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"Minimum Fan Turbine Inlet Temperature Mode Evaluation"

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Minimum Fan Turbine Inlet Temperature Mode Predictions

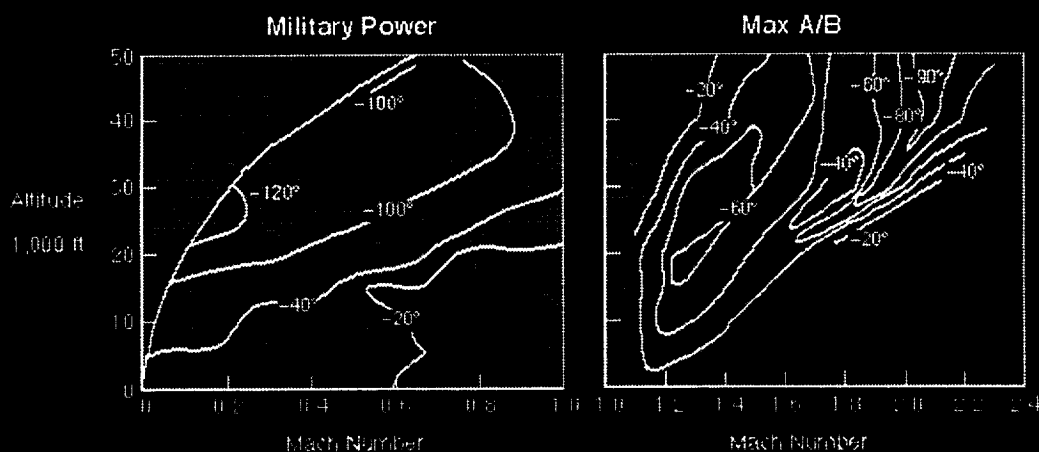
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Predicted FTIT Reduction PSC Minimum FTIT Mode



In the Minimum Fan Turbine Inlet Temperature (FTIT) Mode, FTIT is reduced while baseline engine thrust is maintained. FTIT reductions of up to 120 degrees Fahrenheit at military and up to 90 degrees at maximum power are predicted for the Minimum FTIT Mode. These reductions in FTIT translate into substantial increases in engine life.

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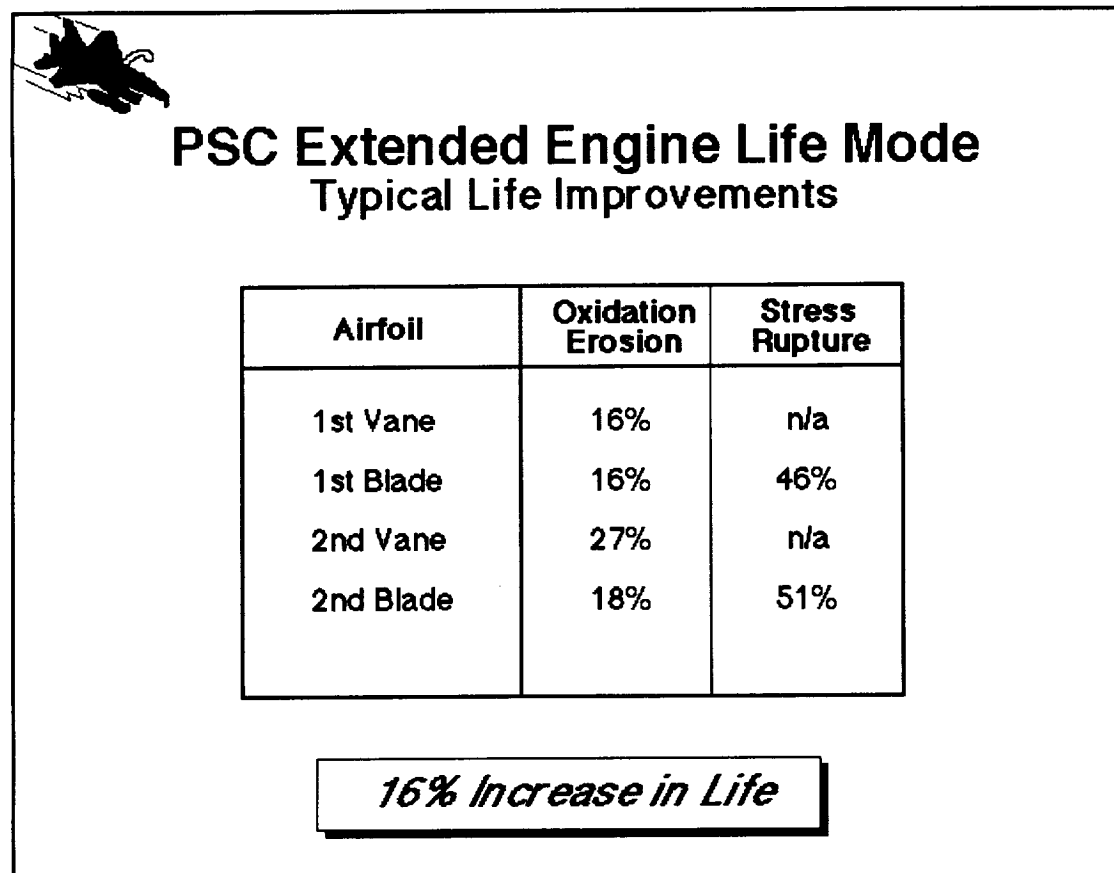
Estimated Extended Engine Life

