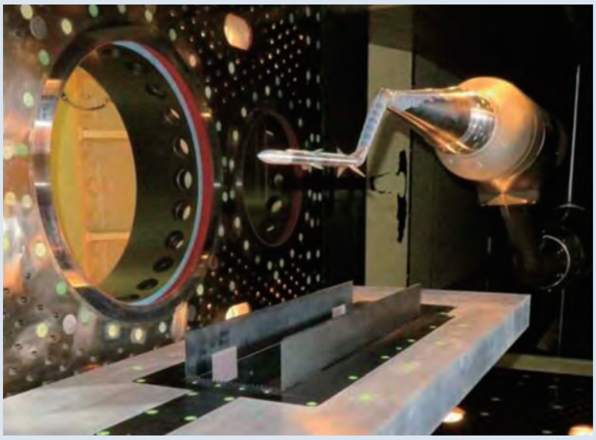
Technical Description

Evaluation of Store Separation Characteristics from Aircraft Using Aerodynamic Technology



The latest military aircraft is equipped with stores in the internal weapon bays to improve stealth and speed performance.

In this context, we developed a store separation characteristics evaluation system to analyze the flow-fields of the subsonic to supersonic ranges and simulate them at the wind tunnel test to identify the flow around the internal weapons bay and how the store is separated from the aircraft in flight for the first time in Japan. This system has been integrated into the Tri-sonic Wind Tunnel in the Chitose Test Center of the Acquisition, Technology & Logistics Agency.

Introduction

One purpose of military aircraft is to carry and drop stores such as missiles and bombs in flight. If stores are attached to the bottom of the fuselage or underwing hardpoints, however, they reflect radar signals and generate aerodynamic drag resulting in decrease stealth and speed performance. To avoid this problem, many of the latest military aircraft feature an internal weapons bay that houses stores to improve performance.

1 Background

When the weapons bay door is opened, it exposes the concavity of the internal weapons bay and generates a cavity flow, which is a complicated air-flow pattern, around the bay. A cavity flow varies greatly in flow velocity and pressure, and ever-changing aerodynamic forces are exerted on stores that pass through this flow. Moreover, cavity-flow conditions for subsonic flight speeds often differ from those for supersonic speeds. Therefore, as the aerodynamic forces on stores vary by flight speeds, it is important to predict trajectories on release from the internal weapons bay.

2 Store separation from aircraft

When a store is separated from an aircraft, there is a risk that it may rise due to aerodynamic force to hit the aircraft. To prevent such accidents and secure safe flights, it is essential to verify the store separation characteristics before flight. For this purpose, the CFD (computational fluid dynamics) analysis is used in addition to a wind tunnel test such as the CTS (captive trajectory system) test.

The MPA (maritime patrol aircraft) P-1, shown in **Fig. 1**, has an internal weapons bay that keeps stores in the fuselage. When using an internal weapons bay, the P-1 flies at a relatively low speed, while fighters fly at transonic or supersonic speed. As **Fig. 2** shows, an air-flow layer called the shear layer, forms between the slow air flow in the internal weapons bay and the fast air flow outside the aircraft. In addition, in the velocity range from transonic to supersonic speeds, the flow field becomes complicated as

Fig. 1 Example of internal weapons bay (P-1)

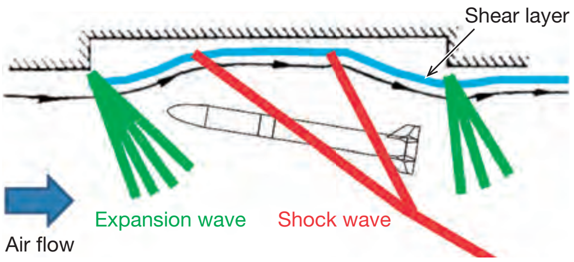


Fig. 2 Example of air flow around internal weapons bay

it involves shock waves and expansion waves, and no analysis of cavity flows with stores has been carried out in Japan until today.

