Flowfield Analysis of Low Bypass Ratio Test Cells

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Abstract

THE operation of an engine test cell at low bypass ratios tends to amplify many adverse flow effects. This synoptic presents the results of a technique for test cell analysis called the combination technique which is a derivative of a three-dimensional panel methods code. The results are compared to experimental data and when coupled with experimental data show that flow separation from the test-cell walls occurs at all cell bypass ratios. The results also indicate a relationship between this wall flow separation and vortex formation and ingestion. This technique represents a simple method to obtain an accurate aerodynamic analysis of a complex three-dimensional flowfield in an engine test cell.

Nomenclature

C_p = pressure coefficient based on front cell pressure
D_F = fan diameter
V_{BF} = bypass flow velocity at highlight
V_{FC} = front cell velocity
X = station
X_{HL} = highlight station

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Obtaining a computational solution for the flowfield within a propulsion system test facility remains a challenge despite recent advances in computer codes and technology. For more than a decade there has been a significant increase in the size, thrust, and flowrate of commercial aircraft engines. However, there has not been a significant change in most engine test cells which were generally designed and constructed for much smaller engines. It is characteristic of the operation of engines of differing sizes in the same cell that the test cell operates at much different cell bypass ratios, which is the ratio of the flow bypassing the engine to the flow entering the engine. A large engine usually operates at cell bypass ratios between 1.0 and 2.0; however, the cell bypass ratio can be below 1.0. For a small engine normal bypass ratios can be greater than 5.0. The operation of a large engine in a test cell at low bypass ratios can amplify or introduce adverse flow effects that can occur during engine testing. Some of these adverse effects include vortex formation and ingestion, nonuniform flowfields, and test-cell-induced secondary flows. These adverse effects can result in unstable engine operation, incorrect thrust measurements, or engine damage for severe conditions.

Due to the complex geometry of a test-cell facility, the use of any computational code to model the complete test cell is not straightforward. Figure 1 shows the analytic model which is composed of the test-cell walls, the engine with a bellmouth, and the engine thrust frame. The test-cell walls are square in cross section and impervious to the flow. The thrust frame is modeled by a solid enclosure. The bellmouth is modeled both internally and externally. To induce the engine flow, a nonzero normal velocity is imposed on the fan face. The core

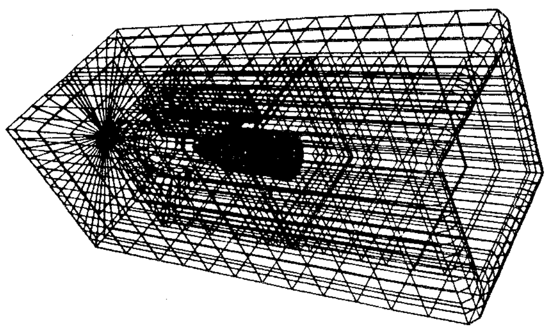

Fig. 1 Completely paneled test cell with engine and thrust frame.

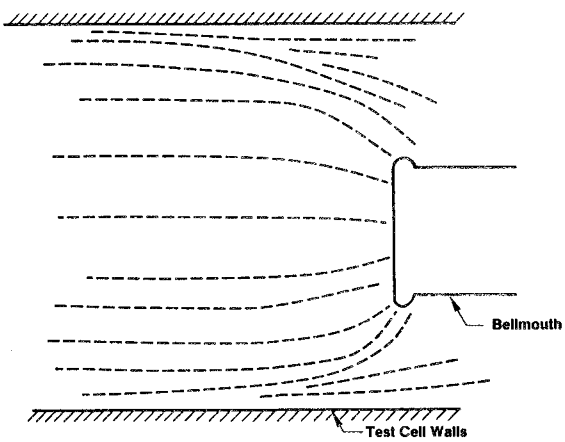

Fig. 2 Side view of the flowfield velocity vectors.

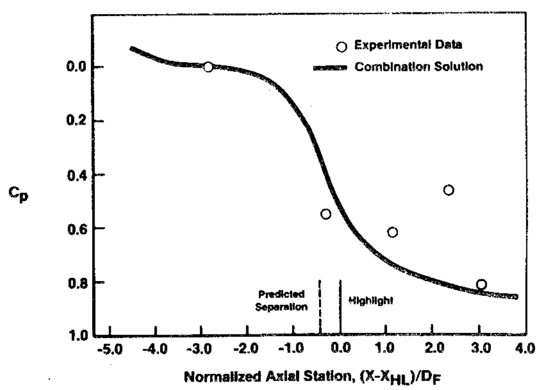

Fig. 3 Comparison of analysis and experimental data on the sidewall, bypass ratio = 0.86.

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cowl is not modeled; rather, a fan plume is simulated from the fan exit to the augmentor. The test-cell bypass flow is then specified by imposing a nonzero normal velocity on the panels in the fan plume. By setting normal velocities on the fan face panels and the plume panels (simulating entrainment), the engine weight flow and test-cell bypass flow may be specified. A more detailed description of the combination technique and its use in test-cell analysis can be found in Ref. 1.