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P&W estimated the increase in engine life due to the reduction in FTIT. They did this for a composite F-15 mission in which the engine was operated over 4,000 TAC cycles. The result was a 16% increase in engine hot part life. This improvement was achieved by reduced oxidation/erosion to the high pressure turbine vanes and blades.

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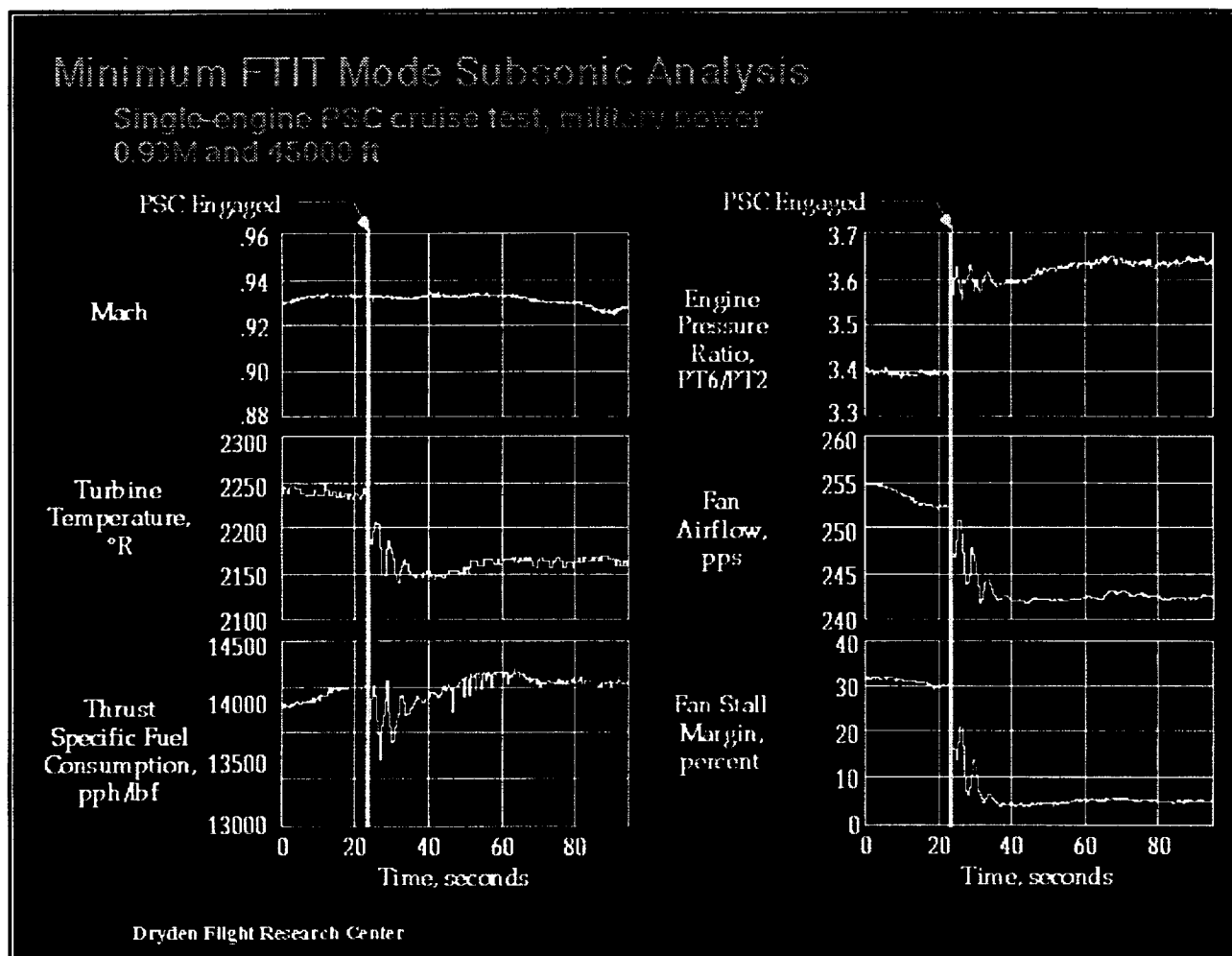
Minimum Fan Turbine Inlet Temperature Mode Subsonic Analysis

