Investigation of Cowl Vent Slots for Supercritical Stability Enhancement in Dual-Mode Ramjet Inlets

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Abstract

THE supercritical stability margin of inward-turning scoop inlets applicable to dual-mode ramjet engines has been greatly enhanced by the incorporation of a series of cowl vent slots just downstream of the inlet throat. Data has been obtained over a range of Mach number, angle of attack, and roll angle, using two single-module inlet models. A data base has been established to characterize the effect of varying available slot spill area on the stable operating range of the inlet and on the maximum inlet air capture and pressure recovery.

Introduction

A particularly attractive cycle for hypersonic air-breathing propulsion systems is the dual-mode ramjet, which operates in a subsonic combustion mode at low supersonic Mach numbers and transitions smoothly to a supersonic combustion mode of operation as the flight Mach number increases. An experimental program has been completed in which the performance of cowl vent slots for use in improving the supercritical stability margin in dual-mode ramjet inlets was demonstrated. Tests have been conducted between Mach 3 and 6 using two single-scoop inlet models consistent with a multiple inward-turning scoop (MITS) inlet concept.

The MITS inlet concept incorporates four "scramjet" scoops, located around a vehicle periphery, each of which captures a portion of the required engine airflow and compresses the captured air by turning it inward toward the vehicle centerline. Furthermore, the internal inlet ducting wraps the flow captured by the four scoops such that at the combustor exit a completely annular stream is delivered. These inlets are designed to operate in a dual mode in that the internal ducting downstream of the inlet throat also serves as an isolator duct for stabilization of the inlet precombustion shock system.[1]

The performance payoff possible with the use of controlled inlet bypass becomes especially beneficial for a dual-mode engine operating with a multimodule inlet feeding a common combustor. When the vehicle is operating at angle of attack the leeward modules are in a less favorable flowfield and are operating at a significantly reduced performance level. Typically, the maximum thrust level attainable corresponds to the combustor equivalence ratio for which the leeward inlets are operating at their maximum total pressure recovery. Incorporation of cowl vent slots would permit stable inlet spillage, with relatively low spillage drag, from the leeward inlets and allow a continued increase in combustor equivalence ratio and, therefore, vehicle thrust (Fig. 1).[2]

The first test series was conducted at Mach 4 to demonstrate the feasibility of using cowl vent slots for supercritical stability enhancement with an inlet model designed such that the forebody shock-on-lip condition was at a freestream Mach number of 6. The internal compression field was designed to be isentropic and focused at a point inside the inlet innerbody at a freestream Mach number of 4. Using this criteria, the inlet is referred to as having $M_{des} = 6/4$. A second series of tests were run at Mach numbers from 3 to 6 using an updated $M_{des} = 5.5/3.5$ inlet model.

Both inlet models had bypass slots in the cowl surface just downstream of the inlet throat. Tests were run with various slots opened selectively to vary both the amount and the location of the spill area. The $M_{des} = 6/4$ inlet model was also equipped with two boundary-layer bleed slots on the innerbody directly below the cowl vent slots and two forebody bleed slots located just upstream of the throat. These bleed slots were opened selectively to investigate any possible performance improvement that might result from the use of bleed from the innerbody in conjunction with, or instead of, the cowl vent slots.

Wind-Tunnel Test Results

The $M_{des} = 6/4$ inlet model was tested at Mach 4.1 for angles of attack of 0 and ± 5 deg. An extensive series of tests was run

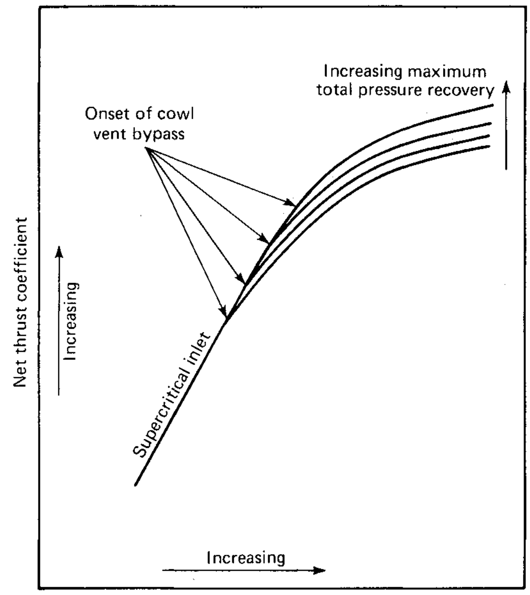

Fig. 1 Net thrust coefficient as a function of engine equivalance ratio for a typical dual-mode ramjet with inlet bypass capability.

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with cowl vent configurations that varied both the available spill area ratio, A_s/A_i, from 0 to 0.19, where A_s is the available spill area and A_i is the projected inlet area, and the relative position of the open area with respect to the inlet throat.

The figures of merit used herein for evaluating the effect of cowl vent slots on inlet performance are the supercritical stability margin and the corresponding percentage decrement in maximum air capture. The supercritical inlet stability margin is calculated as the percentage difference between the maximum air capture for a particular inlet configuration and the air capture at the last stable supercritical operating point. The decrement in maximum air capture is calculated as the percentage difference between the maximum air capture for the inlet configured with no available spill area and that for the inlet configured with the respective amount of available spill area. The values presented for the supercritical stability margin correspond to inlet operation near the maximum inlet total pressure recovery.

