

AFFTC-TR-98-05



**CHANGE IN RANGE FACTOR AS A
RESULT OF AN APPLICATION OF AN
AVIATION POLISH TO A T-38A AIRCRAFT
(HAVE SLICKER)**

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NOVEMBER 1998

FINAL REPORT

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**AIR FORCE FLIGHT TEST CENTER
EDWARDS AIR FORCE BASE, CALIFORNIA
AIR FORCE MATERIEL COMMAND
UNITED STATES AIR FORCE**

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This technical report (AFFTC-TR-98-05, *Change in Range Factor as a Result of an Application of an Aviation Polish to a T-38A Aircraft [HAVE SLICKER]*) was submitted under Cooperative Research and Development Agreement Number CR980100 by the Commandant, USAF Test Pilot School, Edwards Air Force Base, California 93524-6485.

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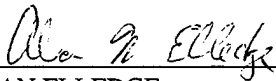


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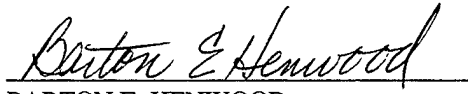
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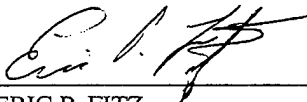
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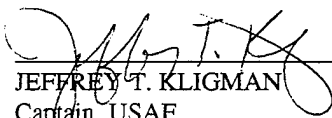
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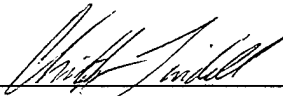
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PREFACE

This report presents the results of an evaluation of a change in range factor as a result of an application of Racer's Edge polish to a T-38A aircraft (HAVE SLICKER). The objective was to characterize range factor (true airspeed multiplied by aircraft gross weight divided by fuel flow) changes due to polish application on a Northrop T-38A aircraft. Testing was conducted at Edwards AFB, California, by the USAF Test Pilot School from 16 March through 9 April 1998. Testing was requested by the Air Force Flight Test Center Single Face to the Customer Office at Edwards AFB and

conducted under Cooperative Research and Development Agreement number CR980100.

Sincere appreciation is expressed to Mr. Larry Sweetser of American Aviation & Toolcraft for loaning the test team a Taylor-Hobson Surtronic 10 Ra surface analyzer. Special thanks are extended to Messrs. Pete Jozsa, T-38 Shadow Maintenance (412 TS/LGFSG), and Dick Shutte, Special Instrumentation (412 LG/LGMSS) for outstanding support and troubleshooting throughout the HAVE SLICKER test.

EXECUTIVE SUMMARY

This report presents the results of an evaluation of a change in range factor as a result of an application of Racer's Edge polish to a T-38A aircraft (HAVE SLICKER). The HAVE SLICKER test program was a limited evaluation of an aviation polish developed and manufactured by Racer's Edge and marketed by American Aviation & Toolcraft under a USAF Cooperative Research and Development Agreement (CR980100) between the Air Force Flight Test Center (AFFTC), Edwards AFB, California, and American Aviation & Toolcraft, Quartz Hill, California. The testing was conducted by the USAF Test Pilot School at the AFFTC. Fourteen Northrop T-38A (USAF S/N 68-8153) test sorties, totaling 19.4 flight test hours were conducted from 16 March through 9 April 1998.

The test item, Racer's Edge Polymer Aviation Polish, was a water-soluble, thin-film polish. Application of this polish deposited a limited buildup (1 micron, or 0.00005 inch) on the aircraft surface. This buildup was considered a minor modification and did not require removal after testing.

The overall test objective was to characterize the average range factor (true airspeed multiplied by aircraft gross weight divided by fuel flow) change

resulting from Racer's Edge polish application to the T-38A aircraft. The specific test objective was to determine, within a 90-percent confidence level, if there was a range factor change of at least 1.2 percent attributable to the application of Racer's Edge polish. The estimated instrumentation resolution was ± 0.6 percent; therefore, a 1.2 percent change in range factor was the estimated minimum resolvable difference between a baseline and treated data point. The measure of performance was a comparison between the range factor of the baseline (untreated) aircraft versus the treated test aircraft using the weight to ambient air pressure ratio flight test technique.

The overall HAVE SLICKER test objective was met. While flight test results revealed a trend toward improved average range factors at both altitudes, the improvement was less than the ± 0.6 percent instrumentation uncertainty. Test results revealed a 0.7 percent improvement in the range factor at 11,000 feet pressure altitude and a 0.3 percent improvement at 13,500 feet pressure altitude; therefore, a 90-percent confidence in a measurable improvement in the range factor was not attained at either altitude, and no meaningful statistical confidence could be obtained.

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INTRODUCTION

GENERAL

This report presents the results of an evaluation of a change in range factor as a result of an application of Racer's Edge polish to a T-38A aircraft (HAVE SLICKER). The overall test objective was to characterize the range factor (true airspeed multiplied by aircraft gross weight divided by fuel flow) change as a result of the Racer's Edge polish application to a Northrop T-38A aircraft.

Testing was conducted by the Air Force Flight Test Center (AFFTC) USAF Test Pilot School (TPS), Edwards AFB, California, under USAF Cooperative Research and Development Agreement number CR980100, between the AFFTC and American Aviation & Toolcraft, the marketing agent for Racer's Edge aviation polish. The test team consisted of three test pilots, one flight test navigator, and two flight test engineers. A total of 19.4 hours of flight tests were conducted using a single T-38A aircraft, USAF S/N 68-8153, from 16 March through 9 April 1998. Seven baseline (without polish application) test sorties and seven treated (after polish application) test sorties were flown and the results directly compared. Flight tests were conducted in the Edwards AFB R-2508 complex and the airspace between Daggett and Needles, California.

A similar test project, HAVE SLICK (Reference 1), was conducted by the USAF TPS in 1995. The HAVE SLICK test team tested the Thin Film Systems' MICROCLEAN™ product on a T-38A aircraft for drag reduction effects. Results

indicated a 1-percent improvement in specific range (range factor divided by aircraft gross weight) and drag reduction as a result of the chemical treatment.

PROGRAM CHRONOLOGY

The HAVE SLICKER test project was conducted from 7 January through 9 June 1998. Flight tests were conducted from 16 March through 9 April 1998. Significant project milestones are summarized in Table 1.

TEST DESCRIPTION

Test Item Description:

Racer's Edge was a water-soluble polish. Application of the polish deposited a limited buildup (1 micron, 0.00005 inch) on the aircraft surface. The polish was nontoxic, biodegradable, and required no HAZMAT devices, clothing, or protocol throughout the test. Racer's Edge polish could be applied to painted and clear-coated metal or composite surfaces. The polish dissipates in 6 to 12 months and did not require removal. Further polish information and the material safety data sheet can be found in the Program Information Document (Appendix A).

Test Aircraft Description:

The test aircraft, a Northrop T-38A, was a two-place, twin-turbojet, supersonic trainer. The fuselage

Table 1
PROGRAM SCHEDULE

| Date | Event |
|-----------|-----------------------------------|
| 7 Jan 98 | Program Introduction |
| 12 Feb 98 | Test Plan Working Group Meeting |
| 17 Feb 98 | Test Plan Complete |
| 2 Mar 98 | Technical and Safety Review Board |
| 16 Mar 98 | Flight Tests Begin |
| 9 Apr 98 | Flight Tests Conclude |
| 17 Apr 98 | Draft Technical Report Complete |
| 1 Jun 98 | Final Technical Report Complete |
| 8 Jun 98 | Final Oral Report |

had an area-rule shape, with moderately swept-back wings and empennage. The aircraft had irreversible flight control systems. It was powered by two J85-GE-5 engines, each producing 2,050 pounds of thrust in military power (sea level, static).

The production noseboom of the test aircraft was replaced with a flight test noseboom. In addition, the aircraft was also equipped with sensitive instruments to gather performance data. The aircraft was considered production representative since the modifications had negligible effects on the aircraft's cg^1 and aerodynamics, and no effect on the aircraft's thrust characteristics. A complete description of the T-38A and class II modifications are contained in the T-38A Flight Manual (Reference 2) and the aircraft Modification Flight Manual (Reference 3). The polish was applied to approximately 88 percent of the aircraft's wetted area in the cruise configuration. Application of the polish was covered by a modification note.

Test Instrumentation Description:

The T-38A test aircraft was equipped with a Rosemount Model 850A yaw angle-of-attack (AOA) and Pitot-static noseboom, which provided angle-of-sideslip, AOA, and Pitot-static sensor information. A Rosemount Model E102AL total air temperature probe was also incorporated on the lower portion of the forward fuselage to provide total air temperature data. Sensitive airspeed indicators, altimeters, and Mach meters replaced production versions in both cockpits. A complete description of all modifications can be found in Reference 3. In addition, the aircraft was equipped with a Metraplex Data Acquisition System (DAS) containing a 1/4-inch tape recorder for collecting aircraft test parameters. A detailed description of the Metraplex DAS can be found in the USAF TPS Instrumentation Handbook (Reference 4). Calibration records for all instrumentation and cockpit instruments were maintained by the USAF TPS Technical Support Division. Specific calibration records, resolutions, and accuracies can be found in Appendix B.

Data Acquisition System:

The T-38A test aircraft's onboard DAS recorded performance data. The onboard DAS was critical for

accurate data acquisition and was the main go/no-go criteria. The DAS data were processed using the existing USAF TPS Aydin processor. The T-38A DAS collected airspeed, altitude, fuel flow, vertical velocity, AOA, fuel used, total air temperatures, and horizontal stabilator position data during each test point. A complete listing of DAS recorded parameters is presented in Appendix B.

All DAS data were backed up by hand-held data collected at regular intervals during the 3-minute test points. Hand-held data included fuel counter, fuel quantity, altitude, indicated velocity, vertical velocity, fuel flow, engine rpm, and qualitative pilot comments to include turbulence. These comments were used to assess the overall test point quality. Postflight data reduction was conducted to verify data quality and to calculate the aircraft's range factor for each test point. The DAS file was downloaded into the USAF TPS Aydin processor for conversion to engineering units and then converted to a USAF TPS flight test analysis system DAS file. This file was subsequently converted to an ASCII file which was used in the test-team developed data reduction spreadsheet. Appendix C contains the equations used to calculate range factor.

TEST OBJECTIVE

Overall Test Objective - Range Factor Characterization:

The overall test objective was to characterize the T-38A aircraft range factor change as a result of application of the Racer's Edge polish. Specifically, the range factor of the T-38A test aircraft with and without application of the polish was compared, using the gross weight to ambient air pressure ratio (W/δ) flight test technique (FTT).

Specific Test Objective - Range Factor Comparison:

The specific objective was to determine, within a 90-percent confidence interval, if a change in range factor of at least 1.2 percent occurred as a result of an application of the Racer's Edge Polymer Aviation Polish on the T-38A test aircraft. The 1.2-percent change was the estimated uncertainty in range factor due to instrumentation uncertainty.

¹ All cg 's in this report are longitudinal cg 's, in percent mean aerodynamic chord.

**Measure of Performance - Range
Factor Comparison:**

Based on previous testing (HAVE SLICK, Reference 1), the test team estimated 25 test points at each W/ δ and Mach number combination were required to compare the range factors of the baseline versus the treated test aircraft. Appendix D shows specific W/ δ test points.

LIMITATIONS

A limitation governing the conduct of this flight test was instrumentation uncertainty. The resolution

and uncertainty of the T-38A DAS limited the FTTs available. The W/ δ FTT was the best technique available to obtain repeatable cruise data within the T-38A DAS limitations. Based on the ± 0.6 -percent instrumentation uncertainty in range factor, the polish needed to improve the range factor by at least 1.2 percent in order to conclude that a change in range factor was evident. This instrumentation uncertainty was one of the primary factors in test point selection (Appendix C).

TEST AND EVALUATION

GENERAL

The overall test objective was to characterize the range factor change as a result of an application of the Racer's Edge polish to a T-38A aircraft. If Racer's Edge polish was proven to improve range factor, there could be potential savings in fuel cost for both military and commercial flight operations. However, the test had to be performed to a high degree of certainty since the potential improvement due to the polish application was predicted to be the same order of magnitude as the instrumentation uncertainty.

TEST AIRCRAFT CONFIGURATION CONTROL

All tests were conducted in the cruise configuration (flaps, speedbrakes and landing gear retracted). The evaluation used the W/ δ FTT as described in the USAF TPS Performance Phase Planning Guide (Reference 5). Test aircraft cg was maintained at 18 ± 0.1 percent during flight testing (Appendix F). The test aircraft was hangedared between test flights to minimize environmental effects.

TEST PREPARATION

Test Item Application:

The test aircraft was washed using standard maintenance procedures prior to the first baseline test sortie and again prior to application of the polish. Two T. Brennan, Inc. (subcontractors to American Aviation & Toolcraft) personnel applied the polish to the test aircraft. Application of the polish was limited to exposed, external, painted surfaces in the cruise configuration. No polish was applied to the noseboom, Pitot-static ports, AOA vanes, total air temperature probes, engine nozzles, inside of the engine inlets, canopy, black anti-glare surfaces, landing gear (other than the exterior surface of the gear doors), or antennae. The total area that remained free of polish was approximately 115 square feet, or 12 percent of the total aircraft wetted area in the cruise configuration. No polish was applied between treated test flights.

Test Aircraft Weight and Balance:

The aircraft weight and cg, as well as fuel quantity indications, were measured with various fuel loads (900, 2,200 and 3,500 pounds fuel) at two pitch attitudes, 0- and 5-degrees nose high. These pitch attitudes bracketed the predicted AOA at the various test points. A gross weight and longitudinal cg table was developed to record measured variations in fuel quantity indications and cg locations as a result of aircraft pitch attitude changes, fuel burn, and fuel imbalances (Tables F1 and F2).

To further minimize gross weight and cg variations, the test team flew a constant pairing of pilot/engineer aircrew. Each specific crew had specific Weight and Balance Clearances (Forms F) (Appendix F) generated to reflect each crew's takeoff gross weight and cg. Based on fuel tank moment data from Technical Order (T.O.) 1T-38A-5 (Reference 6) and the weight & balance measurements, a crew-specific fuel burn curve (Figure F1) and table (Table F3) was created to reflect the desired fuel distribution. This table was used to keep the cg constant at 18 ± 0.1 percent while cruise data were collected.

TEST PROCEDURES

Aircraft Fueling Procedures:

An accurate fuel weight was required to achieve a precise starting gross weight for each test sortie. The aircraft production fuel gauges were calibrated on the weight and balance stand and found to be accurate to 30 ± 9 pounds (the weight and balance stand's uncertainty was ± 0.07 percent. This value multiplied by the maximum aircraft gross weight, 12,973 pounds, resulted in the stand's uncertainty of ± 9 pounds). Fuel was loaded at 25 pounds per square inch line pressure for each sortie and the single point refueling automatic shutoff was used to stop the fuel flow. Using this procedure, accurate and repeatable starting fuel weights were obtained.

Following each test sortie and just prior to refueling, maintenance personnel collected a 1-quart sample of JP-8 fuel from the aircraft's forward fuel

dump valve. Phillips Laboratory, Edwards AFB, California, analyzed the sample for energy content and fuel density at representative test point and refueling temperatures (Appendix G). An additional 1-quart sample was taken from the refueling truck line to measure the temperature of the onloaded fuel.

Surface Roughness Measurement:

Surface roughness measurements were taken with a Taylor-Hobson Surtronic 10 Ra surface analyzer supplied by the customer, American Aviation & Toolcraft. The surface roughness measurements were taken on three occasions: prior to the first baseline test sortie, after aircraft polish application, and after the last treated test sortie. The first two measurements were taken to compare surface roughness before and after polish application, and to determine test altitude and Mach number as discussed in Appendix E. The last measurement was taken to determine changes in surface roughness during the treated test sorties. For all measurements, 40 locations were randomly selected around the airframe and averaged. The results of the surface roughness measurement are shown in Table 2. The results revealed the aircraft surface to be smoother after polish application. No polish was applied between treated test flights. Measurements taken after the last test sortie revealed no degradation in skin smoothness.

Engine Parameters:

Since any degradation in engine performance could severely impact the outcome of the test results,

engine performance was monitored throughout the entire flight test phase. For each flight, a 2-minute engine run at military thrust was accomplished to collect engine data which included engine rpm, fuel flow, exhaust gas temperature, nozzle position, ambient air temperature, and pressure altitude.²

The engine runs showed no significant changes in engine performance during the course of the test. The results are presented in Table 3.

Flight Test Technique:

All test sorties were flown using the W/δ FTT which required the aircraft to be flown at a given Mach number and W/δ. As the aircraft gross weight decreased from fuel burn, the pressure altitude was increased to maintain a constant W/δ. This FTT is described in Reference 5. Each test point was flown for a minimum of 3 minutes to ensure an accurate average fuel flow. The W/δ FTT reduced the number of gross weight and altitude conditions that would otherwise be required. Data reduction required the W/δ to be maintained to within ±2 percent. A more detailed description of this FTT is described in the USAF TPS Performance Phase Planning Guide (Reference 5). Specific data bands and tolerances are summarized in Table 4.

Fuel Heating Value Ratio:

The heat of combustion for each sortie's specific fuel sample was determined by Phillips Laboratory by an average of three bomb calorimeter tests. These values were then divided by the average heat of

Table 2
SURFACE ROUGHNESS MEASUREMENTS

- Measurements made with Taylor-Hobson Surtronic 10 Ra
- S/N 1344647
- Calibrated 20 October 1997
- Resolution = ±4μ inch¹, Uncertainty = ±5 percent or reading or ±1μ inch¹, whichever is greater

| | Low Value (mil) ² | Average Measurement (mil) ² | High Value (mil) ² |
|-------------------------------------|---------------------------------|---|----------------------------------|
| Prior to First Baseline Test Sortie | 0.24 | 0.26 | 0.27 |
| After Polish Application | 0.11 | 0.19 | 0.27 |
| After Last Treated Test Sortie | 0.10 | 0.16 | 0.25 |

- Notes: 1. μ inch = 10⁻⁶ inches
2. 1 mil = 10⁻³ inches, or 0.001 inches

² All altitudes in this report are pressure altitude in feet, unless otherwise specified.