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The Minimum FTIT mode is designed to minimize fan turbine inlet temperature while maintaining constant FNP (effectively extending engine life) during cruise flight conditions. The maneuvers flown consisted of flying 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 FTIT 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 FTIT mode demonstration during a single-engine subsonic test is presented. The cruise flight condition was Mach 0.93 and altitude of 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 (engine pressure ratio(EPR), model estimated fan airflow, and fan stall margin). The PSC system was not engaged from 0 to approximately 25 sec. The steady state value of FTIT with the PSC system disengaged was approximately 2237deg.R. The PSC system was engaged from 25 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 FTIT with the PSC system engaged was approximately 2166deg.R, over a 70deg.R temperature reduction. The FTIT reduction was achieved by increasing EPR and decreasing fan airflow as well as repositioning the compressor and fan variable guide vanes. The fan stall margin was driven to the lower limit of 4% by the change in engine operating condition.

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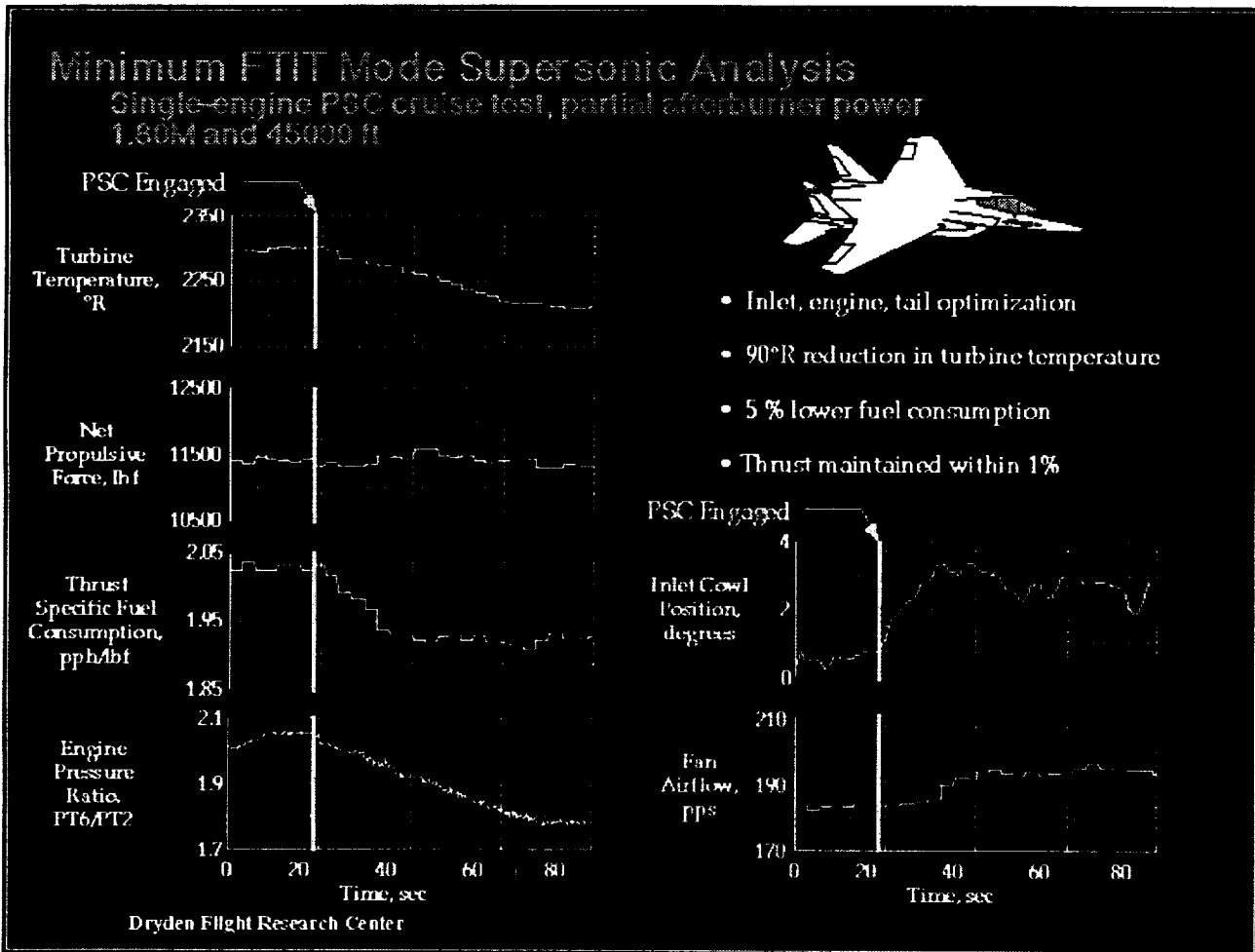
Minimum Fan Turbine Inlet Temperature Mode Supersonic Analysis

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The above figure presents time histories and an illustration of net propulsive force contributions for a typical test of the Minimum FTIT mode for supersonic conditions. The cruise flight condition was Mach 1.80 at an altitude of 45000 ft with a partial afterburner power setting.