While low speed wind tunnels are available in Japan and have to date been used for store separation tests, overseas facilities had to be used for transonic and supersonic velocities.

3 Technological challenges related to evaluation of store separation characteristics

To evaluate store separation characteristics in the transonic and supersonic speed ranges, as shown in **Fig. 3**, one needs to understand the aerodynamic phenomena and conduct store separation tests using a wind tunnel.

(1) Understanding the aerodynamic phenomena

To separate stores from the internal weapons bay safely, it is important to understand the aerodynamic phenomena around the bay1).

At transonic and supersonic speeds, as shown in **Fig. 2**, when the supersonic flow along the aircraft is distorted by the internal weapons bay, expansion waves and shock waves occur. Also, a shear layer forms between the flows inside and outside the bay, around which occurs an unsteady flow that varies greatly with time. When a store separates from the internal weapons bay and enters this unsteady flow, the store may change its behavior and hit the aircraft. Therefore, to separate stores safely when flying at a transonic or supersonic speed, it is necessary to understand the aerodynamic phenomena around the internal weapons bay that affect store behavior. However, no-one has addressed this issue up to the present in Japan.

(2) Wind tunnel test of store separation

Although CTS are available in Japan for tests in a range from low to high subsonic speeds, few of them have

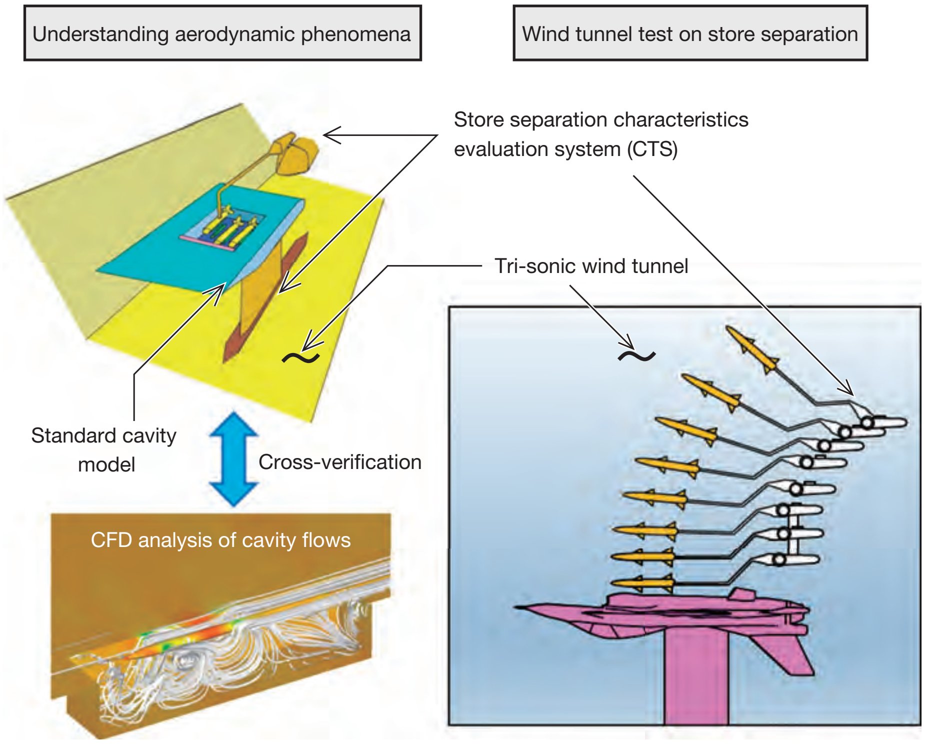


Fig. 3 Concept of store separation characteristics evaluation

conducted simulations on separating stores from the internal weapons bay.

To secure high-quality test results when evaluating store separation characteristics in the transonic and supersonic speed ranges, the most appropriate facility is the Tri-sonic Wind Tunnel[2] at ATLA's (Acquisition, Technology & Logistics Agency) Chitose Test Center. This facility is capable of generating air flows equivalent to those of real flights (a wide Mach range and high Reynolds number). This tri-sonic wind tunnel, which covers a wide range from low to supersonic speeds, needed the development of a CTS that can be used for simulating separation of stores.

