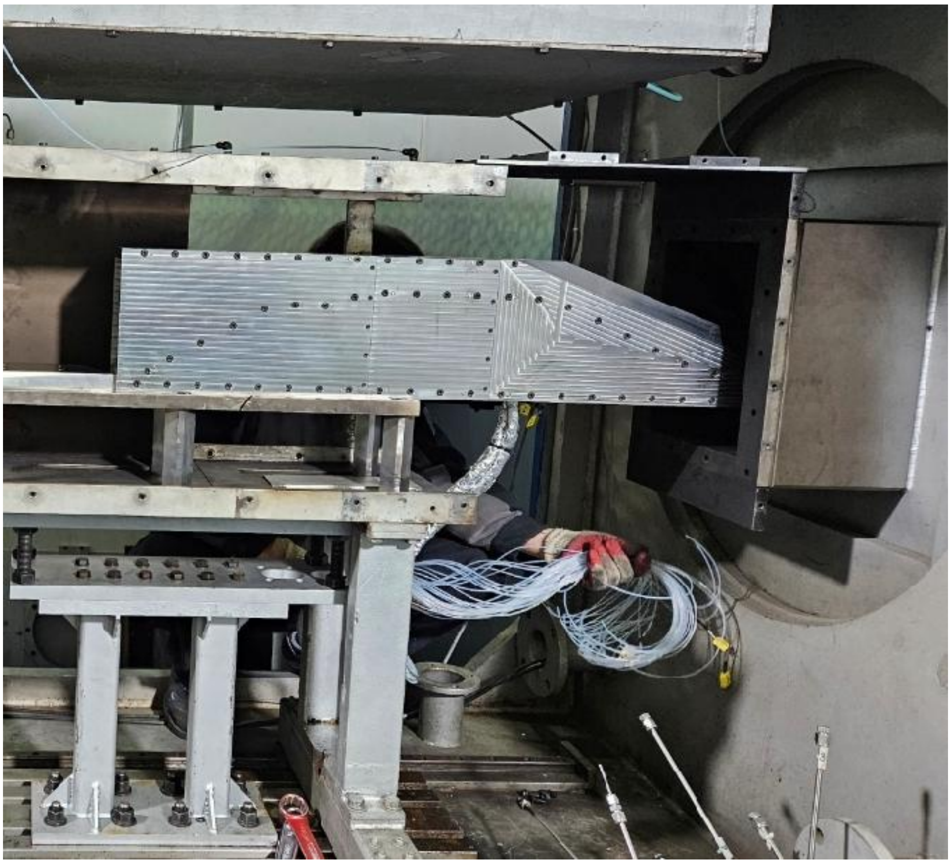

Fig 2. Integrated inlet installed in SETF

Under Mach 5 conditions of SETF, the integrated inlet was observed to have a total pressure ratio of

0.39 and an air capture ratio of 0.77. The performance was confirmed to satisfy the target performance by meeting the Mach 5 design condition of the integrated inlet. The Mach number at the exit of the isolator was observed to be 2.01 and the inflow rate was 0.74 kg/s.

Table 1. Performance of the integrated inlet at Mach 5 condition

Pressure Recovery Ratio	Air Capture Ratio	Mach number at Isolator Exit	Inflow rate
0.39	0.77	2.01	0.74 kg/s

Fig. 3 shows the wall static pressure distribution at the body side centerline under Mach 5 conditions of the integrated inlet. It was confirmed that the pressure peak trend matches well with the three-dimensional CFD analysis using FLUENT.