Table 3
ENGINE RUN ANALYSIS

- T-38A, S/N 68-8153
- J85-GE-5 engines
- JP-8 fuel
- Military power
- Ground level, static

| | OAT | PA | Engine RPM (pct) | | EGT (deg C) | | Nozzle Position (pct) | | Fuel Flow (lb/hr) | |
|-----------------------|-----|-------|------------------|-------|-------------|-------|-----------------------|-------|-------------------|-------|
| | | | Left | Right | Left | Right | Left | Right | Left | Right |
| First Baseline Sortie | 51 | 2,192 | 100.7 | 100.0 | 640 | 640 | 12 | 20 | 2,150 | 2,000 |
| Last Test Sortie | 50 | 2,211 | 100.7 | 100.4 | 640 | 635 | 13 | 20 | 2,200 | 2,000 |

- Notes: 1. OAT - airfield ambient temperature, in degrees Fahrenheit, as reported by the base weather shop
 2. PA - airfield pressure altitude, in feet, as reported by the base weather shop
 3. EGT - exhaust gas temperature

Table 4
W/δ FLIGHT TEST TECHNIQUE DATA BANDS AND TOLERANCES

| Parameter | Data Band | Tolerances |
|---------------------------|-----------|------------|
| Pressure Altitude, ft | ±100 | ±100 |
| Vertical Velocity, ft/min | -- | ±100 |
| Indicated Airspeed, KIAS | ±2 | ±2 |
| W/δ, pounds | 17,600 | ±2 percent |
| cg, percent MAC | 18 | ±0.1 |

- Notes: 1. '---' - not applicable
 2. W/δ - aircraft gross weight
 3. MAC - mean aerodynamic chord

The average heat of combustion was 18,636 British thermal units per pound of fuel. The fuel heating value ratios used throughout the flight tests are presented in Appendix G.

Fuel Density:

The fuel density for each sortie's specific fuel sample was determined by Phillips Laboratory at three different temperatures: the highest and lowest DAS measured test point fuel temperatures, and the lowest of the measured aircraft fuel or refueling truck fuel temperatures. A linear correlation was used to model the density-temperature relationship, which is presented in Appendix G. There was no significant variance in densities from different fuel lots taken at the same temperature, so a uniform lot assumption was made. The density at each test point was determined at the average DAS-measured fuel temperature for the point using the fuel density model. The average DAS-measured volumetric fuel

flow was multiplied by this density value to find the average mass fuel flow for each point.

TEST RESULTS

Baseline Range Factor Characterization:

A total of seven baseline test sorties totaling 8.0 flight hours were flown. The test sorties were flown at 0.77 Mach number and a W/δ ratio of 17,600 pounds. Data points flown below 12,000 feet pressure altitude were standardized to 11,000 feet, while those at 12,000 and above were standardized to 13,500 feet. A total of 62 baseline data points (21 data points standardized to 11,000 feet and 41 data points standardized to 13,500 feet) were flown. Of the 62 data points collected, 42 points were considered good quality; the other 20 test points were of marginal or poor quality due to

turbulence or flying outside parameter tolerances. Within a 90-percent confidence interval, the average range factor for 11,000 feet was 2,055 ±6 nautical air miles (NAM). For 13,500 feet, the average range factor was 2,020 ±5 NAM. Baseline testing was terminated when additional test points did not significantly change the range factor values or confidence intervals.

Treated Range Factor Characterization:

A total of 7 treated test sorties totaling 7.0 flight hours and a total of 57 treated data points (29 data points standardized to 11,000 feet and 28 data points standardized to 13,500 feet) were flown. Out of the 57 data points collected, 45 points were considered good quality; the other 12 test points were of marginal or poor quality due to turbulence or flying outside parameter tolerance. Within a 90-percent confidence interval, the average range factor for

11,000 feet was 2,069 ±6 NAM. For 13,500 feet, the average range factor was 2,027 ±9 NAM. Treated testing was terminated when additional test points did not significantly change the range factor values or confidence intervals.

Average Range Factor Data Comparison:

Qualitative analysis revealed a small improvement in average standardized range factor for the treated aircraft at both altitudes, however, no statistical significance could be assigned to the results due to the instrumentation uncertainty. At 11,000 feet, the difference between baseline (2,055 ±6 NAM) and treated (2,069 ±6 NAM) average range factors was 14 ±12 NAM, or 0.7 ±0.6 percent. At 13,500 feet, the difference between the baseline (2,020 ±5 NAM) and treated (2,027 ±9 NAM) average range factors was 7 ±14 NAM, or 0.3 ±0.7 percent. Table 5 summarizes the average range factor comparison.

Table 5
AVERAGE RANGE FACTOR¹ COMPARISON

- T-38A S/N 68-8153
- J85-GE-5 engines
- Mach number = 0.77
- W/δ = 17,600 pounds
- cg = 18 ±0.1 percent MAC
- JP-8 fuel
- Lower Heating Value = 18,636 Btu/lb

| | Pressure Altitude (ft) | |
|-------------------------------|------------------------|----------|
| | 11,000 | 13,500 |
| Baseline (NAM) | 2,055 ±6 ² | 2,020 ±5 |
| Treated, (NAM) | 2,069 ±6 | 2,027 ±9 |
| Difference (NAM) | 14 ±12 | 7 ±14 |
| Difference ³ (pct) | 0.7 ±0.6 | 0.3 ±0.7 |

Note: NAM - nautical air miles

¹ Range factor = (true airspeed) X (aircraft gross weight)/(fuel flow)

² Tolerances represent 90-percent confidence intervals

³ Difference = (treated - baseline)/baseline * 100

Error analysis determined the maximum instrumentation uncertainty in range factor to be ± 0.6 percent (Appendix E). Figure 1 shows the average range factor data with instrumentation uncertainty error bars for the baseline and treated aircraft at each standard altitude. This instrumentation uncertainty was greater than the observed change in range factor, therefore, it was not possible to determine within a 90-percent confidence interval, whether or not a change in range factor attributable to Racer's Edge polish was evident. **The test should be re-accomplished with a DAS having a better instrumentation uncertainty. (R1)³**

Additional Observations:

Flight test data showed that the calculated instrumentation uncertainty was correct. As statistical confidence approached 99.9 percent, the confidence interval for the range factor data approached ± 0.6 percent, which was equal to the calculated instrumentation uncertainty.

The HAVE SLICKER test results corresponded with hydraulic smoothness theory presented in Appendix E and previous tests (Reference 7). The test team found an average range factor dependence on altitude. This was primarily caused by two factors, both attributable to decreasing Reynolds number with altitude. First, there was an increase in skin friction drag due to a lower Reynolds number.⁴ Reynolds number was defined as the ratio of airflow momentum to airflow viscosity. As Reynolds number decreased, the viscous effects became more pronounced, thus increasing skin friction drag. Second, there was a decrease in fuel efficiency due to lower engine component efficiencies. The decrease in average range factor for the T-38A aircraft was approximately 0.7 percent per thousand feet of altitude. This was comparable to previous F-16 and B-52 performance tests (Reference 7).

³ Numerals preceded by an R within parentheses at the end of a paragraph correspond to recommendation numbers tabulated in the Conclusions and Recommendations section of this report.

$${}^4 R_N = \frac{Ul}{\nu} \text{ where:}$$

U = true airspeed,
l = characteristic length, in this case, wing chord, and
 ν = kinematic viscosity

Dates: 16 March 1998 - 9 April 1998
 Aircraft: T-38A, S/N 68-8153
 Engines: J85-GE-5
 Fuel: JP-8
 Air Conditioning: On
 Pitot Heat: Off

Modifications: YAPS nose boom/Sensitive Airspeed/
 Sensitive Altimeter/Total Temperature Probe
 Configuration: Cruise, Landing Gear, Flaps, Speedbrakes Up
 Standard Pressure Altitudes: 11,000 and 13,500 feet
 Data Acquisition System: ATIS DAS

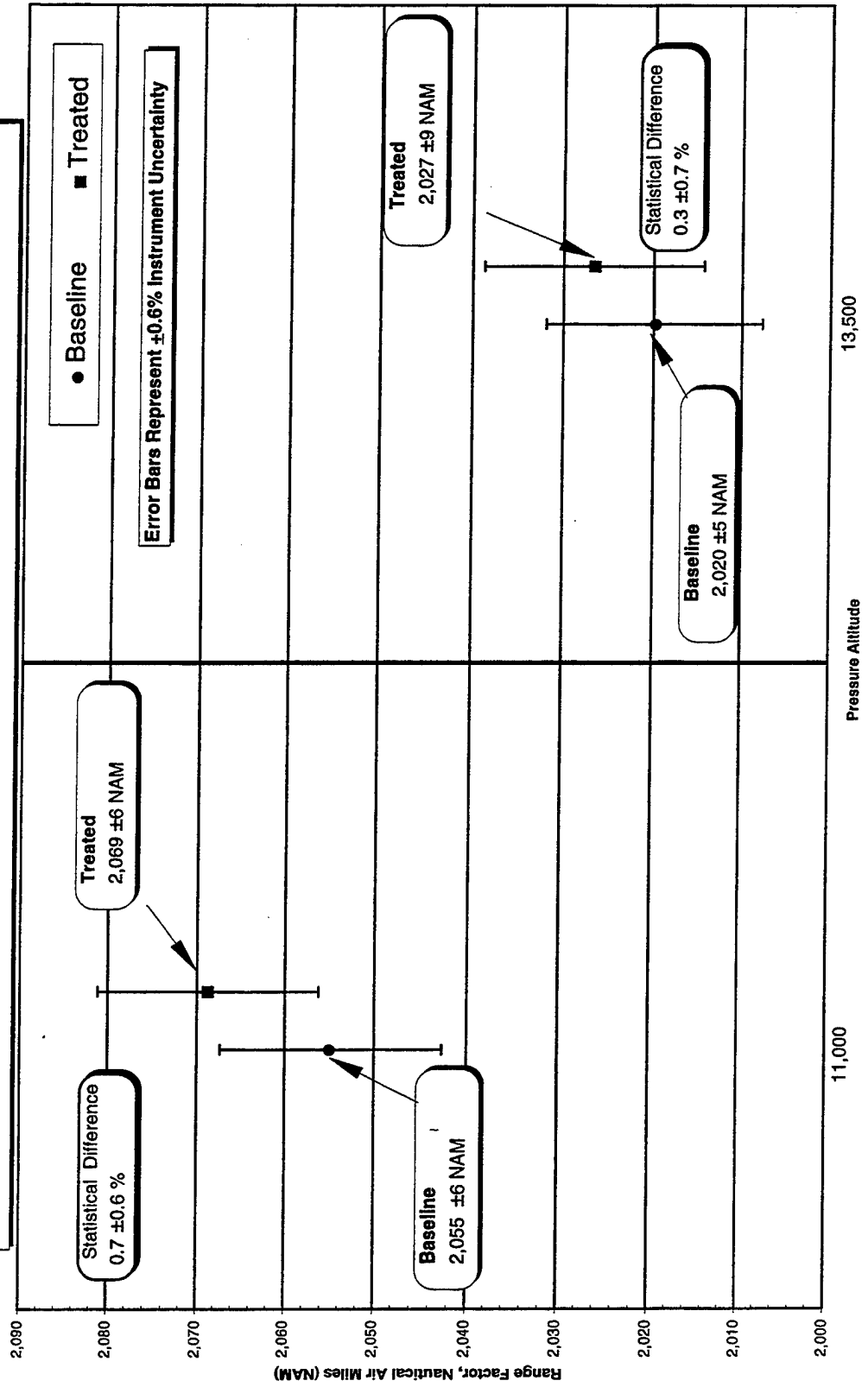


Figure 1 Standard Range Factor at Two Pressure Altitudes (11,00 feet and 13,500 feet)

CONCLUSIONS AND RECOMMENDATION

The overall test objective of characterizing the range factor (true airspeed multiplied by aircraft gross weight divided by fuel flow) change as a result of an application of the Racer's Edge polish to a T-38A aircraft was met. While flight test results revealed a trend toward improved range factors at both altitudes, the improvement was less than the ± 0.6 -percent instrumentation uncertainty. Test results revealed a 0.7-percent improvement in the range factor at 11,000 feet pressure altitude and a

0.3-percent improvement at 13,500 feet pressure altitude; therefore, a 90-percent confidence interval in a measurable improvement in the range factor was not attained at either altitude, and no meaningful statistical confidence could be obtained.

- 1. The test should be re-accomplished with a data acquisition system having a better instrumentation uncertainty. (Page 10)*

REFERENCES

1. Tennent, Scott G., Captain, USAF, *A Limited Evaluation of a Surface Treatment for Aircraft Drag Reduction (HAVE SLICK)*, AFFTC-TLR-95-38, Air Force Flight Test Center, Edwards AFB, California, June 1995.
2. Flight Manual, USAF Series Aircraft, T-38A, Technical Order 1T-38A-1, San Antonio ALC/TILT, Kelly AFB, Texas, 1 July 1987, change 10, 1 June 1997.
3. Modification Flight Manual, T-38 S/N: 68-153, 412 OG/OGV, Edwards AFB, California, 7 October 1997.
4. USAF Test Pilot School Instrumentation Handbook, USAF TPS/TSF, Edwards AFB, California, June 1996.
5. USAF Test Pilot School Performance Phase Planning Guide, USAF TPS/ED, Edwards AFB, California, July 1997.
6. Basic Weight Checklist & Loading Data, USAF Series Aircraft, T-38A, Technical Order 1T-38A-5, San Antonio ALC/TILT, Kelly AFB, Texas, 30 Aug 1996.
7. Olsen, Wayne. June 1982. *Aircraft Performance Short Course Notes Volume I*. AFFTC Flight Dynamics Branch, Edwards AFB, California.
8. *USAF TPS Cruise Textbook*, USAF TPS/ED, Edwards AFB, California, 1991.
9. Hayes, B.R., *Flight Manual Performance USAF Model T-38A Trainer Airplane with Two J85-GE-5 Engines*, NOR-60-350, Northrop Corporation, NORAIR Division, 1960.
10. Walski, W.F., *Flight Test Performance Analysis of the Northrop T-38A with Two J85-GE-5 Engines Supersonic Basic Trainer*, NOR-62-34, Northrop Corporation, NORAIR Division, 1962.
11. Perry, L.J., *Standard Aircraft Characteristics Performance of the Northrop T-38A Supersonic Basic Trainer with Two J85-GE-5 Engines*, NOR-62-16, Northrop Corporation, NORAIR Division, 1962.
12. Schlichting, Hermann, Dr. 1960. *Boundary Layer Theory*. New York: McGraw-Hill Book Company, Inc.

APPENDIX A
PROGRAM INTRODUCTION DOCUMENT

PROGRAM TITLE: HAVE SLICKER

CUSTOMER DATA:

a. Requesting Agency:

American Aviation and Toolcraft
6034 Country Lane
Quartz Hill, CA 93526

b. Project Representative: Larry Sweetser (808) 823-0733

c. Statement of Capability Desired Date: ASAP

d. Other support agencies:

Prime/subcontractors:

Racer's Edge (POC: James Krug (818) 772-1760)
T Brennan, Inc. (818) 363-5300

Support Agency:

AFFTC/XPST (POC: Kurt Buehler)

PROGRAM IDENTIFICATION INFORMATION:

Begin Date: 7 Jan 98
First Test Date: 9 Feb 98 (TPWG)
Completion date: 10 Jun 98

SYSTEM BACKGROUND INFORMATION: The Racer's Edge product is a unique, water soluble, thin-film, polish/wax. Applications of this product makes the surface smoother reducing the friction factor. Early investigative studies show possible benefit in aircraft glide ratios, lift-to-drag ratios, and decreasing parasitic drag. There is potential for improved fuel economies. The coating will not change the appearance of the plane. There is limited build-up (1 micron) when the product is applied and the product will not degrade the surface. This product is also non-toxic, biodegradable and requires no HAZMAT devices nor clothing nor protocol (Ref: AFFTC Bio-environmental Material Health and Safety Bulletin).

TEST PROGRAM AND MISSION INFORMATION/OBJECTIVES: The objective of this test is to provide initial flight test measurements of the aerodynamic drag reduction capabilities of the Racer's Edge polish (provided by American Aviation & Toolcraft).

ENVIRONMENTAL CONSIDERATIONS: See material and safety bulletin from the AFFTC bio-environmental office.

ACTIVITY PLAN: American Aviation & Toolcraft will provide the Racer's Edge product to be tested, as well as supervise application on the surface of an instrumented T-38 (Tail # 153 - verify tail # w/ Shadow - Joe Everett). The test planning, test conduct, data reduction, data analysis, and reporting will use current technology TPS test assets. It is anticipated that approximately 10 sorties will be required to accomplish the test. Initial sorties will be flown without the polish so as to provide a basis for comparison.

SYSTEM INFORMATION: T-38 (instrumented, Tail # 153). Racer's Edge Polish.

ELECTRONIC/ELECTRO-OPTICAL SYSTEM INFORMATION: N/A

INSTRUMENTATION SYSTEMS: N/A

TELEMETRY/DATA RANGE: N/A

AIR/GROUND COMMUNICATIONS: N/A

DATA PROCESSING/DISPLAY/CONTROL: AFFTC/TS in the person of Mr. Frank Brown to provide limited consultation support.