The most effective way of reducing turbine temperature is by reducing core fuel flow. If afterburner fuel flow was included as a control for the Minimum FTIT mode, as it is for the Minimum Fuel mode, then core flow would be cut back and afterburner flow increased. The optimum minimized FTIT in this case would result from producing as much thrust as possible from the very fuel-inefficient afterburner. The excessive amount of fuel burned in this "optimum" engine configuration would far outweigh any extended engine life benefits from reducing turbine temperature. Thus, afterburner fuel flow is not included as a control for the Minimum FTIT mode. Another method for reducing core fuel flow is to lessen the thrust required for flight. By reconfiguring the integrated aircraft and propulsion system, decreases in gross drag will reduce the required net thrust while still maintaining FNP.

Time histories are given for the engine operating parameters (EPR and airflow), inlet cowl angle, and

performance parameters (TSFC, FNP, and FTIT). After approximately 20 seconds of steady-state trim cruise condition, PSC was engaged. After converging, steady-state results are reflected from approximately 70 seconds until the end of the maneuver. With the use of PSC, FTIT was reduced by 90deg.R, and FNP was maintained to within 1 percent of baseline engine operation. In addition, TSFC was reduced by approximately 5 percent. EPR decreased from 2.05 to 1.80 and airflow was up trimmed by 11 pps to produce the FTIT and TSFC savings.

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Minimum Fan Turbine Inlet Temperature Mode Supersonic Analysis (contd.)