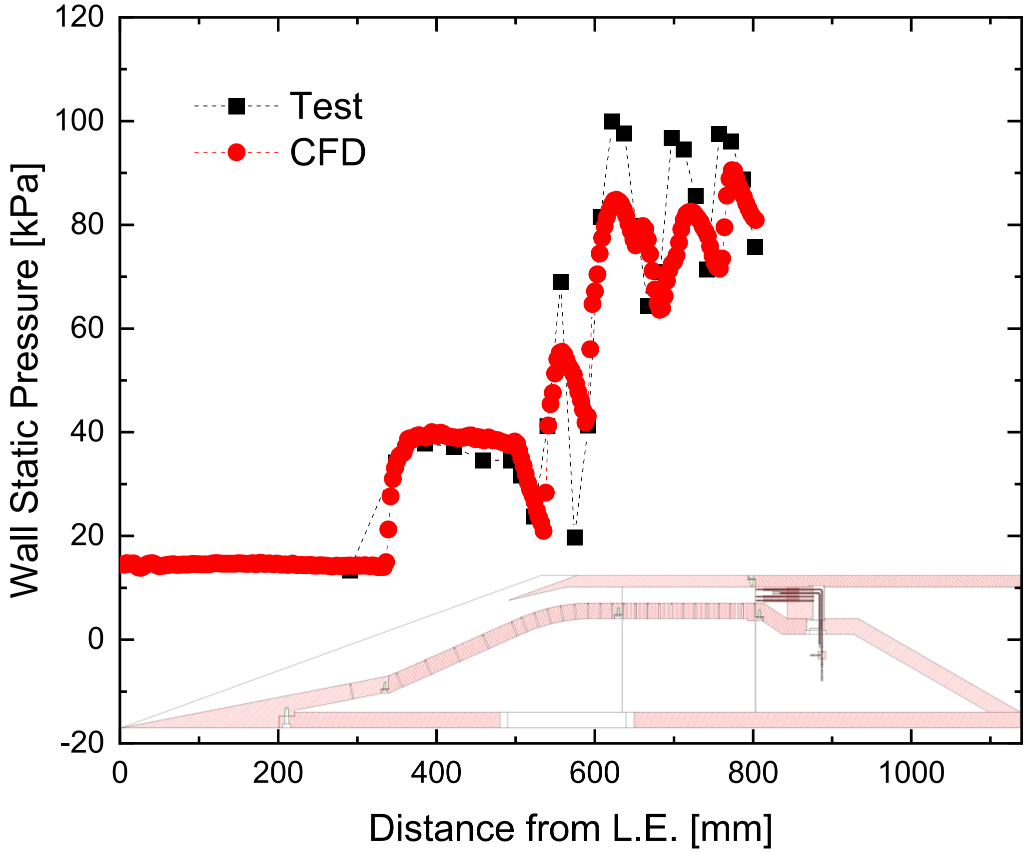

Fig 3. Wall static pressure (Body side) under Mach 5 condition of the SETF

In addition, for the Mach 3.5 condition experiment where the engine transition mode will be executed, a Mach 3.5 nozzle of SETF was designed, and the applicability of the facility nozzle and the integrated inlet was examined by three-dimensional numerical analysis using CFD. The integrated inlet designed for Mach 6 condition does not self-start at Mach 3.5 condition. Therefore, the cowl angle is adjusted from 11 degrees to 10 degrees to enable self-start. Fig. 4 shows the Mach contour of the integrated inlet in SETF with a Mach 3.5 nozzle on the plane of symmetry. It was confirmed that the Mach 3.5 nozzle designed for the transition point performance test secured the core flow field required for the integrated inlet test and had an appropriate contour required for equipment start-up.

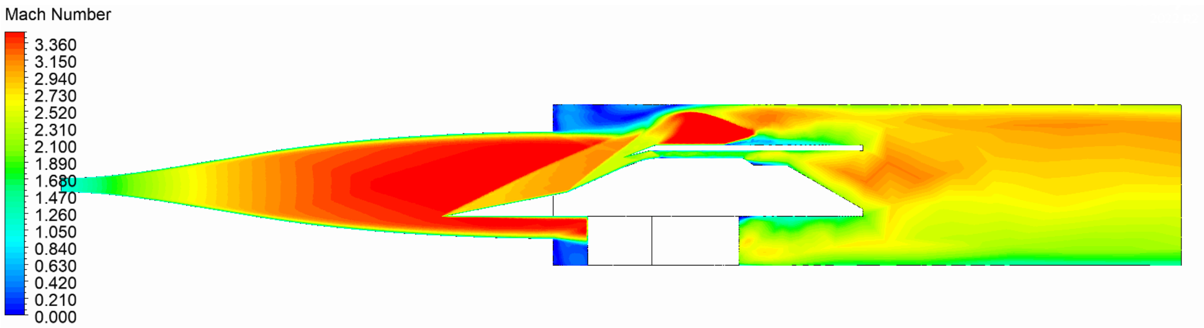

Fig 4. Mach number contour of the integrated inlet mounted on the SETF with Mach 3.5 nozzle (@ symmetry plane)

4. Future works

Additionally, a model was made in which the side wall was removed from the external compression region. Through this model, the performance of the integrated inlet according to the presence or absence of the sidewall at the external compression zone will be performed under Mach 5 and Mach 3.5 conditions.

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