PHOTOGRAPHIC SUPPORT: At the cost and discretion of TPS.

METEOROLOGICAL: N/A

RECOVERY: N/A

OTHER TECHNICAL SUPPORT: N/A

MEDICAL: Standard medical support for TPS sorties.

PUBLIC AFFAIRS SERVICES: N/A

BASE FACILITIES/LOGISTICS: N/A

SERVICES REQUIRED:

Fire and rescue: Standard TPS support

Security and safety: N/A

Community Education and Food Service: N/A

Utilities: Standard TPS support

Air Conditioning and Environmental: N/A

Physical and/or Life Science Experiments: N/A

Propellants, Gases, and Chemicals: N/A

Fuels and Lubricants, Hydraulic Fluids. Preservatives, etc.: Standard

Requesting Agency Aircraft: N/A

Air Operations: Standard flight test support

Sea Craft: N/A
Marine Operations: N/A
Chemical Cleaning: N/A

LABORATORY: N/A

MAINTENANCE PLANNING: The only services required will be general aircraft maintenance as required. However, assuming the polish is applied at Edwards, the team of 4 personnel from T Brennan Inc. responsible for applying the polish will need access to Hangar 1600. Procedure takes roughly 5 hours.

MANPOWER AND PERSONNEL: N/A

SUPPLY SUPPORT: N/A

SUPPORT EQUIPMENT: Standard ground support equipment for a T-38.

TECHNICAL DATA: Suggested reference for details concerning potential methods for data acquisition and reduction: HAVE SLICK Test Report (POC Mr Dave Lazerson).

TRAINING REPORT: N/A

COMPUTER RESOURCES: N/A

FACILITIES: A hangar is needed for use during the application of the polish

PACKAGING, HANDLING, STORAGE, AND TRANSPORTATION: N/A

MODIFICATION: Addition of the polish will be considered a mod note (preferred) or a Class 2 Mod. TPS POC: Sharlene Lim (ext 3410).

SPECIALTY ENGINEERING: N/A

MATERIAL HEALTH AND
SAFETY BULLETIN

MANUFACTURER'S NAME

RACER'S EDGE PRODUCTS

DIRECT ADDRESS

19431 BUSINESS CENTER DR. # 30

CITY, STATE AND ZIP CODE

NORTHRIDGE CALIFORNIA 91324

EMERGENCY PHONE NUMBER (24 Hours):

Transportation Emergencies Call: CHEMTREC (800) 424-9300

Health Emergencies Call: Los Angeles Poison Information Center (213) 664-2121

PRODUCT: AUTO POLISH

WARNING STATEMENT:

CHEMICAL NAME:

DANGER: Contains Petroleum distilled and morpholine. Harmful if swallowed. If swallowed DO NOT induce vomiting. Call a Physician immediately. Avoid eye contact and prolonged skin contact.

CAS NUMBER: (Not Applicable for Blends)

DOT (Proper Shipping Name)

USE IN WELL VENTILATED AREAS.
KEEP OUT OF THE REACH OF CHILDREN
FOR INDUSTRIAL USE ONLY.

HAZARD RATING NFPA

| | | | |
|------------|------------|---|---|
| EAST | FIRE | - | 1 |
| LIGHT | TOXICITY | - | 2 |
| 2-MODERATE | REACTIVITY | - | 0 |
| 3-HIGH | SPECIAL | - | |
| 4-EXTREME | | | |

SECTION I .. INGREDIENTS

| PRODUCT | CAS NUMBER | TLV | PEL | PERCENTAGES |
|---|------------|------|---------|-------------|
| Mineral Spirits Stoddard Solvents) | 64741-41-9 | 100A | 100 ppm | 10-12% |
| Parafins, Cycloparafins and Aromatics | | NE | NE | 10-15% |
| Isopropanol | 67-63-0 | 400A | 400 ppm | 2-5% |
| Turpentine | 800-66-42 | 100A | 100 ppm | 2-5% |
| Morpholine | 110-91-8 | 20B | 20 ppm | 2-1% |
| Water Emulsion Blend: Polysiloxane Mixture | 9016-00-6 | NE | NE | 60-70% |

A, Osha [x] B, ACGII [x] C, See Section III [] D, Other [] Cal Osha

Section II .. EMERGENCY AND FIRST AID PROCEDURES

EMERGENCY: Have a physician call: LOS ANGELES POISON INFORMATION CENTER
(24 Hrs.) (213) 644-2121

| | |
|--------------|--|
| EYE CONTACT | Gently flush with large quantities of water for at least 15 minutes. Seek medical attention immediately. |
| SKIN CONTACT | Remove any contaminated clothing. Wash with soap and large quantities of water. Seek medical attention if irritated. |
| INHALATION | If breathing difficulties, dizziness, or light-headedness occur when working in areas with high vapor concentration, move to outside air immediately. If breathing stops, begin artificial respiration and seek immediate medical attention. |
| INGESTION | If this product is swallowed, seek medical attention immediately. <u>DO NOT</u> induce vomiting unless directed by a physician. |

Section III .. PHYSIOLOGICAL EFFECTS AND HEALTH INFORMATION

| | |
|------------------|--|
| EYE EFFECTS | This product may be an eye irritant. |
| SKIN EFFECTS | Prolonged skin contact may result in irritation and/or Dermatitis. |
| SYSTEMIC EFFECTS | Various studies have shown a possible association with exposure to this product and the following: NONE |

MUTAGENICITY: NTP IARC MONOGRAPHS OSHA

NONE KNOWN



RACERS EDGE AVIATION POLISH

Racers Edge Polymer Aviation Polish protects all non-porous substrates from premature deterioration and destruction due to the particular environment that the substrate is subjected to. Typical substrates for which such protection is desired includes metal or composite surfaces, painted, clearcoated or otherwise with any combination of paints including acrylic, enamel or lacquer. Applying the polymer polish to these materials forms a barrier between the surface of the substrate and the environment to protect the underlying material from deterioration which, if left unchecked could, result in the decline of the aesthetic appearance as well as damage.

By providing a protective film on the surface of the treated material, the polymer polish prevents materials from bonding or sticking to the surface of the treated substrate. The polymer polish which contains 2-propenoic acid-2-cyano-3, 3-diphenyl-2-ethylhexyl ester provides for surface bonding and the high gloss polymer protective layers for enhancement of the surface's color. Furthermore, it will not discolor over time. The polish contains new liquid ultraviolet light absorbers from the hydroxyphenylbenzotriazole class. This inhibitor is unique of it high thermal stability and thermal permanence. The polish provides 100% absorption over the UV spectrum.

Significantly, the polymer polish restores the original luster to the dull or faded surfaces by the interaction of the polish with the substrate itself. The polymer polish removes oxidation on the surface and then adheres to the substrate itself through polar bonding or entrapment due to the color absorbent particles in the polish. Critical application is therefore not required because of the bonding properties. Application of a thin layer to the surface will suffice to enable the polymers to adhere.

The backbone of the polymer polish is a unique blend of polysiloxanes which through the polycondensation chemical reaction form hydrophobic (water sheeting) and extremely hard coating films which are superior to classical wax and cleaner formulations.

The rheological additives provide the polymer polish composition with the desire elasticity, viscosity and plasticity allowing for ease of use and mistake free application. It will clean oxidized surfaces, hard water spots, mineral residue, and oils from the surface and spread the polish evenly as it smooths the silicone layers. It also helps to buff the treated surface and causes color from a treated surface to blend. Because of the silicone polymers unique to the polish and the rheological additives a single coating of the polish should provide durability of the protective coating for 6 to 12 months.

APPENDIX B

T-38A, USAF S/N 68-8153, CALIBRATION RECORDS

T-38 ON AIRCRAFT INSTRUMENTATION CALIBRATION VALIDATION

TAIL NUMBER: 153

DATE: 10 MAR 98

| FRONT COCKPIT TTU-205 S/N | | Altitude S/N 9815 | | Airspeed S/N 11029 | | Mach S/N 14731 | |
|------------------------------|------------------|----------------------|-------|-----------------------|-------|-------------------|------|
| Alt (ft) | Airspeed (knots) | Up | Down | Hyst | Up | Down | Hyst |
| 2300 | 150 ±5 | 2301 | 2305 | ±25 | 149 | 149.5 | ±2 |
| 5000 | 300 ±5 | 5000 | 5010 | ±25 | 300 | 300.5 | ±2 |
| 10000 | 450 ±8 | 10010 | 10025 | ±30 | 449 | 449.5 | ±3 |
| 15000 | 600 ±8 | 14985 | 15000 | ±30 | 596 | 596 | ±3 |
| 20000 | 500 ±8 | 19965 | 19975 | ±30 | 501 | 500 | ±3 |
| 25000 | 400 ±5 | 24950 | 24955 | ±40 | 398 | 398 | ±3 |
| 30000 | 350 ±5 | 29980 | 29990 | ±40 | 349.5 | 349 | ±3 |
| 35000 | 250 ±5 | 35025 | 35050 | ±40 | 249 | 248.5 | ±3 |
| 40000 | 200 ±5 | 40100 | 40105 | ±40 | 198.5 | 198 | ±3 |

Low Speed Accuracy Test

| Tester @ 3300ft | IND |
|-----------------|-------|
| 200 Kts | 178.5 |
| 190 | 179 |
| 180 | 178.5 |
| 170 | 168.5 |
| 160 | 159 |
| 150 | 149.5 |

Leak Check (PACER A/C 154 & 574)

| | |
|-----------------------|-----|
| 15,000 ft ≤ 50 ft/min | N/A |
| 300 Kts ≤ 1 Kt/min | N/A |
| | |

Leak Check TPS

| | |
|------------------------|-------|
| 15000 ft. ≤ 100 ft/min | 56 |
| 40000 ft. ≤ 200 ft/min | 184 |
| 200 kts. ≤ 3 kts/min | 2.3 |
| 600 kts. ≤ 4 kts/min | .3 kt |

Use the measurement after the third one minute check.

TESTER LEAK CHECK

| | |
|------------|--------|
| @15,000 ft | 8 ft |
| @300 kts | .2 kts |

7.38 153 10 MAR 98

Ray G. Julio P.

FIOP
80163

INSTALLED F/C/P
A/C 153
3-10-98

INSTRUMENT CALIBRATION DATA REDUCTION
412 TEST WING / TSIS
EDWARDS AIR FORCE BASE, CALIFORNIA
(805) 275-4356
DSN 525-4356

Nomenclature : AIRSPEED Work Order # : 45834
Type / Model : MOD-650 Requestor : WINTER
Part Number : 739U-03 Calibrated By : NAKATA
Serial Number : 11029 Press.Amb : 27.758
Manufacturer : KOLLSMAN Temp.Amb : 22.78

DATE CAL : 16 DEC 1997
REMARKS : CAL PER TPS SPEC.
STD USED : 3(211-993-047)

*** RAW DATA LISTING ***

Input Units : KNOTS
Output Units : KNOTS

| Pnt | Input | Reading Up | Correct Up | Reading Down | Correct Down | Hysteresis | Specs Fail |
|-----|---------|------------|------------|--------------|--------------|------------|------------|
| 1 | 50.000 | 50.000 | 0.000 | 50.000 | 0.000 | 0.000 | |
| 2 | 60.000 | 59.000 | 1.000 | 59.000 | 1.000 | 0.000 | |
| 3 | 70.000 | 69.000 | 1.000 | 69.500 | 0.500 | 0.500 | |
| 4 | 80.000 | 80.000 | 0.000 | 81.000 | -1.000 | 1.000 | |
| 5 | 90.000 | 93.000 | -3.000 | 93.000 | -3.000 | 0.000 | |
| 6 | 100.000 | 101.000 | -1.000 | 99.000 | 1.000 | 2.000 | |
| 7 | 110.000 | 110.000 | 0.000 | 110.000 | 0.000 | 0.000 | |
| 8 | 120.000 | 120.000 | 0.000 | 120.000 | 0.000 | 0.000 | |
| 9 | 130.000 | 130.000 | 0.000 | 130.000 | 0.000 | 0.000 | |
| 10 | 140.000 | 140.000 | 0.000 | 140.000 | 0.000 | 0.000 | |
| 11 | 150.000 | 149.000 | 1.000 | 149.000 | 1.000 | 0.000 | |
| 12 | 160.000 | 158.000 | 2.000 | 159.000 | 1.000 | 1.000 | |
| 13 | 170.000 | 168.000 | 2.000 | 168.000 | 2.000 | 0.000 | |
| 14 | 180.000 | 178.000 | 2.000 | 178.000 | 2.000 | 0.000 | |
| 15 | 190.000 | 188.000 | 2.000 | 189.000 | 1.000 | 1.000 | |
| 16 | 200.000 | 198.000 | 2.000 | 198.000 | 2.000 | 0.000 | |
| 17 | 210.000 | 208.000 | 2.000 | 208.000 | 2.000 | 0.000 | |
| 18 | 220.000 | 218.000 | 2.000 | 218.000 | 2.000 | 0.000 | |
| 19 | 230.000 | 228.000 | 2.000 | 228.500 | 1.500 | 0.500 | |
| 20 | 240.000 | 238.000 | 2.000 | 239.000 | 1.000 | 1.000 | |
| 21 | 250.000 | 248.000 | 2.000 | 248.500 | 1.500 | 0.500 | |
| 22 | 260.000 | 258.000 | 2.000 | 259.000 | 1.000 | 1.000 | |
| 23 | 270.000 | 268.000 | 2.000 | 269.000 | 1.000 | 1.000 | |
| 24 | 280.000 | 279.000 | 1.000 | 279.000 | 1.000 | 0.000 | |
| 25 | 290.000 | 289.000 | 1.000 | 290.000 | 0.000 | 1.000 | |
| 26 | 300.000 | 300.000 | 0.000 | 300.000 | 0.000 | 0.000 | |
| 27 | 310.000 | 310.000 | 0.000 | 310.000 | 0.000 | 0.000 | |
| 28 | 320.000 | 320.000 | 0.000 | 320.000 | 0.000 | 0.000 | |
| 29 | 330.000 | 330.000 | 0.000 | 330.000 | 0.000 | 0.000 | |
| 30 | 340.000 | 339.500 | 0.500 | 340.000 | 0.000 | 0.500 | |
| 31 | 350.000 | 349.000 | 1.000 | 350.000 | 0.000 | 1.000 | |
| 32 | 360.000 | 358.000 | 2.000 | 359.000 | 1.000 | 1.000 | |
| 33 | 370.000 | 368.000 | 2.000 | 369.000 | 1.000 | 1.000 | |
| 34 | 380.000 | 378.000 | 2.000 | 378.500 | 1.500 | 0.500 | |
| 35 | 390.000 | 388.000 | 2.000 | 388.500 | 1.500 | 0.500 | |
| 36 | 400.000 | 398.000 | 2.000 | 399.000 | 1.000 | 1.000 | |

