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"Minimum Fuel Mode Evaluation"

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Minimum Fuel Mode Predictions

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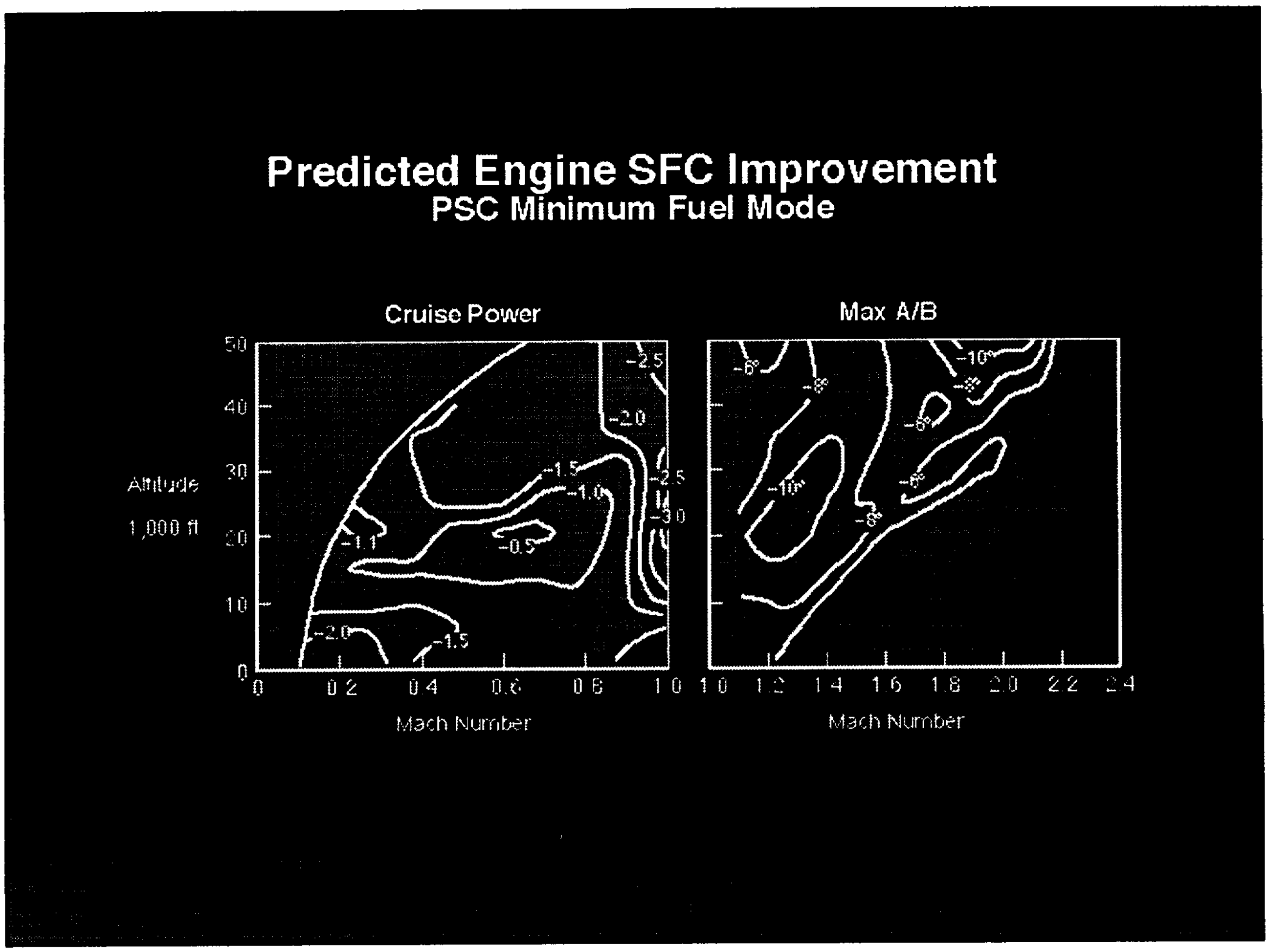

In the Minimum Fuel Mode, fuel flow is reduced while baseline engine thrust is maintained. Thrust Specific Fuel Consumption (TSFC) reductions for the Minimum Fuel Mode are predicted to range from 0.5% to 3% at cruise power settings subsonically and 6% to 10% at maximum power supersonically. These results were generated using the Dynamic Propulsion System Simulation. At part power settings, core fuel flow is reduced while baseline engine thrust is maintained. Much greater TSFC reductions are obtained at maximum power because fuel flow in the inefficient augmentor is reduced and thrust in the engine core is increased.