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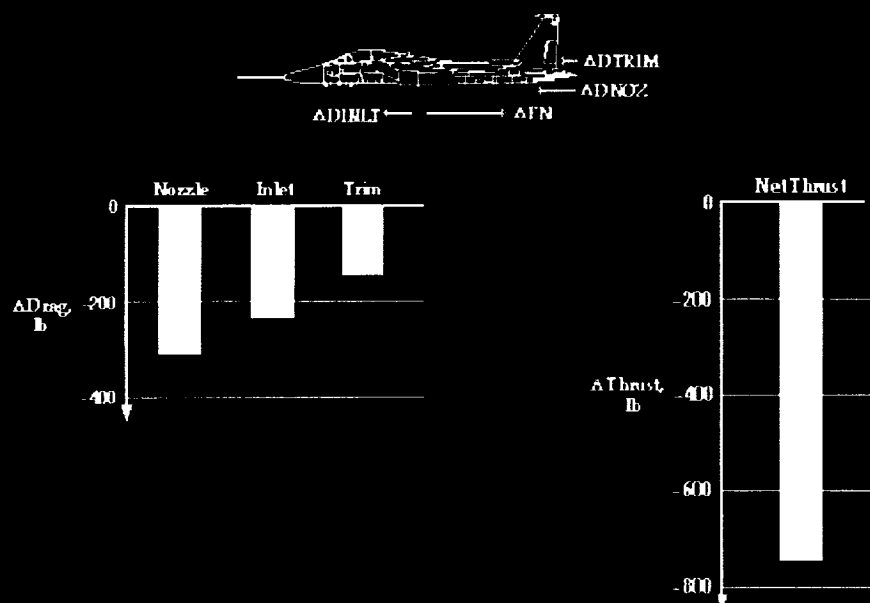
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Minimum FTIT Mode Supersonic Analysis (contd.)

Single-engine PSC cruise test, partial afterburner power
1.80M and 45000 ft

Longitudinal Aircraft Forces: (PSC Estimates)



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According to the PSC models, a combination of drag reductions reduced the required amount of net thrust as seen in the above longitudinal aircraft forces diagram. All three drag components of FNP were decreased and together produced over 670 lbs of drag savings. Together, DINLT and DTRIM, the two drag terms most effected by inlet optimization, indicate that the inlet and stabilator provided an approximately 370 lbs drag reduction.