4 Technological development related to evaluating store separation characteristics

(1) Understanding aerodynamic phenomena

(i) Development of a cavity-flow analysis tool

To acquire basic data on cavity flows in the wind tunnel test, we fabricated a model simulating an internal weapons bay and created a CFD analysis tool, and then carried out cross-verification between the analysis and the wind tunnel test data.

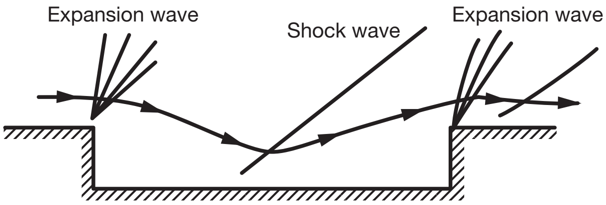
We designed and fabricated a standard wind-tunnel model for studies of cavity flows. This model is designed to form a uniform flow over a plate that simulates the fuselage surface around an aircraft's internal weapons bay. In this model, a cavity with a range of depths and lengths is placed to simulate various internal weapons bays, and measured pressure[3].

In creating the CFD analysis tool, we applied the grid-generation technique nurtured through the development of aircraft such as the P-1 to analyze complicated shapes of internal weapons bays and stores. This CFD analysis tool consists of grid data that work on FLUENT, commercial CFD analysis software, and a file for setting calculation conditions. This tool's accuracy has been improved through several wind-tunnel tests[4].

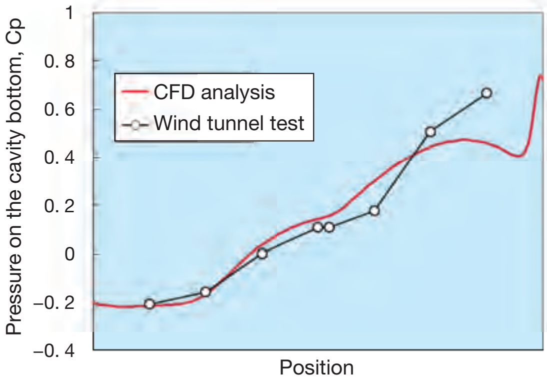
(ii) Cavity flows, which are sensitive to cavity dimensions and the Mach number, are difficult to predict or simulate aerodynamically.

Cavity flow fields are categorized into three types: the open type, the closed type, and the transitional type, which is classed between the former two. They are known to represent different pressure distributions on the cavity's bottom surface.

Figure 4 shows a schematic diagram of a transitional-type flow field and an example of its average pressure distribution on the cavity bottom surface obtained by the CFD analysis and the wind-tunnel test.



(a) Schematic diagram of flow field



(b) Distribution of the pressure on the cavity bottom, Cp

Fig. 4 Example of cavity flow (transitional type, Mach 2.0)

The diagram shows that as an air flow runs from upstream of the cavity an expansion wave occurs when the air flow turns around the leading edge of the cavity and then changes direction to enter the cavity. The air is compressed inside the cavity to generate a shock wave, which changes the air-flow direction, and the flow leaves the cavity. At this point, an expansion wave occurs at the trailing edge of the cavity, and the air flow changes direction to downstream. The average pressure distribution on the cavity bottom surface shows that the expansion wave accelerates the flow velocity at the leading edge of the cavity to make the pressure on the cavity bottom, Cp, negative. After that, the flow is compressed by the shock wave to increase Cp downstream.

We compared the three flow-field types for the CFD analyses results and the pressure distribution obtained from the wind tunnel tests, and then confirmed the CFD analysis could predict cavity flow fields.