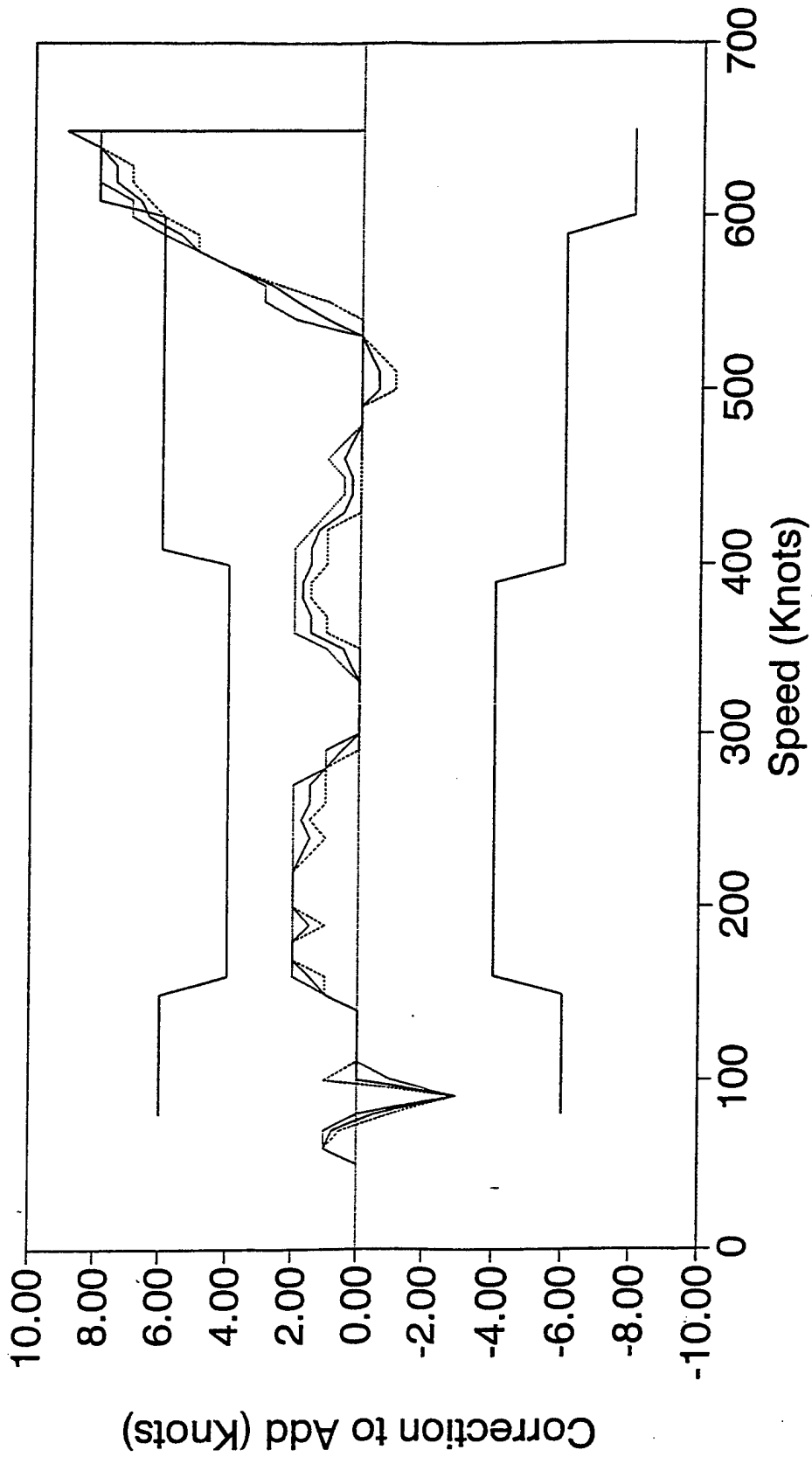
Work Order # : 45834
 Serial # : 11029

RAW DATA LISTING
 Input Units : KNOTS
 Output Units : KNOTS

| Pnt | Input | Reading Up | Correct Up | Reading Down | Correct Down | Hysteresis | Specs Fail |
|-----|---------|---------------|---------------|-----------------|-----------------|------------|---------------|
| 37 | 410.000 | 408.000 | 2.000 | 409.000 | 1.000 | 1.000 | |
| 38 | 420.000 | 418.500 | 1.500 | 419.000 | 1.000 | 0.500 | |
| 39 | 430.000 | 429.000 | 1.000 | 430.000 | 0.000 | 1.000 | |
| 40 | 440.000 | 439.500 | 0.500 | 440.000 | 0.000 | 0.500 | |
| 41 | 450.000 | 449.500 | 0.500 | 450.000 | 0.000 | 0.500 | |
| 42 | 460.000 | 459.000 | 1.000 | 460.000 | 0.000 | 1.000 | |
| 43 | 470.000 | 469.500 | 0.500 | 470.000 | 0.000 | 0.500 | |
| 44 | 480.000 | 480.000 | 0.000 | 480.000 | 0.000 | 0.000 | |
| 45 | 490.000 | 490.000 | 0.000 | 490.000 | 0.000 | 0.000 | |
| 46 | 500.000 | 500.000 | 0.000 | 501.000 | -1.000 | 1.000 | |
| 47 | 510.000 | 510.000 | 0.000 | 511.000 | -1.000 | 1.000 | |
| 48 | 520.000 | 520.000 | 0.000 | 520.500 | -0.500 | 0.500 | |
| 49 | 530.000 | 530.000 | 0.000 | 530.000 | 0.000 | 0.000 | |
| 50 | 540.000 | 538.000 | 2.000 | 540.000 | 0.000 | 2.000 | |
| 51 | 550.000 | 547.000 | 3.000 | 549.000 | 1.000 | 2.000 | |
| 52 | 560.000 | 557.000 | 3.000 | 557.500 | 2.500 | 0.500 | |
| 53 | 570.000 | 566.000 | 4.000 | 566.000 | 4.000 | 0.000 | |
| 54 | 580.000 | 575.000 | 5.000 | 575.000 | 5.000 | 0.000 | |
| 55 | 590.000 | 584.000 | 6.000 | 585.000 | 5.000 | 1.000 | |
| 56 | 600.000 | 593.000 | 7.000 | 594.000 | 6.000 | 1.000 | TPS |
| 57 | 610.000 | 603.000 | 7.000 | 603.500 | 6.500 | 0.500 | |
| 58 | 620.000 | 612.000 | 8.000 | 613.000 | 7.000 | 1.000 | |
| 59 | 630.000 | 622.000 | 8.000 | 623.000 | 7.000 | 1.000 | |
| 60 | 640.000 | 632.000 | 8.000 | 632.000 | 8.000 | 0.000 | |
| 61 | 650.000 | 641.000 | 9.000 | 641.000 | 9.000 | 0.000 | TO/TPS |

AIRSPEED CALIBRATION

12/16/1997 Work Order: 45834 Serial Number: 11029



Reading Up Reading Down Average

R/C/P
T38/153

T-38 ON AIRCRAFT INSTRUMENTATION CALIBRATION VALIDATION

10 MAR 98

| Alt (ft) | REAR COCKPIT Airspeed (knots) | Altitude S/N 9255 | | | Airspeed S/N 11931 | | | Mach S/N 15105 | | |
|----------|-------------------------------------|----------------------|-------|------|-----------------------|-------|------|-------------------|------|------|
| | | Up | Down | Hyst | Up | Down | Hyst | Up | Down | Hyst |
| 2300 | 150 ±5 | 2290 | 2300 | ±25 | 150 | 151.5 | ±2 | / | / | / |
| 5000 | 300 ±5 | 4980 | 4980 | ±25 | 298 | 299 | ±2 | / | / | / |
| 10000 | 450 ±8 | 9990 | 10000 | ±30 | 448 | 449 | ±3 | .8 | .8 | ±.02 |
| 15000 | 600 ±8 | 14980 | 14995 | ±30 | 598 | 598 | ±3 | 1.14 | 1.15 | ±.02 |
| 20000 | 500 ±8 | 19995 | 20000 | ±30 | 499 | 497 | ±3 | 1.04 | 1.05 | ±.02 |
| 25000 | 400 ±5 | 24950 | 24960 | ±40 | 399 | 398 | ±3 | 0.93 | .93 | ±.02 |
| 30000 | 350 ±5 | 29970 | 29990 | ±40 | 349 | 348.5 | ±3 | 0.91 | .91 | ±.02 |
| 35000 | 250 ±5 | 34970 | 34990 | ±40 | 249.5 | 249 | ±3 | 0.74 | .74 | ±.02 |
| 40000 | 200 ±5 | 39960 | 39970 | ±40 | 200 | 200 | ±3 | 0.67 | .66 | ±.02 |

Low Speed Accuracy Test

| Tester @ 3300ft | IND |
|-----------------|-------|
| 150 Kts | 151.5 |
| 160 | 160.5 |
| 170 | 170.5 |
| 180 | 180.5 |
| 190 | 190 |
| 200 | 200 |

R/GP
removed 3027

R/C/P
AK 153
03-10-98

INSTRUMENT CALIBRATION DATA REDUCTION
412 TEST WING / TSIS
EDWARDS AIR FORCE BASE, CALIFORNIA
(805) 275-4356
DSN 525-4356

Nomenclature : AIRSPEED Work Order # : 45782
Type / Model : MOD-650 Requestor : WINTER
Part Number : 739BU-03 Calibrated By : NAKATA
Serial Number : 11931 Press.Amb : 27.758
Manufacturer : KOLLSMAN Temp.Amb : 22.78

DATE CAL : 4 DEC 1997
REMARKS : CAL PER TPS SPEC.
STD USED : 3(211-993-047)

*** RAW DATA LISTING ***

Input Units : KNOTS
Output Units : KNOTS

| Pnt | Input | Reading Up | Correct Up | Reading Down | Correct Down | Hysteresis | Specs Fail |
|-----|---------|------------|------------|--------------|--------------|------------|------------|
| 1 | 50.000 | 54.000 | -4.000 | 55.000 | -5.000 | 1.000 | |
| 2 | 60.000 | 62.000 | -2.000 | 64.000 | -4.000 | 2.000 | |
| 3 | 70.000 | 72.000 | -2.000 | 74.000 | -4.000 | 2.000 | |
| 4 | 80.000 | 83.000 | -3.000 | 85.000 | -5.000 | 2.000 | |
| 5 | 90.000 | 94.000 | -4.000 | 96.000 | -6.000 | 2.000 | TO/TPS |
| 6 | 100.000 | 102.500 | -2.500 | 103.000 | -3.000 | 0.500 | |
| 7 | 110.000 | 111.000 | -1.000 | 112.000 | -2.000 | 1.000 | |
| 8 | 120.000 | 120.000 | 0.000 | 121.000 | -1.000 | 1.000 | |
| 9 | 130.000 | 130.000 | 0.000 | 131.500 | -1.500 | 1.500 | |
| 10 | 140.000 | 141.000 | -1.000 | 142.000 | -2.000 | 1.000 | |
| 11 | 150.000 | 150.000 | 0.000 | 152.000 | -2.000 | 2.000 | |
| 12 | 160.000 | 160.000 | 0.000 | 162.000 | -2.000 | 2.000 | |
| 13 | 170.000 | 171.000 | -1.000 | 171.500 | -1.500 | 0.500 | |
| 14 | 180.000 | 180.000 | 0.000 | 181.500 | -1.500 | 1.500 | |
| 15 | 190.000 | 190.000 | 0.000 | 191.000 | -1.000 | 1.000 | |
| 16 | 200.000 | 200.000 | 0.000 | 200.000 | 0.000 | 0.000 | |
| 17 | 210.000 | 210.000 | 0.000 | 210.000 | 0.000 | 0.000 | |
| 18 | 220.000 | 220.000 | 0.000 | 220.000 | 0.000 | 0.000 | |
| 19 | 230.000 | 229.000 | 1.000 | 230.000 | 0.000 | 1.000 | |
| 20 | 240.000 | 239.000 | 1.000 | 240.000 | 0.000 | 1.000 | |
| 21 | 250.000 | 249.000 | 1.000 | 249.000 | 1.000 | 0.000 | |
| 22 | 260.000 | 259.000 | 1.000 | 260.000 | 0.000 | 1.000 | |
| 23 | 270.000 | 269.500 | 0.500 | 270.000 | 0.000 | 0.500 | |
| 24 | 280.000 | 279.500 | 0.500 | 280.000 | 0.000 | 0.500 | |
| 25 | 290.000 | 289.000 | 1.000 | 289.000 | 1.000 | 0.000 | |
| 26 | 300.000 | 298.000 | 2.000 | 298.500 | 1.500 | 0.500 | |
| 27 | 310.000 | 308.000 | 2.000 | 308.000 | 2.000 | 0.000 | |
| 28 | 320.000 | 317.500 | 2.500 | 318.000 | 2.000 | 0.500 | |
| 29 | 330.000 | 327.000 | 3.000 | 328.000 | 2.000 | 1.000 | |
| 30 | 340.000 | 337.500 | 2.500 | 338.000 | 2.000 | 0.500 | |
| 31 | 350.000 | 348.000 | 2.000 | 348.500 | 1.500 | 0.500 | |
| 32 | 360.000 | 358.000 | 2.000 | 359.000 | 1.000 | 1.000 | |
| 33 | 370.000 | 369.000 | 1.000 | 370.000 | 0.000 | 1.000 | |
| 34 | 380.000 | 379.000 | 1.000 | 380.000 | 0.000 | 1.000 | |
| 35 | 390.000 | 388.500 | 1.500 | 389.000 | 1.000 | 0.500 | |
| 36 | 400.000 | 398.000 | 2.000 | 399.000 | 1.000 | 1.000 | |

Work Order # : 45782
 erial # : 11931

RAW DATA LISTING

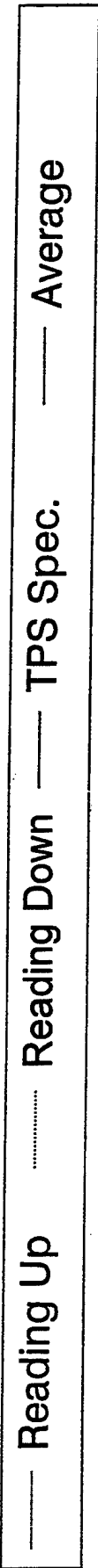
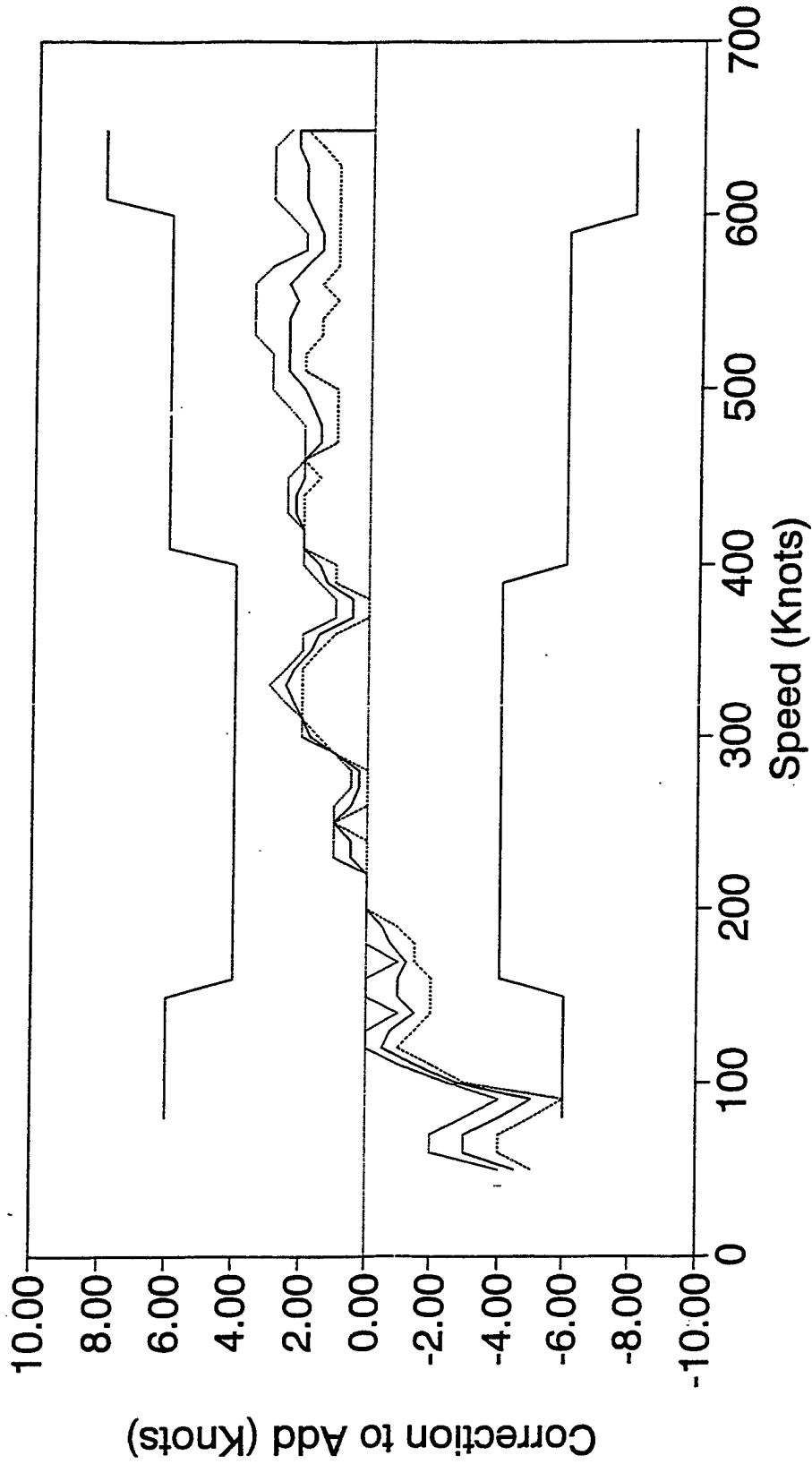
Input Units : KNOTS

Output Units : KNOTS

| <u>Pnt</u> | <u>Input</u> | <u>Reading Up</u> | <u>Correct Up</u> | <u>Reading Down</u> | <u>Correct Down</u> | <u>Hysteresis</u> | <u>Specs Fail</u> |
|------------|--------------|-----------------------|-----------------------|-------------------------|-------------------------|-------------------|-----------------------|
| 37 | 410.000 | 408.000 | 2.000 | 408.000 | 2.000 | 0.000 | |
| 38 | 420.000 | 418.000 | 2.000 | 418.000 | 2.000 | 0.000 | |
| 39 | 430.000 | 427.500 | 2.500 | 428.000 | 2.000 | 0.500 | |
| 40 | 440.000 | 437.500 | 2.500 | 438.000 | 2.000 | 0.500 | |
| 41 | 450.000 | 447.500 | 2.500 | 448.500 | 1.500 | 1.000 | |
| 42 | 460.000 | 458.000 | 2.000 | 458.000 | 2.000 | 0.000 | |
| 43 | 470.000 | 468.000 | 2.000 | 469.000 | 1.000 | 1.000 | |
| 44 | 480.000 | 478.000 | 2.000 | 479.000 | 1.000 | 1.000 | |
| 45 | 490.000 | 487.500 | 2.500 | 489.000 | 1.000 | 1.500 | |
| 46 | 500.000 | 497.000 | 3.000 | 499.000 | 1.000 | 2.000 | |
| 47 | 510.000 | 507.000 | 3.000 | 508.000 | 2.000 | 1.000 | |
| 48 | 520.000 | 517.000 | 3.000 | 518.000 | 2.000 | 1.000 | |
| 49 | 530.000 | 526.500 | 3.500 | 528.500 | 1.500 | 2.000 | |
| 50 | 540.000 | 536.500 | 3.500 | 538.500 | 1.500 | 2.000 | |
| 51 | 550.000 | 546.500 | 3.500 | 549.000 | 1.000 | 2.500 | |
| 52 | 560.000 | 556.500 | 3.500 | 558.500 | 1.500 | 2.000 | |
| 53 | 570.000 | 567.000 | 3.000 | 569.000 | 1.000 | 2.000 | |
| 54 | 580.000 | 578.000 | 2.000 | 579.000 | 1.000 | 1.000 | |
| 55 | 590.000 | 588.000 | 2.000 | 589.000 | 1.000 | 1.000 | |
| 56 | 600.000 | 597.500 | 2.500 | 599.000 | 1.000 | 1.500 | |
| 57 | 610.000 | 607.000 | 3.000 | 609.000 | 1.000 | 2.000 | |
| 58 | 620.000 | 617.000 | 3.000 | 619.000 | 1.000 | 2.000 | |
| 59 | 630.000 | 627.000 | 3.000 | 629.000 | 1.000 | 2.000 | |
| 60 | 640.000 | 637.000 | 3.000 | 638.500 | 1.500 | 1.500 | |
| 61 | 650.000 | 647.500 | 2.500 | 648.000 | 2.000 | 0.500 | |