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Minimum Fuel Mode Subsonic Analysis

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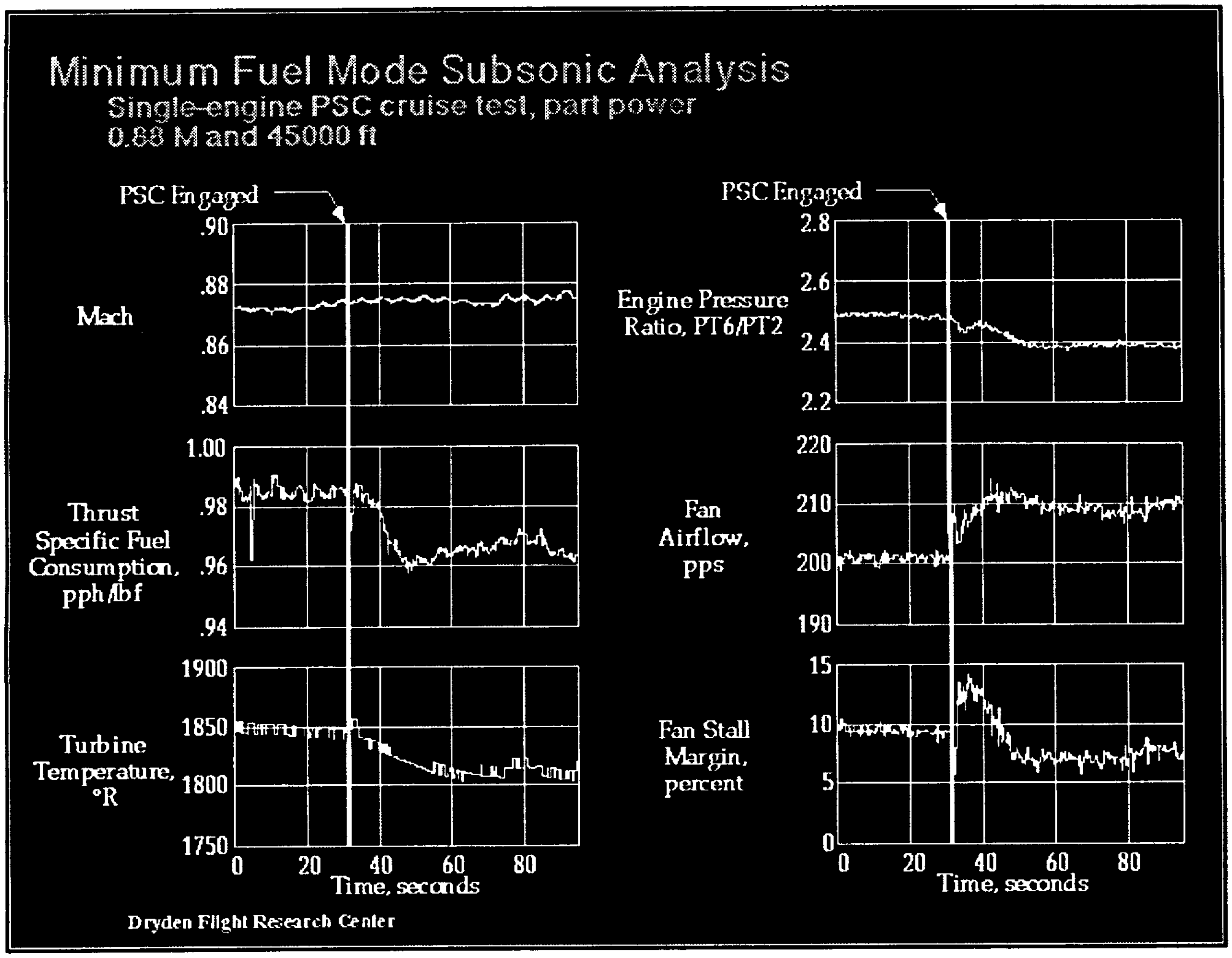