(iii) Evaluating the effect of leading-edge devices

We conducted an investigation on control capability of the cavity flow by the leading-edge devices shown in **Fig. 5**. Without a leading-edge device, as **Fig. 6 (a)** shows, the shear layer enters the cavity to form a transitional-type flow field. On the other hand, **Fig. 6 (b)** reveals that a leading-edge device deflects the shear layer. In this case, the flow field is the open type, which definitely differs from that in the former case. This difference in shear-layer positions also appears in the total pressure distribution, and both the

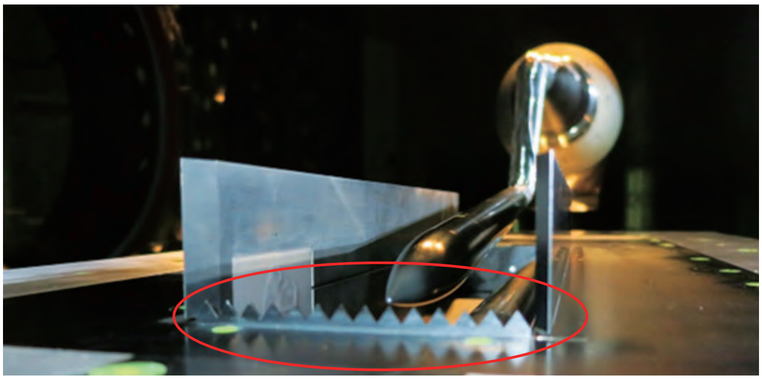
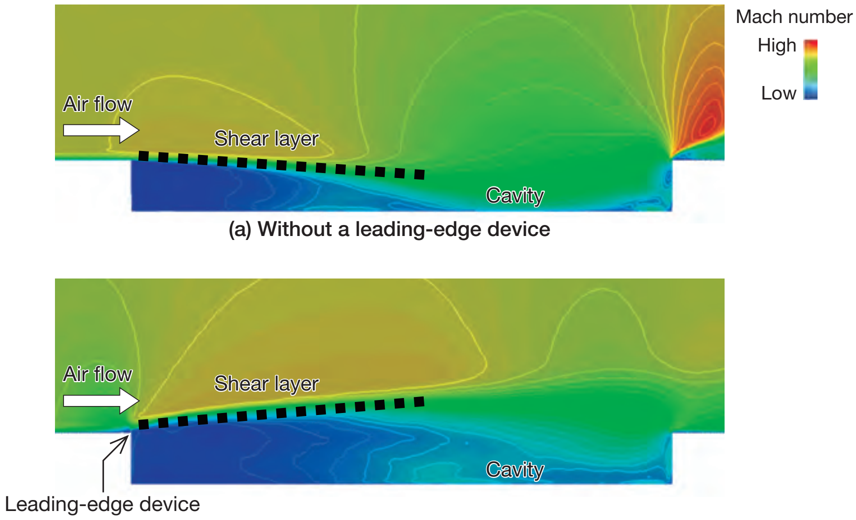


Fig. 5 Shape of leading edge device



(a) Without a leading-edge device

(b) With a leading-edge device

Fig. 6 Effect of leading edge device on cavity flow (Mach contour, free stream Mach 0.85)

wind tunnel test and CFD analysis data show it as well.

Thus, by verifying the CFD analysis results with the wind tunnel test data, we confirmed its capability to appropriately analyze the flow fields around the internal weapons bay with stores in it.

(2) Wind tunnel test on store separation

In 2003, our company developed the CTS for High-Speed Wind Tunnels for the first time in Japan using our own robotic technology, and introduced it into the transonic wind tunnel at the Gifu Works[5). We used this system to evaluate the store-separation characteristics at high speeds in the development of the P-1, and nurtured the know-how of system design and the technique for evaluating store-separation characteristics. We applied this know-how and technique to development the CTS for Tri-sonic Wind Tunnels shown in **Fig. 7**.

The CTS for Tri-sonic Wind Tunnel is a CTS with three-axis robotic arm that supports the store model and varies the model's attitude. This system features a slim shape due to an offset rotary-joint mechanism that has one of its three axes inclined, reducing its aerodynamic influence in the wind tunnel. Before introducing this system, we conducted research and performance verification tests[6).