The feasibility of using the cowl vent slots to enhance inlet stability at Mach 4 is demonstrated in Fig. 2. Increasing the available vent area results in a significant improvement in the supercritical stability margin at all angles of attack. This is particularly significant for the leeward operating conditions, since it is likely that the performance of the leeward inlet will determine the limiting overall inlet system performance. This inlet model was constrained to fixed geometry, so the cowl vent slots are open at all throttle settings. This results in a reduction in the maximum engine air capture, as shown in the figures, due to spill through the slots even when the terminal shock system was well downstream of the slots. This apparent performance penalty resulting from use of the cowl slots can be minimized through the use of "educated" slots[3] or, if the weight trade is favorable, through the use of variable geometry.

A series of tests were run to vary parametrically the cowl vent configuration. The relative effectiveness of the cowl vent slot configuration was determined for different slot locations and differing amounts of available slot area. The effectiveness of using innerbody bleed in conjunction with the cowl vent slots was also investigated.

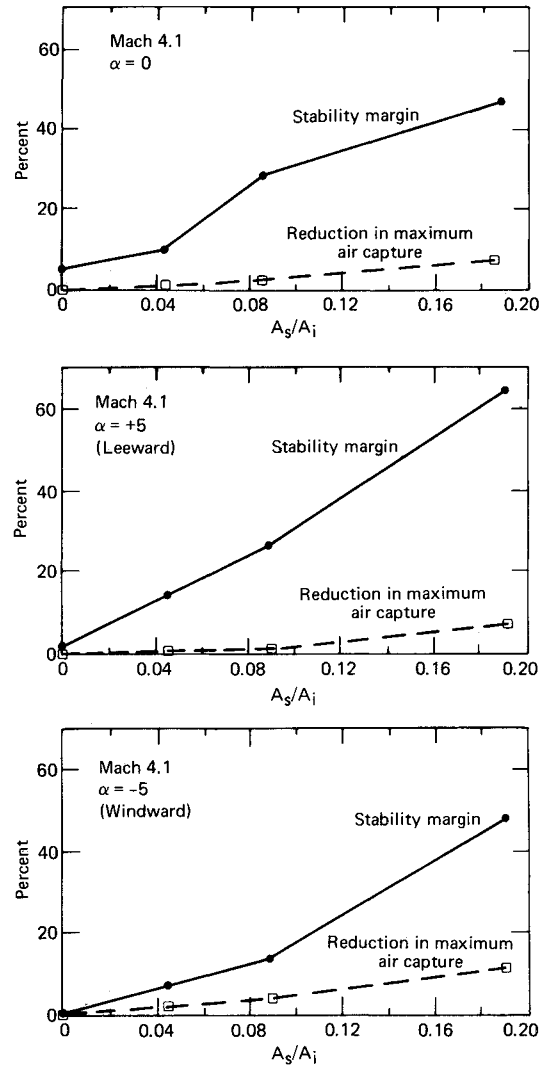

Fig. 2 Maximum stable spill and corresponding reduction in maximum air capture as a function of cowl vent area ratio.

Summary

Some summary comments with regard to this parametric investigation are as follows. The feasibility of using cowl vent slots located just downstream of the throat in the scoop surface was demonstrated for $A_s/A_i = 0.19$. The result was a large supercritical stability margin. However, there was also an approximately 10% reduction in maximum inlet capture and a relatively low maximum total pressure recovery. A parametric optimization of the cowl vent configuration took place during which the amount of available spill area and the position of the spill slots were varied. Of the shock trap configurations tested, the one that appears to be most optimum has the aft six slots open. The basis for this choice involves several factors:

1) Supercritical inlet stability characteristics are good in that the maximum stable spill is as high as 29%.

2) The maximum engine air capture is near that for the inlet operating with no cowl vent slots, indicating minimal spill, while the inlet operates in the supersonic mode (i.e., back pressures low enough for supersonic flow to exist throughout) and when the terminal shock system exists in the diffuser but is significantly downstream of the throat.

3) Maximum inlet total pressure recovery is the highest of all the configurations tested.

Use of limited amount of innerbody bleed downstream of the throat in conjunction with the cowl vent slots generally results in an increase in maximum total pressure recovery, but also causes a slight reduction in the supercritical stability margin.

The $M_{des} = 5.5/3.5$ single-scoop inlet model was tested over a wide range of Mach number, angle of attack, and scoop roll angle and for three different cowl vent configurations. In this inlet test series the effectiveness with which cowl vent slots can be used to enhance supercritical stability was again demonstrated. An extensive inlet performance data base was obtained providing the information required to make performance tradeoffs necessary for choosing an optimum inlet configuration.[2]

For all configurations tested, the cowl vent slots provided a significant improvement in the measured supercritical inlet stability. In general, the effectiveness of the cowl vent slots for improving supercritical inlet stability was enhanced as the inlet module was operated at more leeward angles of attack.

References

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