The Minimum Fuel mode is designed to minimize fuel flow while maintaining constant FNP (effectively reducing TSFC) during cruise flight conditions. The test maneuvers were at stabilized flight conditions. The aircraft test engine was allowed to stabilize at the cruise conditions before data collection initiated; data were then recorded with PSC not-engaged, then data were recorded with the PSC system engaged. The maneuvers were flown back-to-back to allow for direct comparisons by minimizing the effects of variations in the test day conditions. The Minimum Fuel mode was evaluated at subsonic and supersonic Mach numbers and focused on three altitudes: 15,000, 30,000, and 45,000 feet. Flight data were collected for part, military, partial and maximum afterburning power conditions.

Analysis for a typical Minimum Fuel mode demonstration during the single-engine subsonic test phase is shown. The cruise flight condition was Mach, 0.88, and 45,000 feet. When necessary, the pilot maintained flight condition by commanding the non-test engine throttle and stick. This was done for all single engine testing.

Time histories are presented for performance parameters (M, FTIT, and TSFC), and engine operating parameters (EPR, DEEC calculated fan airflow, and fan stall margin). The PSC system was not engaged from 0 to approximately 30 sec. The steady state value of TSFC with the PSC system disengaged was approximately 0.99. The PSC system was engaged from 30 seconds through the end of the run. The PSC algorithm held FNP to within +/−2% of the initial value after the PSC system was engaged. The steady state TSFC with the PSC system engaged was approximately 0.97, a nearly 2% improvement on fuel consumption. The fuel reduction was achieved by decreasing EPR and increasing fan airflow as well as repositioning the compressor and fan variable guide vanes. The fan stall margin was driven lower by the change in engine operating condition. This flight condition is near the optimal minimum TSFC condition for the baseline aircraft.

It is of interest to note the reduction in turbine temperature of nearly 40 deg.R. Since FTIT was not included as part of the performance index of the PSC optimization, the temperature decrease was coincidental. As will be shown later, the Minimum Fuel mode does not always produce a FTIT reduction.

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Minimum Fuel Mode Supersonic Analysis

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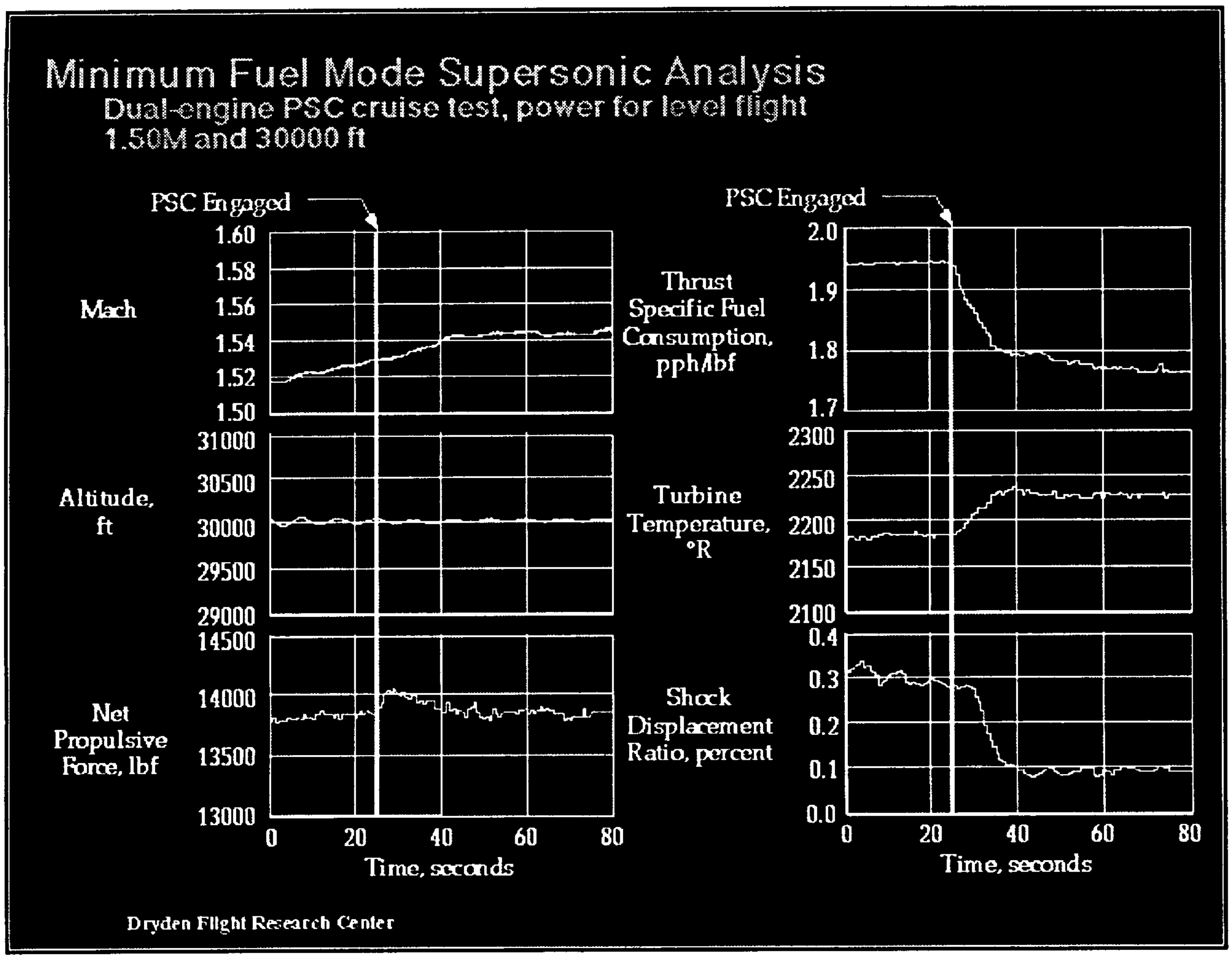