AIRSPEED CALIBRATION

12/4/1997 Work Order: 45782 Serial Number: 11931



A/C TYPE:T-38A TAIL#: 8153

DATE:12MAR98

INSTRUMENT INSTALLATION DATES A/S:10MAR98 ALT:10MAR98
INSTRUMENT SERIAL NUMBERS A/S:11029 ALT:9815

INSTRUMENTATION CORRECTIONS

| VI | DVIC | HI | DHIC | TI | DTIC |
|-----|-------|-------|--------|-----|------|
| 50 | 0.0 | 0 | 0.0 | -50 | 0.0 |
| 60 | 1.0 | 1000 | 7.5 | -46 | 0.0 |
| 70 | 0.75 | 1500 | 2.5 | -42 | 0.0 |
| 80 | -0.5 | 1600 | 7.5 | -38 | 0.0 |
| 90 | -3.0 | 1800 | 5.0 | -34 | 0.0 |
| 100 | 0.0 | 2000 | -10.0 | -30 | 0.0 |
| 110 | 0.0 | 2200 | -10.0 | -26 | 0.0 |
| 120 | 0.0 | 2400 | 0.0 | -22 | 0.0 |
| 130 | 0.0 | 2600 | 0.0 | -18 | 0.0 |
| 140 | 0.0 | 2800 | -2.5 | -14 | 0.0 |
| 150 | 1.0 | 3000 | -17.5 | -10 | 0.0 |
| 160 | 1.5 | 4000 | -15.0 | -6 | 0.0 |
| 170 | 2.0 | 5000 | -15.0 | -2 | 0.0 |
| 180 | 2.0 | 6000 | -25.0 | 2 | 0.0 |
| 190 | 1.5 | 7000 | -22.5 | 6 | 0.0 |
| 200 | 2.0 | 8000 | -30.0 | 10 | 0.0 |
| 210 | 2.0 | 9000 | -35.0 | 14 | 0.0 |
| 220 | 2.0 | 10000 | -35.0 | 18 | 0.0 |
| 230 | 1.75 | 11000 | -30.0 | 22 | 0.0 |
| 240 | 1.5 | 12000 | -30.0 | 26 | 0.0 |
| 250 | 1.75 | 13000 | -22.5 | 30 | 0.0 |
| 260 | 1.5 | 14000 | -10.0 | 34 | 0.0 |
| 270 | 1.5 | 15000 | -5.0 | 38 | 0.0 |
| 280 | 1.0 | 16000 | 5.0 | 42 | 0.0 |
| 290 | 0.5 | 17000 | 15.0 | 46 | 0.0 |
| 300 | 0.0 | 18000 | 15.0 | 50 | 0.0 |
| 310 | 0.0 | 19000 | 15.0 | 54 | 0.0 |
| 320 | 0.0 | 20000 | 15.0 | 58 | 0.0 |
| 330 | 0.0 | 22000 | 15.0 | 62 | 0.0 |
| 340 | 0.25 | 24000 | 22.5 | 66 | 0.0 |
| 350 | 0.5 | 26000 | 30.0 | 70 | 0.0 |
| 360 | 1.5 | 28000 | 12.5 | 74 | 0.0 |
| 370 | 1.5 | 30000 | -15.0 | 78 | 0.0 |
| 380 | 1.75 | 32000 | -15.0 | 82 | 0.0 |
| 390 | 1.75 | 34000 | -77.5 | 86 | 0.0 |
| 400 | 1.5 | 36000 | -100.0 | 90 | 0.0 |
| 410 | 1.5 | 38000 | -145.0 | 94 | 0.0 |
| 420 | 1.25 | 40000 | -172.5 | 98 | 0.0 |
| 430 | 0.5 | 42000 | -165.0 | | |
| 440 | 0.25 | 44000 | -145.0 | | |
| 450 | 0.25 | 46000 | -110.0 | | |
| 460 | 0.5 | 48000 | -65.0 | | |
| 470 | 0.25 | 50000 | -12.5 | | |
| 480 | 0.0 | | | | |
| 490 | 0.0 | | | | |
| 500 | -0.5 | | | | |
| 510 | -0.5 | | | | |
| 520 | -0.25 | | | | |
| 530 | 0.0 | | | | |
| 540 | 1.0 | | | | |
| 550 | 2.0 | | | | |
| 560 | 2.75 | | | | |
| 570 | 4.0 | | | | |

| | |
|-----|------|
| 580 | 5.0 |
| 590 | 5.5 |
| 600 | 6.5 |
| 610 | 6.75 |
| 620 | 7.5 |
| 630 | 7.5 |
| 640 | 8.0 |
| 650 | 9.0 |

T-38 PARAMETERS (DAS Measurements)

| PARAMETER NAME | SOURCE | RANGE | RESOLUTION | APPROXIMATE MEASUREMENT UNCERTAINTY | SAMPLES PER SEC |
|------------------------------|------------------------|----------------|-------------|-------------------------------------|-----------------|
| Right Engine Fuel Flow | Transducer | 0.5 to 10 GPM | 0.05 GPM | 0.05 GPM | 4 |
| Right After Burner Fuel Flow | Transducer | 15 to 25 GPM | 0.05 GPM | 0.05 GPM | 4 |
| Right Fuel Used | Transducer - 20 Bit | 0 to 2000 gal | 0.01 gal | 0.1 GPM * | 4 |
| Left Engine Fuel Flow | Transducer | 0.5 to 10 GPM | 0.05 GPM | 0.05 GPM | 4 |
| Left After Burner Fuel Flow | Transducer | 15 to 25 GPM | 0.05 GPM | 0.05 GPM | 4 |
| Left Fuel Used | Transducer - 20 Bit | 0 to 2000 gal | 0.01 gal | 0.1 GPM * | 4 |
| Event Counter | Transducer | 0 to 99 Count | Discrete | N/A | 4 |
| Event Marker | Transducer | 0 or 1 | Discrete | N/A | 32 |
| Longitudinal Stick Force | Transducer | ±70 lbs | 0.17 lbs | 0.85 lbs | 32 |
| Lateral Stick Force | Transducer | ±35 lbs | 0.08 lbs | 0.5 lbs | 32 |
| Left Rudder Pedal Force | Transducer | 0 to -150 lbs | 0.15 lbs | 0.75 lbs | 32 |
| Right Rudder Pedal Force | Transducer | 0 to 150 lbs | 0.15 lbs | 0.75 lbs | 32 |
| θ - Pitch Angle | Transducer | ±70° | 0.06° | 0.3° | 32 |
| φ - Roll Angle | Transducer | ±175° | 0.35° | 1.75° | 32 |
| p - Roll Rate | Transducer | ±360°/sec | 0.7°/sec | 3.5°/sec | 32 |
| q - Pitch Rate | Transducer | ±20°/sec | 0.05°/sec | 0.25°/sec | 32 |
| r - Yaw Rate | Transducer | ±20°/sec | 0.05°/sec | 0.25°/sec | 32 |
| Total Pressure | Transducer | 0.4 to 38 PSIA | 0.0002 PSIA | 0.0038 PSIA | 32 |

T-38 PARAMETERS, (DAS Measurements)

| PARAMETER NAME | SOURCE | RANGE | RESOLUTION | APPROXIMATE MEASUREMENT UNCERTAINTY | SAMPLES PER SEC |
|-----------------------------|------------|----------------|-------------|-------------------------------------|-----------------|
| Static Pressure | Transducer | 0.4 to 38 PSIA | 0.0002 PSIA | 0.0038 PSIA | 32 |
| Right Engine RPM | Transducer | 25 to 102 %RPM | 0.15% | 0.75% | 32 |
| Left Engine RPM | Transducer | 25 to 102 %RPM | 0.15% | 0.75% | 32 |
| α - Angle of Attack | Transducer | -10 to 30° | 0.04° | 0.2° | 32 |
| β - Angle of Sideslip | Transducer | ±20° | 0.04° | 0.2° | 32 |
| Right Engine Fuel Temp | Transducer | -50° to 150° C | 0.3° C | 1.5° C | 32 |
| Left Engine Fuel Temp | Transducer | -50° to 150° C | 0.3° C | 1.5° C | 32 |
| Total Air Temperature | Transducer | -55° to 85° C | 0.11° C | 0.5° C | 32 |
| Normal Acceleration | Transducer | -3 to 6 g | 0.01 g | 0.05 g | 32 |
| Lateral Acceleration | Transducer | ±1 g | 0.002 g | 0.01 g | 32 |
| Longitudinal Acceleration | Transducer | ±1 g | 0.002 g | 0.01 g | 32 |
| Longitudinal Stick Position | Transducer | -4 to 7 in | 0.02 in | 0.1 in | 32 |
| Lateral Stick Position | Transducer | ±8 in | 0.02 in | 0.1 in | 32 |
| Rudder Pedal Position | Transducer | ±3 in | 0.01 in | 0.05 in | 32 |
| Stabilator Position | Transducer | -6° to 16° | 0.03° | 0.15° | 32 |
| Right Aileron Position | Transducer | -25° to 35° | 0.08° | 0.4° | 32 |
| Left Aileron Position | Transducer | -35° to 25° | 0.08° | 0.4° | 32 |
| Rudder Position | Transducer | ±30° | 0.07° | 0.35° | 32 |
| IRIG Time | | | | | 32 |
| Hot Mike | | | | | |

* Fuel Used is derived from Fuel Flow. It's error is therefore a function of time.

APPENDIX C
RANGE FACTOR CALCULATIONS

RANGE FACTOR CALCULATIONS

GENERAL

The T-38A data acquisition system (DAS) was used to collect data, and the Test Pilot School (TPS) Aydin was used to extract the data from the DAS 1/4-inch tape. These data were loaded into a spreadsheet for data reduction. The theory and equations were all from the USAF TPS Cruise textbook (Reference 8).

The start and end values for pressure altitude (Hc), M, and ambient air temperature (T_a) were obtained from the DAS. The average value for each test point was derived. From the DAS pressure altitude, the test team derived the ambient air pressure ratio (δ_t) with the following equation:

$$\delta_t = (1 - 6.87558(10)^{-6} Hc)^{5.2559} \quad (C1)$$

The standard altitude ambient air pressure ratio (δ_s) was likewise found by:

$$\delta_s = (1 - 6.87558(10)^{-6} Hcs)^{5.2559} \quad (C2)$$

using the standard day pressure altitude (Hc_s). The ambient air temperature ratio (θ_t) was found from:

$$\theta_t = \frac{T_a}{288.15} \quad (C3)$$

where T_a was in degrees Kelvin.

The standard altitude ambient air temperature ratio (θ_s) was likewise found by:

$$\theta_s = \frac{T_{as}}{288.15} \quad (C4)$$

using the standard day ambient air temperature (T_{as}) for that pressure altitude. The standardized average normalized fuel flow (\dot{W}_{fs}) was then defined as:

$$\dot{W}_{fs} = \dot{W}_{ft} \frac{\delta_s \sqrt{\theta_s}}{\delta_t \sqrt{\theta_t}} \quad (C5)$$

where:

\dot{W}_{fs} = standardized, normalized average fuel flow, and

\dot{W}_{ft} = test day average fuel flow, corrected for fuel heating value. This was simply the measured fuel flow times the fuel heating value ratio as determined by Phillips Lab.

From this, the test team computed the standardized specific range (SR_s):

$$SR_s = \frac{Ma_o \sqrt{\theta_s}}{\dot{W}_{fs}} \quad (C6)$$

where:

SR_s = standardized specific range, NAM per pound,

M = Mach number, and

A_o = speed of sound, sea level standard day, 661.48 NAM per hour.

Then from this, the test team computed range factor (RF) with:

$$RF = SR_s W_s \quad (C7)$$

where:

W_s = standard weight.

CORRECTIONS TO DATA

The HAVE SLICK (Reference 1) program showed specific range improvements of about 1 percent. The anticipated change in range factor due to the polish was expected to be equally small (1 to 2 percent). In order to maximize the likelihood of detecting this small change, standardization to a reference set of conditions (pressure altitude and

M) and corrections for specific excess thrust and specific range due to M variations were applied to the data. Data from each 3-minute data point were reduced to a single average data point.

To minimize trim drag effects, all points were flown as closely as possible to the same cg (18 percent mean aerodynamic chord [MAC]). However, due to lack of available data on trim drag effects due to cg, no corrections were made for actual cg variation from 18 percent MAC.

Standardization To A Reference Set Of Conditions:

For the statistical sample, the test team estimated that at least 25 baseline and 25 treated data points had to be compared at the same flight conditions. The aircraft gross weight to ambient air pressure ratio (W/δ) flight test technique permitted the data to be gathered at a constant W/δ . As fuel was consumed (decreasing aircraft gross weight) a constant W/δ was maintained by flying at progressively at higher altitudes (decreasing ambient air pressure).

Correction For Specific Excess Thrust:

The cruise test point began with a trim shot, where the desired test parameters were set, including throttle position. A small error in throttle setting would cause an excess thrust (P_s) which would cause a change in altitude, velocity, or a combination of both. Once the test point started, small climbs or descents were corrected with minor pitch adjustments. However, any velocity changes were dealt with postflight by correcting for the specific excess thrust. By definition,

$$P_s = \dot{H} + \frac{V_t}{g} \dot{V}_t \quad (C8)$$

where:

\dot{H} = time rate of change of tapeline altitude, feet per second,

V_t = true airspeed, feet per second,

\dot{V}_t = time rate of change of true airspeed, feet per second squared, and longitudinal flight path acceleration (n_x), measured in g's was:

$$n_x = \frac{P_s}{V_t} \quad (C9)$$

Since excess thrust (F_{ex}) was defined by:

$$F_{ex} = n_x GW \quad (C10)$$

where:

GW = aircraft average gross weight for the test point.

Excess fuel flow (FF_{ex}) was defined in terms of F_{ex} and thrust specific fuel consumption (TSFC) by:

$$FF_{ex} = F_{ex} (TSFC) \quad (C11)$$

For the T-38A, let TSFC = 1.00 lb/hr/lb.

Making the appropriate substitutions, the test team arrived at:

$$FF_{ex} = \frac{(P_s)(GW)(TSFC)}{V_t} \quad (C12)$$

This value was subtracted from the measured fuel flow value to account for excess power to give corrected fuel flow (FF_{corr}):

$$FF_{corr} = FF_{test} - FF_{ex} \quad (C13)$$

Corrections For Specific Range:

Mach number error, in the context of this report, was the change in drag due to flying a test point at an off-target M. Any variation in M would change the actual drag experienced by the aircraft. This slight change in M would cause a change in the drag and, therefore, fuel flow. To correct for M variations, the test team used specific range data presented in Northrop Corporation NORAIR Reports NOR 60-35 and NOR 62-34 (References 9 and 10). These reports contained flight test and wind tunnel derived aerodynamic coefficients and aircraft performance estimates. Specific range versus M plots gave a local slope at the test M. This local slope was used to find a specific range correction due to the error in M. The measured specific range was corrected and then used to find a corrected range factor.