The analysis described above has been applied to several test cells, the results presented in this work will be for one test cell with a large engine. Figure 2 shows a side view of the test-cell flowfield which is typical of a large engine operating in a test cell having a relatively low cell bypass ratio. The flowfield shown is typical but varies depending on engine size, engine location, and bypass ratio. The figure implies that flow along the test-cell walls experiences a severe diffusion as it approaches the bellmouth since the flow captured by the engine has a cross-sectional area larger than the engine itself.

As indicated, the flow velocity in the test cell experiences large changes in both magnitude and direction. The flow characteristics along the test-cell walls can be an important indicator of the overall test-cell flow quality. Figure 3 shows the axial variation of the pressure coefficient C_p on the sidewall of the test cell for a bypass ratio of 0.86. The normalized axial station is determined from the location of the bellmouth highlight X_{HL} and the engine fan diameter D_F. This figure shows that upstream of the bellmouth highlight the flow experiences a severe diffusion due to the large percentage of the total test-cell flow entering the bellmouth. However, if the flow in the test cell is unable to diffuse as the potential flow solution indicates, flow separation along the walls occurs due to viscous effects. Boundary-layer analysis indicates that the flow along the test-cell wall separates for all cell bypass ratios. The separation location is indicated in Fig. 3. Other cell bypass ratios have been analyzed and are presented in Ref. 1. As is seen in Ref. 1, the separation location moves downstream as the cell bypass ratio is increased. For large values of cell bypass ratio, the flow separation point actually moves downstream of the highlight. Also shown in Fig. 3 are experimental data.[1] These data are available only at a relatively limited number of locations but suggest that the flow does separate from the test-cell wall at approximately the same location as predicted by the analysis.

Figure 4 shows the variation of the bellmouth-plane-to-front-cell velocity ratio V_{BP}/V_{FC} as a function of cell bypass ratio. This velocity ratio is based on the cell bypass flow only and is defined as the ratio of the average velocity at the location of the highlight to the front-cell velocity. The velocity ratio is a parameter used to quantify the extent of diffusion along the test-cell wall. Figure 4 shows curves that are representative of large and small engines and indicates that a flow condition having a velocity ratio less than 0.5 is likely to have a vortex form in the test cell. The regions in which vortex formation is likely and unlikely to form are indicated in the figure. As indicated by Fig. 4, the two engines have different cell bypass ratio values when the velocity ratio V_{BF}/V_{FC} is equal to 0.5. However, as shown in Ref. 1, the separation location at the critical cell bypass ratio of 0.5 occurs at approximately the same physical distance upstream of the bellmouth for both engines. This result is expected since the engine centerline is the same distance from the wall for both engines. It has been demonstrated that a large engine operating at a relatively low cell bypass ratio of 0.8 can have problems with vortex formation and ingestion.[1] The present analysis indicates that for low cell bypass ratios the flow separation occurs well upstream of the highlight. This flow separation upstream of the highlight, coupled with the axial and secondary velocity components, is an indication of the likelihood of vortex formation and ingestion. Therefore, having the flow separation point on the wall occur at or downstream of the highlight could prevent the formation of a vortex. An approach to eliminate the possibility of vortex formation is to reduce the diffusion along the test-cell walls by test-cell-area reduction in the vicinity of the bellmouth.

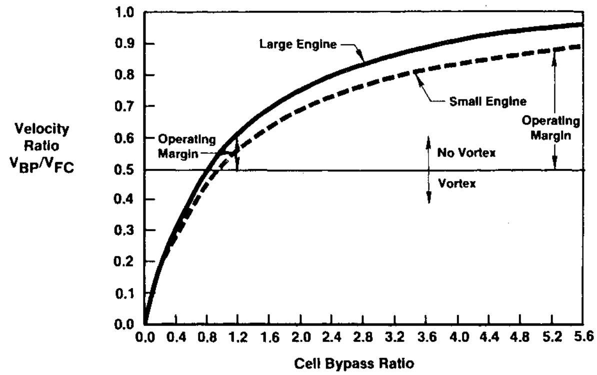

Fig. 4 Engine operating margin as a function of cell bypass ratio.

Concluding Remarks

The application of the combination technique to the analysis of the flow in an engine test cell has been demonstrated. The analysis has been applied specifically to a test cell operating at a low bypass ratio. The results are compared to experimental data and indicate that flow separation from the test-cell walls occurs at all test-cell bypass ratios. When experimental results are considered, the analysis suggests a relationship between flow separation and vortex formation.

References

[1] Kromer-Oehler, S. L. and Dietrich, D. A., "Computational Analysis of the Flow Field in an Engine Test Cell," AIAA Paper 84-0285, Jan. 1984.