The figure shown presents time histories for a typical test of the Minimum Fuel mode demonstration during the dual-engine supersonic test phase. The cruise flight condition was Mach 1.50 at an altitude of 30,000 feet. At supersonic conditions, PSC controls the inlet ramps and afterburner fuel flow in addition to all the other engine controls. Because this was a two engine test, the pilot made no throttle inputs and Mach number was controlled indirectly by the PSC system maintaining a constant Net Propulsive Force (FNP). Any model errors in FNP will show up in a change in Mach number. During the test Mach number was unaffected by engaging PSC, lending confidence in the modeled FNP being maintained well within 2% of initial FNP.

Time histories are presented for flight condition (M and altitude), performance parameters (FNP, FTIT, and TSFC), engine operating parameters (EPR, airflow, total fuel flow, and variable vane angle) and inlet parameters (inlet ramp angles and shock displacement ratio). The PSC system was not engaged from 0 to approximately 25 sec. The steady state value of TSFC with the PSC system disengaged was approximately 1.95. The PSC system was engaged from 25 seconds through the end of the run. The steady state TSFC with the PSC system engaged was approximately 1.77, over a 9% improvement on fuel consumption.

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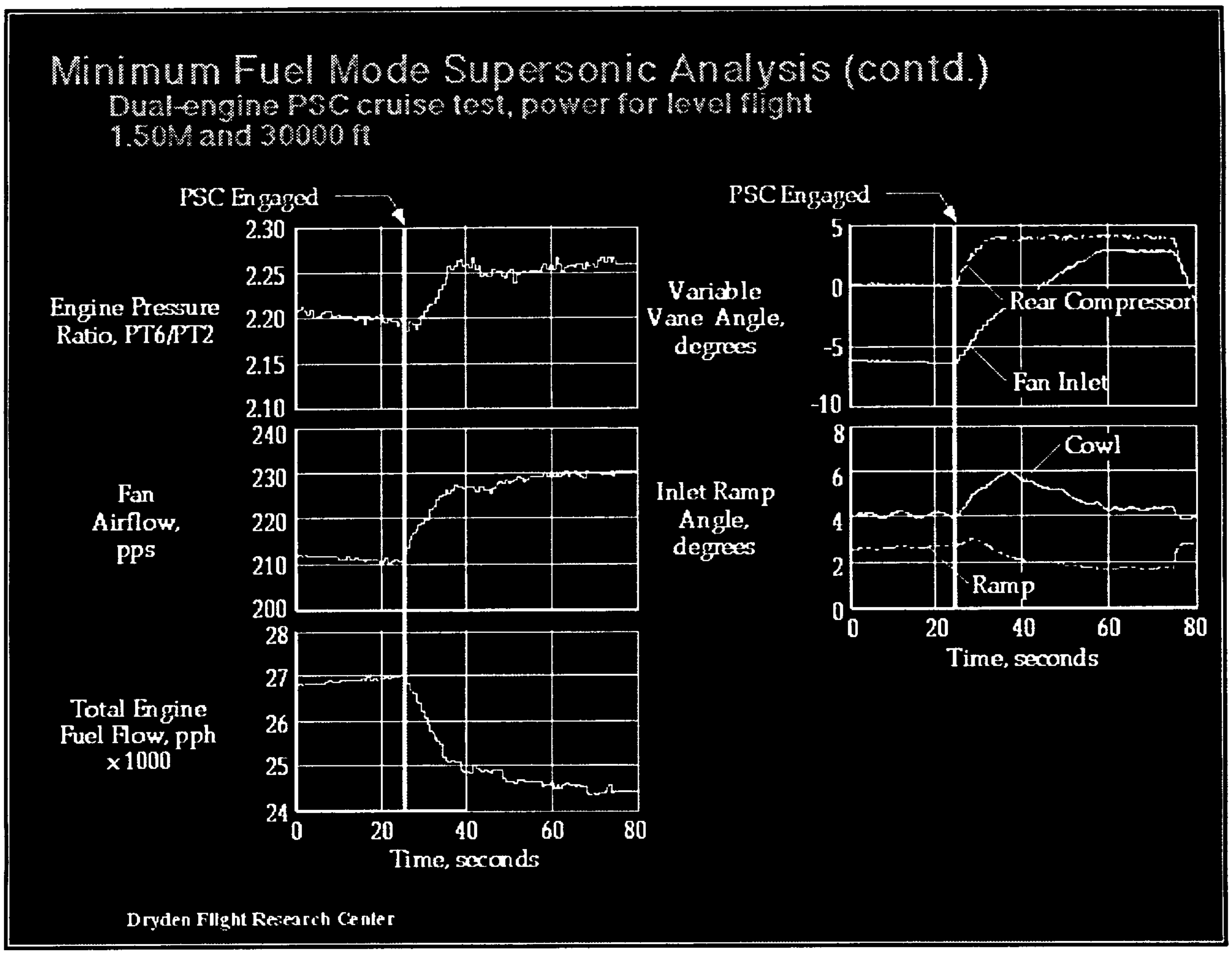

A fuel reduction of about 2500 pph was achieved by increasing EPR and fan airflow, while reducing afterburner fuel flow. In effect, thrust produced by the less efficient afterburner was traded for thrust produced from the engine core. The result is evident from the increase in turbine temperature, reflecting more thrust and fuel flow in the core. The shock displacement ratio, a measure of the distance the oblique shock wave stands from the inlet cowl, was driven to its lower limit of approximately 10% by the change in airflow and inlet cowl position.

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Summary of Results for the Minimum Fuel Mode