APPENDIX D
TEST POINTS AND FLIGHT ENVELOPE

Test Aircraft: T-38A SN# 68-8153
 Test Date: 16 March 1998 to 9 April 1998
 Configuration: Cruise (Gear, Flaps, and Speed Brakes Retracted)
 Crew Weight: Varied (see Form F's)
 Engines: J85-GE-5
 LOX: 8.5 lifters
 Anti-Ice & Canopy Defog: Off
 Pitot-Heat & Air Conditioning: On
 Ballast: 60 lbs at Station 504
 Fuel: JP-8

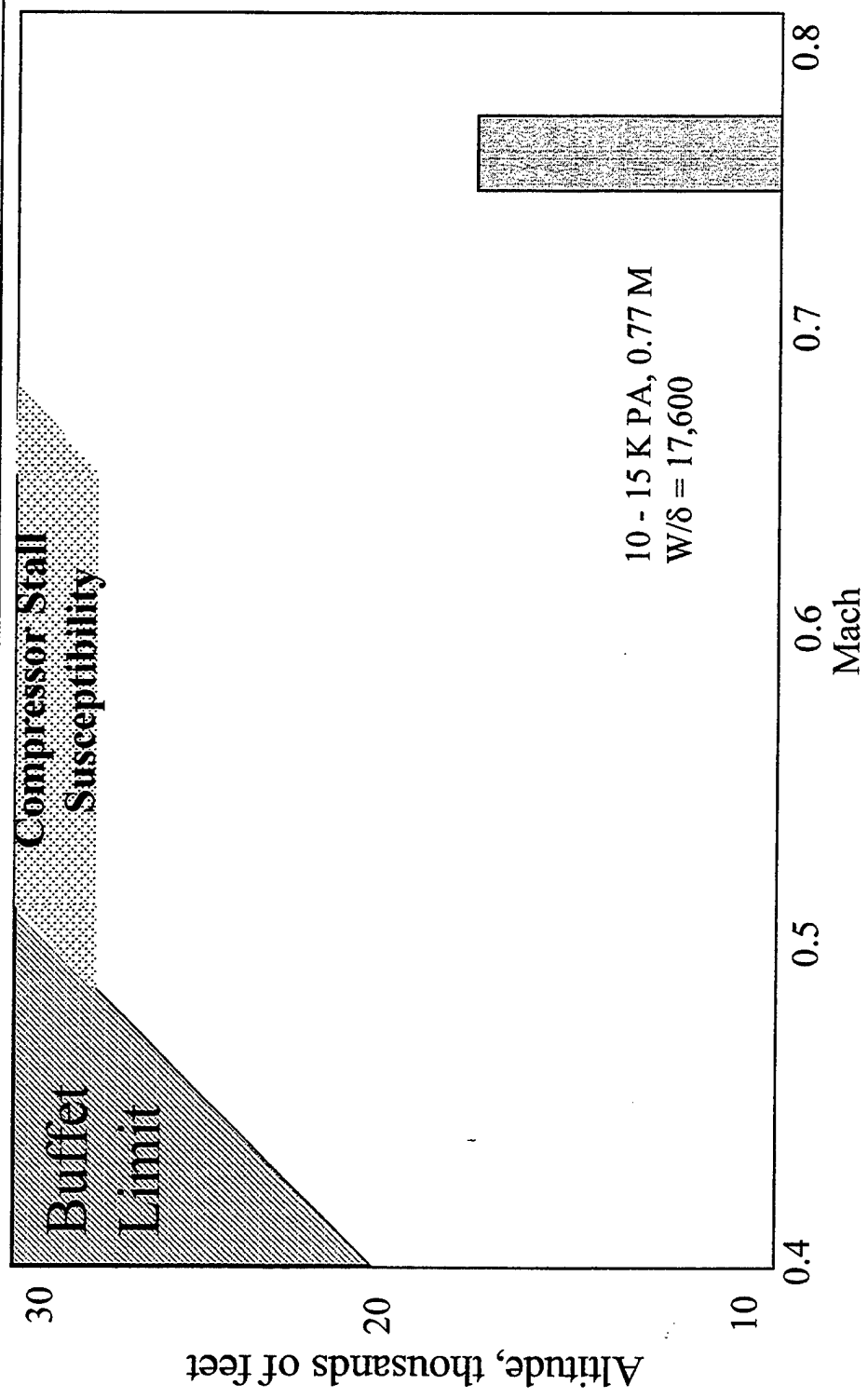


Figure D1 HAVE SLICKER Test Point and Flight Envelope

APPENDIX E
ERROR ANALYSIS AND TEST POINT SELECTION

ERROR ANALYSIS AND TEST POINT SELECTION

GENERAL

The basis for a change in range factor due to an application of Racer's Edge polish was a change in drag. The test team did not have the capability to accurately measure the drag of the test aircraft. However, range factor was determined from measurable quantities available from the currently available instrumentation system. This appendix gives a general discussion of aircraft drag and its relationship to range factor, as well as quantifying drag changes, the drag savings mechanism, selecting the test conditions, and corrections to the data.

AIRCRAFT DRAG AND RANGE FACTOR

Aircraft Drag:

Total aircraft drag (C_D) could be expressed as:

$$C_D = C_{D_i} + C_{D_f} + C_{D_p} + C_{D_b}$$

where:

- C_{D_i} = coefficient of drag due to lift,
- C_{D_f} = coefficient of skin friction drag,
- C_{D_p} = coefficient of pressure drag, and
- C_{D_b} = coefficient of base drag.

Northrop conducted both wind tunnel and flight tests to determine the drag values throughout the flight envelope (Reference 11). Table E1 summarizes the composition of the different drag components at one of the flight conditions ($W/\delta=17,600$ pounds, gross weight = 12,500 to 9,500 pounds, Mach number = 0.77, pressure altitude = 9,500 to 17,500 feet).

Range Factor:

Range factor was calculated from the following:

$$RF = SR * GW \quad (E1)$$

where:

- RF = range factor, nautical air miles (NAM),
- SR = specific range (NAM/lb), and

GW = aircraft gross weight, (lb),

$$SR = V_t / FF_{ec} \quad (E2)$$

where:

V_t = true airspeed, (kt),

FF_{ec} = energy corrected fuel flow, (lbs/hr), and

$$FF_{ec} = FF_m * FHVR \quad (E3)$$

where:

FF_m = measured volumetric fuel flow, (lb/hr),

FHVR = fuel heat value ratio, (dimensionless),

$$FF_m = FF_v * r_f(F_t) \quad (E4)$$

where:

FF_v = measured volumetric fuel flow, (gal/hr),
and

$r_f(F_t)$ = fuel density as a function of fuel temperature, F_t , (lb/gal).

The energy corrected fuel flow (FF_{ec}) was the measured volumetric fuel flow (FF_v) times the fuel density (a function of fuel temperature) all corrected for variations in fuel heat value ratio (FHVR).

AIRCRAFT DRAG AND RANGE FACTOR RELATIONSHIP

For each 3-minute stable point, the following assumptions were made:

1. Thrust and drag were constant,
2. Thrust equals drag after correcting for energy height through excess thrust corrections,
3. Volumetric fuel flow was constant,
4. Fuel temperature was constant,
5. Aircraft gross weight was constant, and
6. Thrust was a function of mass fuel flow.

Table E1
DRAG COEFFICIENTS

- Lift Coefficient = 0.14
- Mach Number = 0.72
- Pressure Altitude = 13,500 ft

| Component of Drag | Coefficient | Percent of Total |
|-------------------------------|-------------|------------------|
| Drag due to Lift, C_{D_i} | 0.00200 | 12.2 |
| Skin Friction Drag, C_{D_f} | 0.01200 | 73.4 |
| Pressure Drag, C_{D_p} | 0.00250 | 15.3 |
| Base Drag, C_{D_b} | -0.00015 | -0.9 |
| Total | 0.01635 | 100.0 |

From these assumptions and the previous equations, it was assumed that: range factor (RF) was inversely proportional to drag.

The test team concluded that changes in range factor were inversely proportional to changes in drag. Therefore, changes in range factor were used as the basis for determining changes in drag after application of the polish.

QUANTIFYING DRAG CHANGES

Accurate, absolute values of range factor, or drag, were not critical; only relative changes were required to show an improvement. Relative changes in range factor were used to quantify any changes in drag.

REDUCING SKIN FRICTION DRAG

Test point selection was made on the assumption that an improvement in range factor would most likely come in the form of reduced skin friction drag. Two methods existed for reducing skin friction drag. The first was to delay the transition from laminar to turbulent boundary layer. However, since the T-38A aircraft was already sufficiently smooth and the flight Reynolds number was high, the transition point was most likely fixed by the pressure gradient and free-stream turbulence. The other method was to reduce the turbulent boundary layer skin friction drag by reducing the surface roughness.

Protuberances Outside the Laminar Sublayer:

At the test flight conditions, the boundary layer over the entire T-38A was almost completely turbulent (Reference 12). According to Schlichting (Reference 12) "in the case of the turbulent boundary layer roughness has no effect, and the wall is hydraulically smooth if all protuberances are contained within the laminar sublayer." However, Schlichting (Reference 12) also stated "in most practical applications connected with the flat plate (e.g. ships, lifting surfaces of an aircraft, turbine blades) the wall cannot be considered hydraulically smooth." Therefore, the T-38A aircraft was not hydraulically smooth and had some roughness associated with protuberances outside the laminar sublayer of the turbulent boundary layer.

Admissible Roughness:

According to Schlichting (Reference 12):

the amount of roughness which is considered "admissible" in engineering applications was that maximum height of individual roughness elements which caused no increase in drag compared to a smooth wall.

In layman's terms, the admissible roughness was the maximum height of surface elements that did not increase drag over that of a perfectly smooth wall. For practical purposes, if a surface had a roughness larger than the admissible roughness (protuberances outside the laminar sublayer), the drag increased. If the roughness was less than the admissible roughness (hydraulically smooth), then the drag was no more than that of a perfectly smooth surface.

Figure E1 shows a hydraulically smooth surface. Notice how the surface protuberances lay within the laminar sublayer, thus, was not contributing to the drag of the hydraulically smooth surface. Figure E2 shows a surface with increased drag due to surface roughness. Notice that the surface protuberances extended beyond the region of the laminar sublayer, thereby increasing skin friction drag.

In order to characterize a reduction in skin friction drag due to a polish application, the aircraft was operated in a region where the admissible roughness was smaller than the roughness of the surface. This caused the baseline test flights to be conducted with the protuberances penetrating through the laminar sublayer, into the turbulent

boundary layer. For drag reduction to occur, the polish must reduce the height of the protuberances (by filling in the gaps between the protuberances, effectively reducing their height above the skin surface) such that they did not penetrate beyond the laminar sublayer. The roughness, or average root mean squared height of the surface protuberances, of the T-38A aircraft was measured as 0.26 mils (0.00026 inches). The admissible roughness was independent of the length of the surface; it was determined solely by the velocity and kinematic viscosity (i.e., it was a function of the Reynolds number):

$$K_{adm} \leq 100 * \nu / U_{\infty} \quad (E5)$$

where:

ν = viscosity, and

U_{∞} = the free stream velocity.

In order to obtain an admissible roughness less than 0.00026 inches, the aircraft was operated in a region of high freestream velocity and low viscosity (the lower right corner of the flight envelope). A plot of admissible roughness is shown in Figure E3.

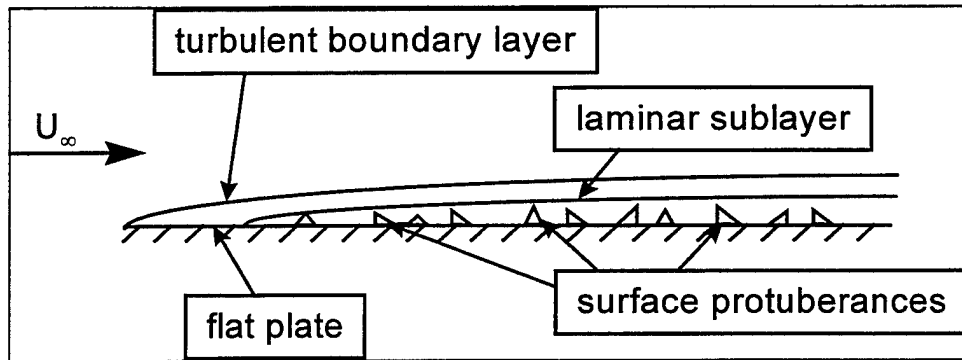


Figure E1 Hydraulically Smooth Surface

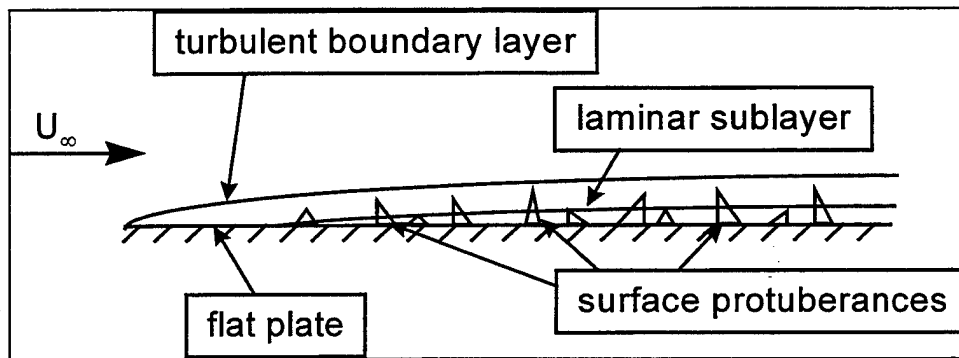


Figure E2 Nonhydraulically Smooth Surface

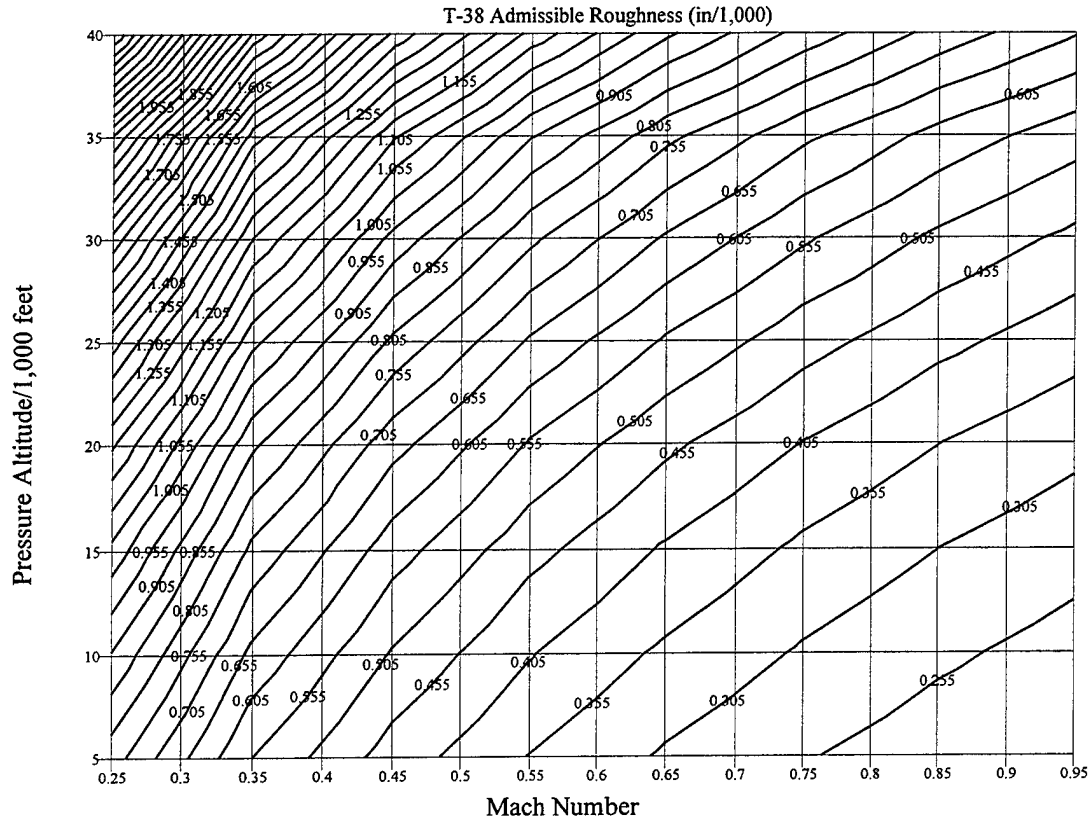


Figure E3 Plot of Admissible Roughness

SELECTING THE TEST CONDITIONS

Selecting the flight test W/δ and Mach number involved both the admissible roughness and expected variations in drag due to airspeed variations. First, the test point had to be where the admissible roughness was less than the baseline roughness of the T-38A aircraft. Therefore, all of the test W/δ data points had to have an admissible roughness of 0.00026 inches or less. When this was true, the protuberances were larger than the laminar sublayer of the boundary layer. A W/δ of 17,600 pounds at 0.77 Mach number satisfied these conditions.

Sensitivity Analysis:

A sensitivity analysis was performed to estimate the uncertainties in range factor between the baseline

flights and the treated flights. The analysis was performed using the following equation:

$$Error_{RMS} = \Delta s = \sqrt{\left(\frac{\partial s}{\partial u_1} \Delta u_1\right)^2 + \left(\frac{\partial s}{\partial u_2} \Delta u_2\right)^2 + \dots} \quad (E6)$$

This equation defined the uncertainty in s as Δs , where s was a function of u_1 , u_2 , etc. Repeated applications of Equation 6 were made on Equations 7 through 28 using the conservative representative values listed in Tables E2 through E15. (If a range of values for a parameter was available, the most conservative values were used to ensure the uncertainty was worst case.)

Fuel Mass:

$$FFm = FF_v * \rho \tag{E11}$$

where:

FFm = mass fuel flow, (lb/min),
 FF_v = volumetric fuel flow, (gal/min), and
 ρ = fuel density, (lb/gal).

Table E4
 MASS FUEL FLOW DERIVATION AND UNCERTAINTY VALUES

| Parameter | Expected Value | Source of Data | Uncertainty | Source of Uncertainty |
|-----------------|----------------|-------------------------------|----------------|-----------------------|
| FFm | 33.8352 lb/min | Equation 11 | 0.1679 lb/min | Equation 6 |
| FF _v | 4.9001 gal/min | Data acquisition system (DAS) | 0.0183 gal/min | DAS |

- Notes: 1. FFm - mass fuel flow
 2. FF_v - volumetric fuel flow
 3. DAS - data acquisition system

Altitude and Hdot:

$$H = 1 - (P/14.696)^{0.190255} / (6.87558 * 10^{-6}) \tag{E12}$$

$$Hdot = (H_f - H_i) / \text{time} \tag{E13}$$

where:

H = pressure altitude, (ft),
 Hdot = time rate of change in altitude, (ft/sec),
 H_f = final altitude, (ft),
 H_i = initial altitude, (ft), and
 time = time of cruise point, (sec).