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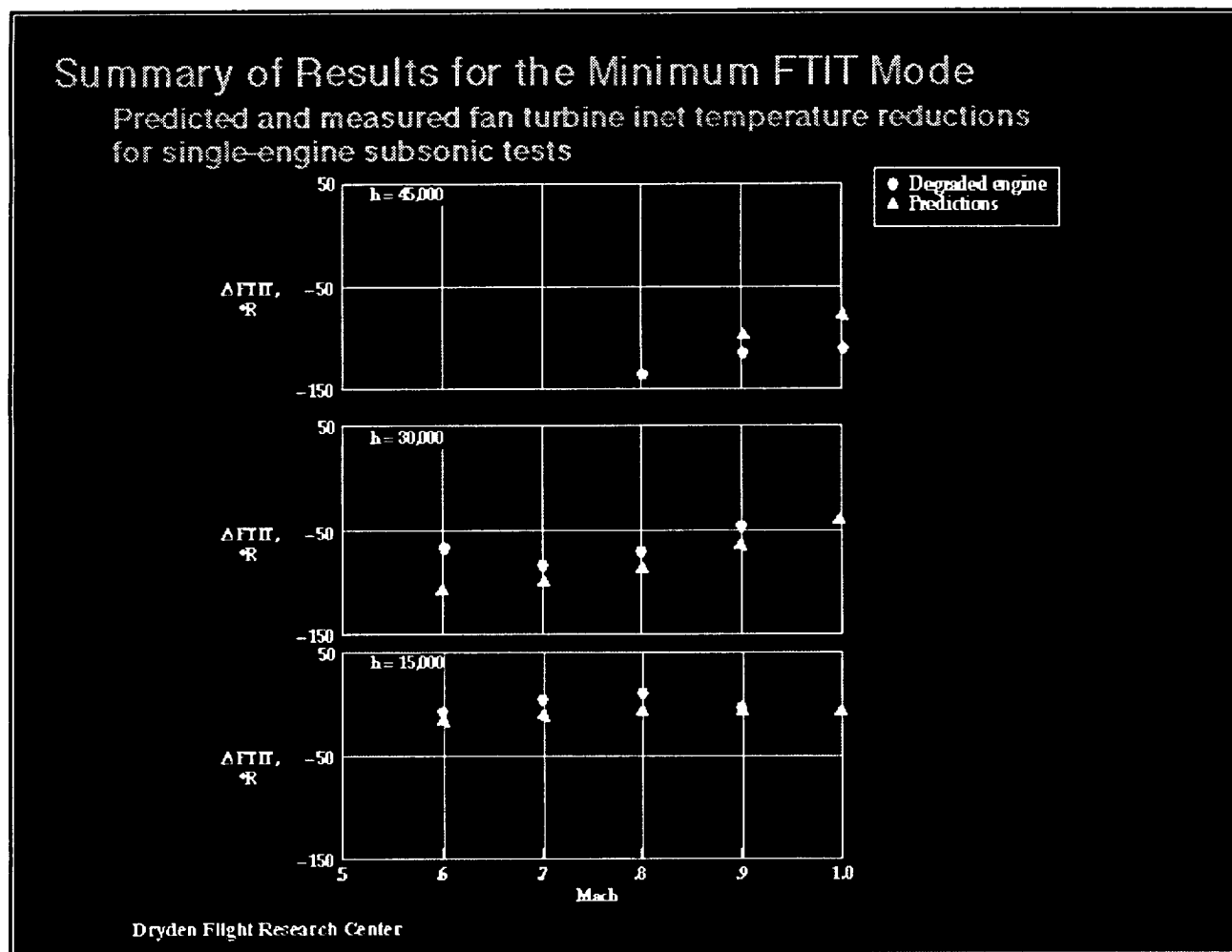
Summary of Results for the Minimum Fan Turbine Inlet Temperature Mode

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A comparison of measured and predicted FTIT reductions as a result of the PSC system is shown for the engine at a MIL power setting. Data were collected at 15,000, 30,000, and 45,000 feet altitudes. The FTIT reductions are large at 45,000 feet ranging from in excess of 100deg.R at the lower Mach numbers and diminishing slightly as transonic Mach numbers are approached. The measured and predicted FTIT reductions agree well for all flight conditions.

To put these temperature reductions in perspective, every 70deg.R reduction will double turbine life caused by temperature effects. These benefits are very important especially at high power settings where the engine operates near its temperature limit. At 30,000 feet, the FTIT reductions range from 45deg.R to 80deg.R at the higher subsonic Mach numbers. Although less than those at 45,000 feet, these reductions are still significant in terms extending engine life. The FTIT reductions at 15,000 feet are at best small, and in some cases small increases in temperatures were observed. These small temperature reductions at lower altitudes are consistent with predictions. The variations in the data at 15,000 feet also reflect the resolution and accuracy of the closed-loop PSC algorithm throughout the flight

envelope.