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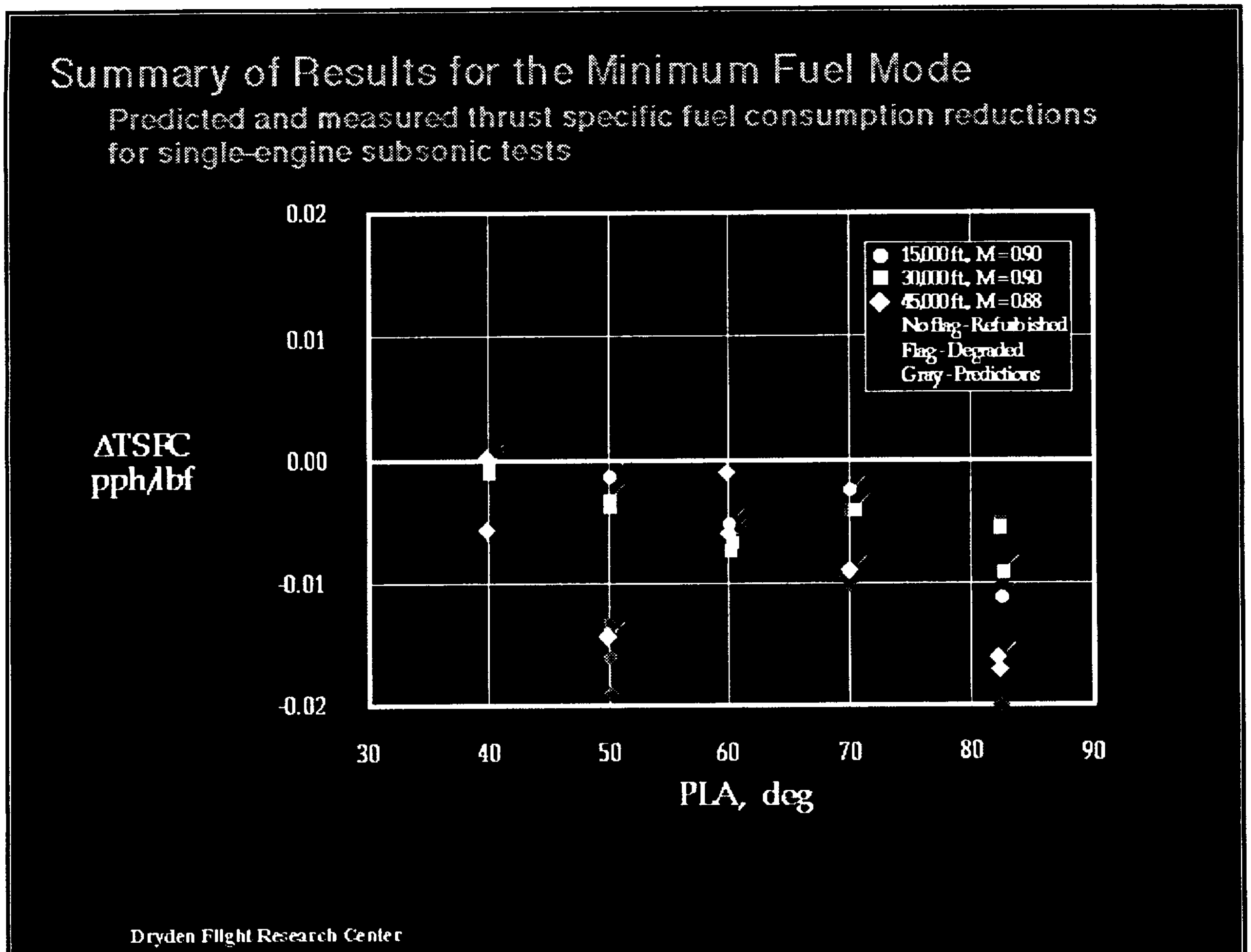

A comparison of measured and predicted TSFC savings which resulted from the PSC system during the single–engine and deteriorated engine test phase is presented above as a function of test engine power setting and flight condition. Data were collected at Mach 0.9 at an altitude of 15,000 and 30,000 feet, and at Mach 0.88 at an altitude 45,000 feet for both the refurbished and degraded engines. The TSFC savings are in general relatively small. The calculation of TSFC is especially sensitive to the parameters that define it (TSFC = total fuel flow/net propulsive force) and the relatively short run of data collected. In spite of the scatter, the TSFC savings are clearly established with savings ranging from a few tenths of a percent at the lowest power settings to one and one–half percent savings at the MIL power setting. The flight data are in good agreement with the predictions at the high PLAs but are noticeably lower than predictions at 50deg. PLA. In general, the best improvements appear to be at 45,000 feet altitude. Based on the general similarity of the data, it is clear that the PSC algorithm has the ability to adapt to the specific health state of the engine.

Although not large, the TSFC reductions could significantly reduce takeoff gross weight or increase range when considering long–range cruise segments, as might be encountered for a second–generation supersonic transport.

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Summary of Results for the Minimum Fuel Mode (contd.)