Table E5
 ALTITUDE AND HDOT DERIVATION AND UNCERTAINTY VALUES

| Parameter | Expected Value | Source of Data | Uncertainty | Source of Uncertainty |
|----------------|----------------|---|--------------|-----------------------|
| H | 13,489 ft | Equation 12 | 10.830 ft | Equation 6 |
| Hdot | 1.111 ft/sec | Data Band Tolerance | 0.085 ft/sec | Equation 6 |
| H _f | 13,589 ft | Data Band Tolerance | 10.830 ft | Equation 6 |
| H _i | 13,389 ft | Data Band Tolerance | 10.830 ft | Equation 6 |
| time | 180 sec | t(H _f) - t(H _i) | none | N/A |

- Notes: 1. H - pressure altitude
 2. Hdot - time rate of change in altitude
 3. H_f - final altitude
 4. H_i - initial altitude
 5. time - time of cruise point
 6. N/A - not applicable

True Airspeed and Vdot:

$$T = T_r / 0.995 * (1 + 0.2 * M^2)^{-1} \tag{E14}$$

$$V_t = M * 38.967 * T^{0.5} \tag{E15}$$

$$V_{\dot{t}} = (V_{tf} - V_{ti}) / \text{time} \tag{E16}$$

where:

- T_r = recovery temperature, (deg K),
- T = ambient air temperature, (deg K),
- V_t = true airspeed, (ft/sec),
- $V_{\dot{t}}$ = time rate of change in true airspeed, ([ft/sec]/sec),
- V_{tf} = final true airspeed, (ft/sec), and
- V_{ti} = initial true airspeed, (ft/sec).

Table E6
TRUE AIRSPEED AND VDOT DERIVATION AND UNCERTAINTY VALUES

| Parameter | Expected Value | Source of Data | Uncertainty | Source of Uncertainty |
|---------------|----------------|-------------------------------|---------------|-----------------------|
| T_r | 287.31 deg K | Data acquisition system (DAS) | 0.5 deg K | DAS |
| T | 261.4 deg K | Equation 14 | 0.411 deg K | Equation 6 |
| V_t | 769.7 ft/sec | Equation 15 | 0.802 ft/sec | Equation 6 |
| $V_{\dot{t}}$ | 0.022 ft/sec | Data Band Tolerance | 0.0063 ft/sec | Equation 6 |
| V_{tf} | 771.7 ft/sec | Data Band Tolerance | 0.802 ft/sec | Equation 6 |
| V_{ti} | 767.7 ft/sec | Data Band Tolerance | 0.802 ft/sec | Equation 6 |

- Notes:
1. T_r - recovery temperature
 2. T - ambient air temperature
 3. V_t - true airspeed
 4. $V_{\dot{t}}$ - time rate of change in true airspeed
 5. V_{tf} - final true airspeed
 6. V_{ti} - initial true airspeed
 7. K - Kelvin

Specific Excess Power:

$$P_s = H_{\dot{t}} + V_t / g * V_{\dot{t}} \tag{E17}$$

where:

- P_s = specific excess power, (ft/sec), and
- g = acceleration due to gravity, (ft/sec²).

Table E7
EXCESS POWER DERIVATION AND UNCERTAINTY VALUES

| Parameter | Expected Value | Source of Data | Uncertainty | Source of Uncertainty |
|-----------|---------------------------|----------------|----------------|-----------------------|
| P_s | 1.6372 ft/sec | Equation 17 | 0.17304 ft/sec | Equation 6 |
| g | 32.18 ft/sec ² | constant | none | constant |

- Notes:
1. P_s - specific excess power
 2. g - acceleration due to gravity

Longitudinal Acceleration:

$$n_x = P_s/V_t \quad (E18)$$

where:

n_x = longitudinal acceleration in the flight path axes, (dimensionless).

Table E8
LONGITUDINAL ACCELERATION DERIVATION AND UNCERTAINTY VALUES

| Parameter | Expected Value | Source of Data | Uncertainty | Source of Uncertainty |
|-----------|----------------|----------------|-------------|-----------------------|
| n_x | 0.002127 | Equation 18 | 0.00022 | Equation 6 |

Note: n_x - longitudinal acceleration in the flight path axes

Gross Weight:

$$GW = W_{empty} + V_{olf} \cdot \rho - W_{fuelused} \quad (E19)$$

where:

GW = total gross weight at the test point, (lbs),
 W_{empty} = aircraft empty gross weight plus crew weight, (lbs),
 V_{olf} = volumetric fuel prior to engine start, (gal), and
 $W_{fuelused}$ = weight of fuel used since engine start, (lbs).

Table E9
GROSS WEIGHT DERIVATION AND UNCERTAINTY VALUES

| Parameter | Expected Value | Source of Data | Uncertainty | Source of Uncertainty |
|----------------|----------------|-----------------------|----------------|-----------------------|
| GW | 10,774.4 lb | Equation 19 | 43.68 lb | Equation 6 |
| W_{empty} | 8,981 lb | scales | 0 ¹ | constant |
| V_{olf} | 480.3 gal | fuel truck | 2.0 gal | estimated |
| $W_{fuelused}$ | 1523 lb | estimate ² | 40 lb | estimated |

- Notes: 1. GW - total gross weight at the test point
2. W_{empty} - aircraft empty gross weight plus crew weight
3. V_{olf} - volumetric fuel prior to engine start
4. $W_{fuelused}$ - weight of fuel used since engine start

¹ Weight and balance stand was assumed to have zero error

² Estimate based on 45 minutes into flight at the average fuel flow, (FFm) (See Table E4).

Excess Thrust:

$$F_{ex} = n_x \cdot GW \quad (E20)$$

where:

F_{ex} = excess thrust, (lbs).

Table E10
EXCESS THRUST DERIVATION AND UNCERTAINTY VALUES

| Parameter | Expected Value | Source of Data | Uncertainty | Source of Uncertainty |
|-----------------|----------------|----------------|-------------|-----------------------|
| F _{ex} | 22.92 lb | Equation 20 | 2.424 lb | Equation 6 |

Note: F_{ex} - excess thrust

Excess Mass Fuel Flow:

$$FF_{ex} = F_{ex} * TSFC / 3600 \quad (E21)$$

where:

FF_{ex} = excess mass fuel flow, (lb/sec), and
TSFC = thrust specific fuel consumption, (1/hr).

Table E11
EXCESS MASS FUEL FLOW DERIVATION AND UNCERTAINTY VALUES

| Parameter | Expected Value | Source of Data | Uncertainty | Source of Uncertainty |
|------------------|-----------------|----------------|----------------|-----------------------|
| FF _{ex} | 0.006367 lb/sec | Equation 21 | 0.00068 lb/sec | Equation 6 |
| TSFC | 1.0 1/hr | constant | 0.01 1/hr | estimated |

Notes: 1. FF_{ex} - excess mass fuel flow
2. TSFC - thrust specific fuel consumption

Correction to Mass Fuel Flow:

$$FF_{mcor} = FF_m - FF_{ex} \quad (E22)$$

where:

FF_{mcor} = corrected mass fuel flow, (lb/sec).

Table E12
CORRECTION TO MASS FUEL FLOW DERIVATION AND UNCERTAINTY VALUES

| Parameter | Expected Value | Source of Data | Uncertainty | Source of Uncertainty |
|--------------------|----------------|----------------|----------------|-----------------------|
| FF _{mcor} | 0.55755 lb/sec | Equation 22 | 0.00288 lb/sec | Equation 6 |

Note: FF_{mcor} - corrected mass fuel flow

Standard Day Correction to Corrected Mass Fuel Flow:

$$\delta_t = (1 - 6.87558 * 10^{-6} * H)^{(5.2559)} \quad (E23)$$

$$\theta_t = T / 288.15 \quad (E24)$$

$$\delta_s = (1 - 6.87558 * 10^{-6} * H_s)^{(5.2559)} \quad (E25)$$

$$\theta_s = T_s / 288.15 \quad (E26)$$

$$FF_{mcor,s} = FF_m * (\delta_s / \delta_t) * (\theta_s / \theta_t)^{0.5} \quad (E27)$$

where:

- δ_t = test ambient air pressure ratio,
- θ_t = test ambient air temperature ratio,
- H_s = standardization altitude, (ft),
- δ_s = standard altitude ambient air pressure ratio,
- T_s = standardization ambient air temperature, (deg K),
- θ_s = standard altitude ambient air temperature ratio, and
- $FF_{mcor,s}$ = standardized corrected mass fuel flow, (lb/sec).

Table E13
STANDARD DAY CORRECTION TO CORRECTED MASS FUEL FLOW DERIVATION
AND UNCERTAINTY VALUES

| Parameter | Expected Value | Source of Data | Uncertainty | Source of Uncertainty |
|---------------|----------------|----------------|----------------|-----------------------|
| δ_t | 0.59956 | Equation 23 | 0.000050 | Equation 6 |
| θ_t | 0.906717 | Equation 24 | 0.001430 | Equation 6 |
| δ_s | 0.59929 | Equation 25 | 0 | N/A |
| H_s | 13,500 ft | N/A | 0 | Constant |
| θ_s | 0.90728 | Equation 26 | 0 | N/A |
| T_s | 261.433 deg K | atmos table | 0 | N/A |
| $FF_{mcor,s}$ | 0.55734 lb/sec | Equation 27 | 0.00088 lb/sec | Equation 6 |

- Notes:
1. δ_t - test ambient air pressure ratio
 2. θ_t - test ambient air temperature ratio
 3. δ_s - standard altitude ambient air pressure ratio
 4. H_s - standardization altitude
 5. θ_s - standard altitude ambient air temperature ratio
 6. T_s - standardization ambient air temperature
 7. $FF_{mcor,s}$ - standardized, corrected mass fuel flow
 8. N/A - not applicable

Fuel Heating Value Ratio:

$$FHVR = LHV_t/LHV_s \quad (E28)$$

where:

- $FHVR$ = fuel heat value ratio,
- LHV_t = lower heating value of the fuel sample, (Btu/lb), and
- LHV_s = standard lower heating value, (Btu/lb).

Table E14
FUEL LOWER HEATING VALUE RATIO DERIVATION AND UNCERTAINTY VALUES

| Parameter | Expected Value | Source of Data | Uncertainty | Source of Uncertainty |
|-----------|----------------|----------------|-------------|-----------------------|
| FHVR | 1.0054 | Equation 28 | 0.00385 | Equation 6 |
| LHV_t | 18,500 Btu/lb | Phillips Lab | 50 Btu/lb | Phillips Lab estimate |
| LHV_s | 18,400 Btu/lb | Phillips Lab | 50 Btu/lb | Phillips Lab estimate |

- Notes:
1. $FHVR$ - fuel heat value ratio
 2. LHV_t - lower heating value of the fuel sample
 3. LHV_s - standard lower heating value
 4. Btu - British thermal unit

Range Factor:

$$RF = Vt * GW/FF_{mcor,s}/FHVR \quad (E29)$$

where:

RF = range factor, NAM.

Table E15
RANGE FACTOR DERIVATION AND UNCERTAINTY VALUES

| Parameter | Expected Value | Source of Data | Uncertainty | Source of Uncertainty |
|-----------|----------------|----------------|-------------|-----------------------|
| RF | 2, 436 NAM | Equation 29 | 14 NAM | Equation 6 |

- Notes: 1. RF - range factor
2. NAM - nautical air mile

Tracking the significant digits throughout all of the calculations yields four significant digits in the range factor. Keeping two digits in the uncertainty yields an instrumentation uncertainty of 0.6 percent (14/2436*100).

APPENDIX F
WEIGHT AND BALANCE

HAVE SLICKER WEIGHT AND BALANCE TEST DATA

Table F1
FUELING DATA

| Desired Fuel Weight (Dispensed/Total) | Fuel Sample Density/Temperature | Fuel Truck Counter (Indicated/Actual) | Truck Dispensed Fuel Weight (Calculated) | Truck Error (Calculated Fuel Weight vs Scale Measured Change) |
|--|------------------------------------|---|--|---|
| Zero | -- | -- | -- | -- |
| 900 lb/900 | 6.76/14 deg C | 133.1/133.4 | 902 | -16 |
| 1,300 lb/2,200 | 6.75/15 deg C | 192.6/192.3 | 1,298 | +18 |
| 3,500 lb/3,500 | 6.75/17 deg C | 192.6/192.1 | 1,297 | -1 |
| 3,982 lb/Full at 25 psi | 6.74/19 deg C | 71.5/82.8 | 558 | -- |
| | | Total actual 600.6 gal | Total 4,055 | -- |

Note: '---' - not applicable

Table F2
WEIGHT AND BALANCE DATA

| Desired Total Fuel Weight (lbs) | Pitch Attitude | Aircraft Fuel Quantity Indications | Aircraft Total Fuel (Indicated) | Total Indicated Fuel vs Scale Weight Error | Aircraft Weight (Scale Reading) | Fuel Weight Change | Center of Gravity Inches/Pct MAC |
|---------------------------------------|-------------------|---------------------------------------|------------------------------------|--|------------------------------------|-----------------------|-------------------------------------|
| Zero | Level | 0/0 | 0 | --- | 8,477 | --- | --- |
| 900 | Level | 390/390 | 780 | -138 | 9,395 | 918 | 354.97/25.60 |
| | 5 deg | 390/400 | change +10 | --- | 9,396 | --- | 356.06/26.80 |
| 2,200 | Level | 990/1,160 | 2,150 | -48 | 10,675 | 1,280 | 353.90/24.47 |
| | 5 deg | 985/1,160 | change -5 | --- | 10,683 | total 2,198 | 354.72/25.36 |
| 3,500 | Level | 1,490/2,000 | 3,490 | -6 | 11,973 | 1,298 | 353.62/24.17 |
| | 5 deg | 1,490/1,970 | change -30 | --- | 11,984 | total 3,496 | 354.48/25.10 |
| Full (3,982) | Level | 1,970/2,010 | 4,080 | +25 | 12,531 calc | 558 (Truck) | --- |
| | | | | | | Total 4,054 | |

Notes: 1. '---' - not applicable

2. MAC - mean aerodynamic chord

Fuel Gauge Errors: 0% -5% W/Delta 17600 Pilot 258 lb / Engineer 224 lb
 Assumptions: Pitch = 0.00 LOX 8.5 Mach = 0.77

| Total Fuel | 18V/0.1% sg Fuel Indications | | L Boost Pumps | | Crossfeed | | H _i for | | H _i for |
|------------|------------------------------|-----------|---------------|-----|-----------|-----------|--------------------|--------------------|--------------------|
| | imb _{bal} +/- 30 | L R | L | R | 200# Band | 100# band | H _i for | H _i for | |
| 3500 | -392 | 1554 1849 | on | NO | on | NO | 9378 | 9292 | |
| 3400 | -382 | 1509 1796 | on | NO | on | NO | 9588 | 9483 | |
| 3300 | -390 | 1455 1753 | on | NO | on | NO | 9800 | 9694 | |
| 3200 | -400 | 1400 1710 | on | NO | on | NO | 10013 | 9906 | |
| 3100 | -410 | 1345 1667 | on | NO | on | NO | 10228 | 10120 | |
| 3000 | -412 | 1294 1621 | on | NO | on | NO | 10444 | 10336 | |
| 2900 | -405 | 1248 1570 | OFF | YES | on | YES | 10662 | 10553 | |
| 2800 | -390 | 1205 1515 | OFF | YES | on | YES | 10881 | 10771 | |
| 2700 | -365 | 1168 1456 | OFF | YES | on | YES | 11102 | 10991 | |
| 2600 | -335 | 1133 1394 | OFF | YES | on | YES | 11325 | 11213 | |
| 2500 | -302 | 1099 1331 | OFF | YES | on | YES | 11549 | 11437 | |
| 2400 | -270 | 1065 1268 | OFF | YES | on | YES | 11774 | 11661 | |
| 2300 | -235 | 1033 1204 | OFF | YES | on | YES | 12002 | 11888 | |
| 2200 | -200 | 1000 1140 | OFF | YES | on | YES | 12231 | 12116 | |
| 2100 | -170 | 965 1078 | OFF | YES | on | YES | 12462 | 12346 | |
| 2000 | -138 | 931 1016 | OFF | YES | on | YES | 12694 | 12578 | |
| 1900 | -110 | 895 955 | OFF | YES | on | YES | 12929 | 12811 | |
| 1800 | -82 | 859 894 | OFF | YES | on | YES | 13165 | 13047 | |
| 1700 | -53 | 824 833 | OFF | YES | on | YES | 13403 | 13284 | |
| 1600 | -28 | 786 773 | OFF | YES | on | YES | 13643 | 13523 | |
| 1500 | 0 | 750 713 | OFF | YES | on | YES | 13885 | 13764 | |
| 1400 | 25 | 713 653 | OFF | YES | on | YES | 14128 | 14006 | |
| 1300 | 45 | 673 596 | OFF | YES | on | YES | 14374 | 14251 | |
| 1200 | 60 | 630 542 | on | NO | on | NO | 14622 | 14498 | |
| 1100 | 72 | 586 488 | on | NO | on | NO | 14872 | 14747 | |
| 1000 | 75 | 538 439 | on | NO | on | NO | 15124 | 14998 | |
| 900 | 65 | 483 397 | on | NO | on | NO | | | |

TO FLY VFR HEMISPHERIC ALTITUDE:

| H _i for | E | | W | | E | | W | | E | | W | |
|---------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| | on | NO | on | NO | on | NO | on | NO | on | NO | on | NO |
| W/Delta | 9500 | 10500 | 10500 | 11500 | 12500 | 13500 | 14500 | 15500 | 16500 | 17500 | 18500 | 19500 |
| 17,600 | 9485 | 10468 | 11470 | 12474 | 13484 | 14493 | 15503 | 16513 | 17523 | 18533 | 19543 | 20553 |
| Mean GW | 12340 | 11871 | 11415 | 10975 | 10548 | 10134 | 9720 | 9306 | 8892 | 8478 | 8064 | 7650 |
| High Fuel | 3483 | 3008 | 2549 | 2103 | 1672 | 1254 | 836 | 418 | 0 | -418 | -836 | -1254 |
| Low Fuel | 3236 | 2771 | 2320 | 1884 | 1461 | 1052 | 644 | 228 | -188 | -396 | -604 | -812 |
| imb _{bal} +/- 30 | -401 | -401 | -287 | -287 | -138 | -138 | 64 | 64 | 192 | 192 | 384 | 384 |
| Boost Pump | on | on | on | on | on | on | on | on | on | on | on | on |
| Crossfeed | NO | NO | YES | YES | YES | YES | YES | YES | YES | YES | YES | YES |
| Start | 1544 | 1842 | 1296 | 1626 | 1111 | 1366 | 966 | 1081 | 812 | 817 | 653 | 572 |
| imb _{bal} +/- 30 | -395 | -416 | -326 | -326 | -172 | -48 | 51 | 51 | 192 | 192 | 384 | 384 |
| End | 1415 | 1730 | 1192 | 1500 | 1037 | 1220 | 890 | 945 | 733 | 692 | 565 | 463 |
| imb _{bal} +/- 30 | -406 | -387 | -247 | -247 | -105 | -4 | 77 | 77 | 192 | 192 | 384 | 384 |