Using this CTS verified that the store-separation tests can be conducted in the speed range of Mach 0.3 to 2.5, assumed for future fighter aircraft. Also, to establish the technique that simulates the separation of stores from an

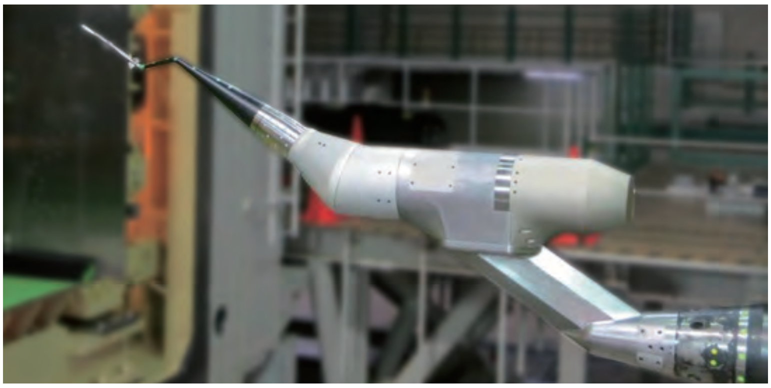
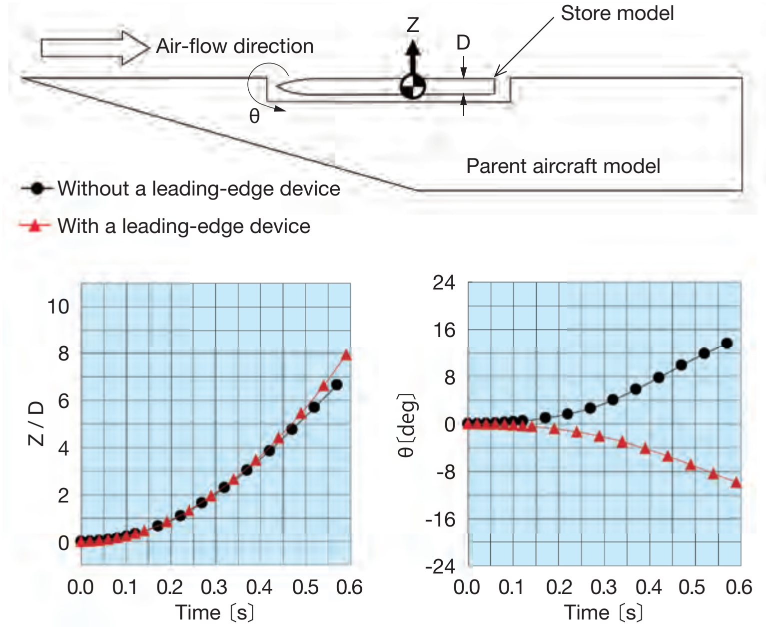


Fig. 7 CTS for Tri-sonic Wind Tunnel



(a) Position in the vertical direction〔Z/D〕 (b) Pitch angle〔θ〕

Fig. 8 Store separation trajectories with or without leading edge device

internal weapons bay, we conducted store-separation tests. These tests used the standard cavity model, and the results showed that it is possible to simulate the separation of a store from its initial position inside the bay for the range covering transonic to supersonic speeds.

Figure 8 shows the separation simulation results with and without a leading-edge device. The difference between shear layer positions due to the presence/absence of the leading-edge device did not affect the vertical positions (Z/D) of the store, whereas it so greatly affected the pitch angle (θ) that the sign was reversed.

Conclusion

By creating a CFD analysis tool that evaluates the air flow around an internal weapons bay, we clarified the aerodynamic phenomena related to cavity flows. This achievement can be applied to R&D for aircraft such as future fighters. In addition, by developing the CTS for Trisonic Wind Tunnels, we became the first in Japan to demonstrate that the system can simulate store separation for flight speeds up to the supersonic range. We plan to use this system to simulate store separation in the development of future aircraft.

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