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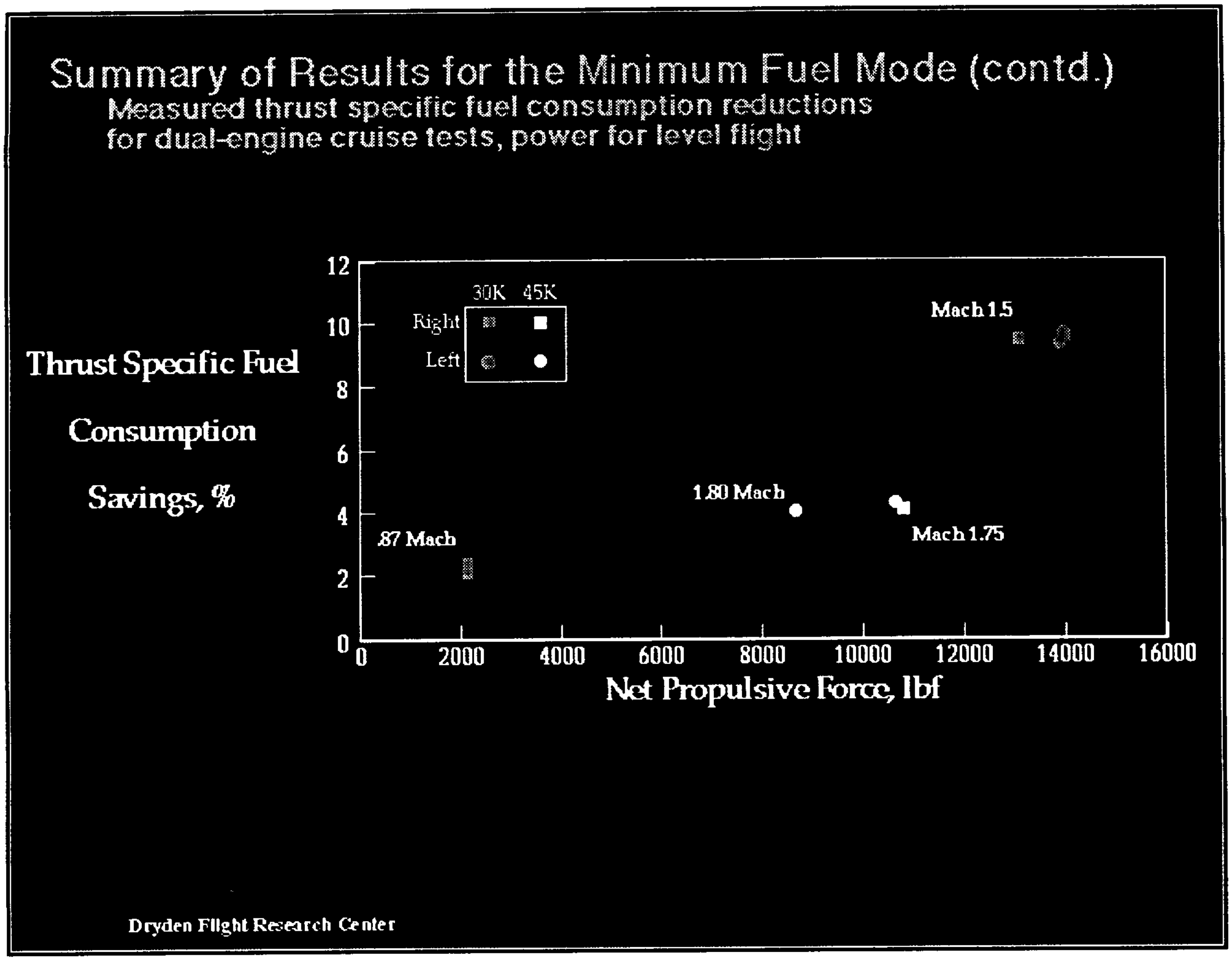

Measured TSFC savings which resulted from the PSC system during the dual–engine test phase are presented above as a function of test engine net propulsive force (FNP) and flight condition. Data were collected at altitudes of 30,000 and 45,000 feet. The TSFC savings at supersonic Mach numbers are in general much larger than at subsonic Mach numbers because of PSC trims to the afterburner (A/B). Supersonically, TSFC savings range from approximately 4% to nearly 10 %. The magnitude of these savings is phenomenal. Reductions in TSFC of this order usually come about only through significant and costly hardware reconfigurations. PSC has achieved very substantial results with computer software alone.

The results indicate more TSFC savings at higher FNP levels. At higher FNP levels the afterburner is consuming more fuel, allowing for larger afterburner fuel flow down trims. It is clear from the data that the PSC algorithm produces similar results independent of the specific engine it is applied to.

The TSFC reductions could significantly reduce takeoff gross weight or increase range when considering long–range cruise segments, as might be encountered for a second–generation supersonic transport.