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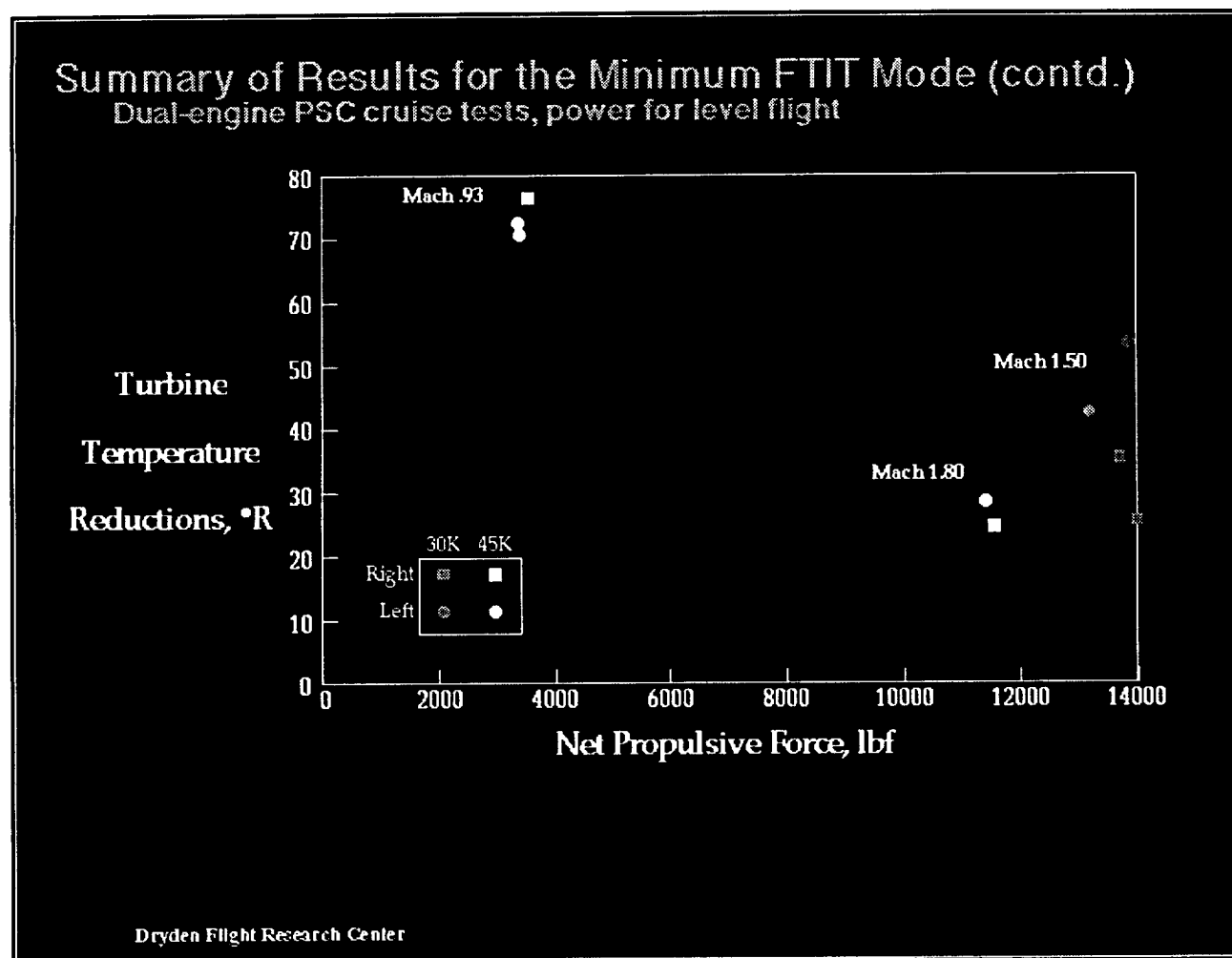
Summary of Results for the Minimum Fan Turbine Inlet Temperature Mode (contd.)

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Measured reductions in turbine temperature which resulted from the application of the PSC Minimum FTIT mode during the dual-engine test phase is presented above as a function of net propulsive force and flight condition. Data were collected at altitudes of 30,000 and 45,000 feet at military and partial afterburning power settings. The FTIT reductions for the supersonic tests are less than at subsonic Mach numbers because of the increased modeling and control complexity. In addition, the propulsion system was designed to be optimized at the mid supersonic Mach number range.

Subsonically at military power, FTIT reductions were above 70deg.R for either the left or right engines, and repeatable for the right engine. At partial afterburner and supersonic conditions, the level of FTIT reductions were at least 25deg.R and as much as 55deg.R. Considering that the turbine operates at or very near its temperature limit at these high power settings, these seemingly small temperature reductions may significantly lengthen the life of the turbine.

In general, the Minimum FTIT mode has performed well, demonstrating significant temperature reductions

at military and partial afterburner power. Decreases of over 100deg.R at cruise flight conditions were identified. Temperature reductions of this magnitude could significantly extend turbine life and reduce replacement costs.

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