Table F3 : Sample Crew-Specific Flight Card

Test Aircraft: T-38A SN# 68-8153
 Test Date: 16 March 1998 to 9 April 1998
 Configuration: Cruise (Gear, Flaps, and Speed Brakes Retracted)
 Engines: J85-GE-5
 Fuel: JP-8

Anti-Ice & Canopy Defog: Off
 Pitot-Heat & Air-Conditioning: On
 Crew Weight: 258Lb Pilot / 224 Lb Engineer
 Ballast: 60 lbs at Station 504
 LOX: 8.5 liters

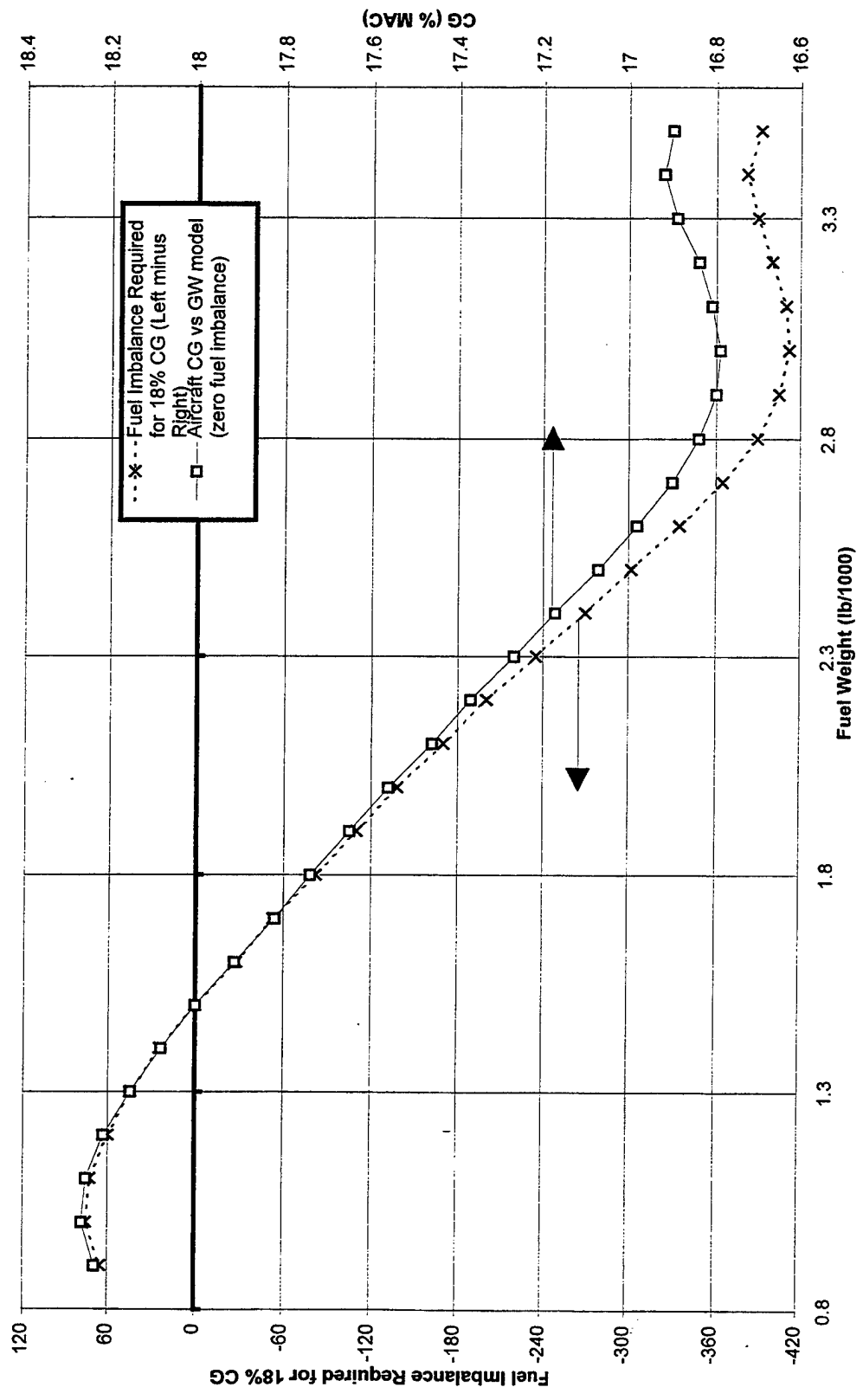


Figure F1 Sample Crew-Specific Fuel Burn Curves

FORM F - WEIGHT & BAL CLEARANCE (TACTICAL)

FORMAT: NO

| | | | | |
|---------|--------------|------|-----------|--------------|
| DATE | MODEL/DESIGN | FROM | HOME BASE | GEAR MOM CHG |
| 270725 | T38A | | ERFB, CA. | -1.6 |
| MISSION | SERIAL NO | TO | PILOT | CONSTANT |
| CANNED | 6B-8153 | | FITZ | 1000 |

| REMARKS | ITEM | WEIGHT | MOMENT |
|---------------------------------|-------------------------|--------|--------|
| MIN LANDING FUEL 408# REMAINING | BASIC A/C From Chart C | 8464 | 2997.4 |
| | Oil in Airplane | N/A | N/A |
| AFT C.G. CONDITION | PILOT | 258 | 48.8 |
| | CO-PILOT | 224 | 56.0 |
| | LOX(10 LITERS) | 26 | 3.3 |
| | BALLAST (1) @STA.504.0" | 60 | 30.2 |
| OPERATING WEIGHT | | 9032 | 3135.7 |

| CMPT ITEM | Corrections | Additional Load | WEIGHT | MOMENT |
|-----------|-------------|-----------------|----------------------|-------------|
| | WEIGHT | MOMENT | | |
| SEAT PACK | -23 | -5.6 | FUEL, INT.(583 GALS) | 3964 1387.5 |

| Less Expendables | WEIGHT | MOMENT | | |
|------------------|--------|--------|------------------------|--------------|
| FUEL | 3556 | 1240.3 | TAKEOFF (Uncorrected) | 12996 4523.2 |
| | | | CORRECTIONS | -23 -5.6 |
| | | | TAKEOFF (Corrected) | 12973 4517.6 |
| | | | LESS EXPENDABLES | 3556 1240.3 |
| [WC] | 200 | 50.0 | LANDING (Fuel 408 lbs) | 9417 3277.3 |

| (CG in ZMAC) | LIMITATIONS | 2 PILOTS | | 1 PILOT | |
|-------------------|-------------|----------------|---------|----------------|---------|
| | | W/ CORR | NO CORR | W/ CORR | NO CORR |
| TAKEOFF (GROS-WT) | 13500 | 12973 | 12996 | 12749 | 12772 |
| LANDING (GROS-WT) | 13500 | 9417 | 9440 | 9193 | 9216 |
| TAKEOFF (GEAR-DN) | 14.0 25.0 | 18.4 | 18.2 | 20.2 | 20.0 |
| LANDING (GEAR-DN) | 14.0 25.0 | 18.1 | 17.9 | 20.7 | 20.4 |
| TAKEOFF (GEAR-UP) | N/A N/A | 18.2 | 18.0 | 20.1 | 19.9 |
| LANDING (GEAR-UP) | N/A N/A | 17.9 | 17.7 | 20.5 | 20.2 |
| WORST CASE CONFIG | 14.0 25.0 | MOST FWD: 17.0 | | MOST AFT: 21.1 | |

COMPUTED BY: HPABA

WT. & BAL. AUTHORITY: J. Wittau 23/03/8
 ST

FORM F - WEIGHT & BAL CLEARANCE (TACTICAL) | FORMAT: NI

DATE: 2/2/82 MODEL/DESIGN: T38A FROM: HOME BASE: EAFB, CA. GEAR MOM CHG: -1.6
 PILOT: NEO CONSTANT: 1000
 SERIAL NO: 68-8153 TO: PILOT: NEO

| REMARKS | ITEM | WEIGHT | MOMENT |
|-------------------------------|--------------------------|-------------|---------------|
| REMAINING FUEL 408# REMAINING | BASIC A/C From Chart C | 8464 | 2997.4 |
| CONDITION | Oil in Airplane | N/A | N/A |
| | PILOT | 208 | 39.3 |
| | CO-PILOT | 228 | 57.0 |
| | LOX (10 LITERS) | 26 | 3.3 |
| | BALLAST (1) @STA. 504.0" | 60 | 30.2 |
| | OPERATING WEIGHT | 8986 | 3127.2 |

| CMPT ITEM | Corrections | Additional Load | WEIGHT | MOMENT |
|------------------|-------------|------------------------|--------|--------|
| | WEIGHT | | | |
| SEAT PACK | -25 | FUEL, INT. (583 GALS) | 3964 | 1387.5 |
| Less Expendables | | | | |
| FUEL | 3556 | | | 1240.3 |
| | | TAKEOFF (Uncorrected) | 12950 | 4514.7 |
| | | CORRECTIONS | -25 | -5.6 |
| | | TAKEOFF (Corrected) | 12927 | 4509.1 |
| | | LESS EXPENDABLES | 3556 | 1240.3 |
| [MC] | 200 | LANDING (Fuel 408 lbs) | 9371 | 3268.8 |

| (CG in AMAC) | LIMITATIONS | 2 PILOTS | | 1 PILOT | |
|-------------------|-------------|----------------|---------|----------------|---------|
| | | W/ CORR | NO CORR | W/ CORR | NO CORR |
| TAKEOFF (GROS-WT) | 13500 | 12927 | 12950 | 12699 | 12722 |
| LANDING (GROS-WT) | 13500 | 9371 | 9394 | 9143 | 9166 |
| TAKEOFF (GEAR-DN) | 14.0 25.0 | 19.0 | 18.8 | 20.9 | 20.7 |
| LANDING (GEAR-DN) | 14.0 25.0 | 19.0 | 18.7 | 21.7 | 21.4 |
| TAKEOFF (GEAR-UP) | N/A N/A | 18.9 | 18.7 | 20.8 | 20.6 |
| LANDING (GEAR-UP) | N/A N/A | 18.8 | 18.5 | 21.5 | 21.2 |
| WORST CASE CONFIG | 14.0* | MOST FWD: 17.9 | | MUST AFT: 22.0 | |

COMPUTED BY: H. Exter

WT. & BAL. AUTHORITY: J. Pittman 23/03/82

FORM F - WEIGHT & BAL CLEARANCE (TACTICAL)

FORMAT: N2

DATE: 07/25 MODEL/DESIGN: T38A FROM: HOME BASE: EAFB, CA. GEAR MOM CHG: -1.4
 PILOT: LINDELL CONSTANT: 1000
 SERIAL NO: 68-8153 TO:

| REMARKS | ITEM | WEIGHT | MOMENT |
|-------------------------------|-------------------------|--------|--------|
| REMAINING FUEL 408# REMAINING | BASIC A/C From Chart C | 8464 | 2997.4 |
| | Oil in Airplane | N/A | N/A |
| ACFT IN CONDITION | PILOT | 255 | 48.2 |
| | CO-PILOT | 201 | 50.3 |
| | LOX (30 LITERS) | 26 | 5.3 |
| | BALLAST (1) @STA.504.0* | 60 | 30.2 |
| OPERATING WEIGHT | | 9006 | 3129.4 |

| CHG ITEM | Corrections | Additional Load | WEIGHT | MOMENT |
|-----------|-------------|-----------------------|--------|--------|
| | WEIGHT | | | |
| SEAT PACK | -23 | FUEL, INT. (583 GALS) | 3964 | 1587.5 |
| | -5.6 | | | |

| Less Expendables | WEIGHT | MOMENT |
|-----------------------------|--------|--------|
| FUEL | 3556 | 1240.5 |
| TAKEOFF (Uncorrected) | 12970 | 4516.9 |
| CORRECTIONS | -23 | -5.6 |
| TAKEOFF (Corrected) | 12947 | 4511.3 |
| LESS EXPENDABLES | 3556 | 1240.5 |
| (WE) LANDING (Fuel 408 lbs) | 9391 | 3271.0 |

| (CG in ZMAC) | LIMITATIONS | 2 PILOTS | | 1 PILOT | |
|-------------------|-------------|----------------|---------|----------------|---------|
| | | W/ CORR | NO CORR | W/ CORR | NO CORR |
| TAKEOFF (GROS-WT) | 15500 | 12947 | 12970 | 12746 | 12769 |
| LANDING (GROS-WT) | 15500 | 9391 | 9414 | 9190 | 9213 |
| TAKEOFF (GEAR-DN) | 14.0 25.0 | 18.6 | 18.4 | 20.3 | 20.1 |
| LANDING (GEAR-DN) | 14.0 25.0 | 18.4 | 18.2 | 20.8 | 20.5 |
| TAKEOFF (GEAR-UP) | N/A N/A | 18.5 | 18.3 | 20.1 | 19.9 |
| LANDING (GEAR-UP) | N/A N/A | 18.3 | 18.0 | 20.6 | 20.3 |
| WORST CASE CONFIG | 14.0 25.0 | MOST FWD: 17.4 | | MOST AFT: 21.4 | |

COMPUTED BY: *AP/bs*

WT & BAL. AUTHORITY: *J. J. Jettou 23/03/8*

APPENDIX G
FUEL LOG, FUEL DENSITY, AND FUEL LOWER
HEATING VALUES BY SORTIE

FUEL LOG

- T-38A S/N 69-8153
- J85-GE-5 engines
- JP-8 fuel
- Refueling pressure 25 psi

| Date Serviced | Fuel Indicators (prefueling) | | Fuel Indicators (postfueling) | | Truck/Cart ID# | Quantity Serviced (gal) | Fuel Truck | | Fuel Sample |
|---------------|------------------------------|------------|-------------------------------|------------|----------------|-------------------------|--------------------|--------------------|--------------|
| | Left (lb) | Right (lb) | Left (lb) | Right (lb) | | | Fuel Temp (deg F) | Fuel Temp (deg F) | Temp (deg F) |
| 19-Mar | 280 | 210 | 1960 | 1900 | 90L494 | 522.3 | | 66 | 67 |
| 23-Mar | 380 | 360 | 1940 | 1900 | 91L66 | 470.3 | | 76 | 72 |
| 24-Mar | 420 | 200 | 1940 | 1900 | 91L68 | 469.9 | | 70 | 74 |
| 24-Mar | 320 | 270 | 1940 | 1890 | 90L493 | 506.4 | | 74.5 | 76.5 |
| 27-Mar | 295 | 270 | 1940 | 1900 | 90L695 | 502.7 | | 57 | 62 |
| 27-Mar | 340 | 270 | 1940 | 1900 | 90L494 | 502.8 | | 61 | 63 |
| 30-Mar | 410 | 270 | 1970 | 1910 | 90L695 | 480.9 | | 56 | 54.5 |
| 30-Mar | 300 | 280 | 1975 | 1900 | 90L695 | 494 | | 65 | 64 |
| 2-Apr | 1590 | 1680 | 1980 | 1910 | 91L69 | 95.6 | | 50.5 | 52 |
| 2-Apr | 370 | 280 | 1970 | 1905 | 91L69 | 485 | | 56 | 57.5 |
| 3-Apr | 445 | 405 | 1990 | 1905 | 91L67 | 433 | | 55 | 62 |
| 3-Apr | 245 | 200 | 1970 | 1900 | 91L69 | 517 | | 64 | 65 |
| 6-Apr | 370 | 300 | 1970 | 1905 | 90L494 | 484.6 | | 55 | 59 |
| 7-Apr | 370 | 270 | 1980 | 1910 | 90L698 | 500.5 | | 55 | 57 |
| 8-Apr | 250 | 270 | 1960 | 1905 | 90L494 | 510 | | 56 | 60 |
| 9-Apr | 650 | 605 | 1970 | 1910 | 90L494 | 413.8 | | 53 | 60.5 |

Table G1: HAVE SLICKER Fuel Log

PHILLIPS LAB RESULTS

- T-38A S/N 69-8153
- J85-GE-5 engines
- JP-8 fuel
- Refueling pressure 25 psi

| Date Serviced | Low Refueling Temp (deg C) | Density (lb/gal) | Highest Temp DAS (deg C) | Density (lb/gal) | Lowest Temp DAS (deg C) | Density (lb/gal) | LHV (Btu/lb) | LHV ratio ¹ |
|---------------------|----------------------------|------------------|--------------------------|------------------|-------------------------|------------------|--------------|------------------------|
| 19-Mar ² | 19 | | 38 | | 35 | | | |
| 23-Mar | 22 | 6.729 | 38 | 6.634 | 35 | 6.651 | 18625 | 0.9994 |
| 24-Mar | 21 | 6.735 | 41 | 6.617 | 36 | 6.644 | 18649 | 1.0007 |
| 24-Mar | 24 | 6.711 | 41 | 6.610 | 37 | 6.632 | 18649 | 1.0007 |
| 27-Mar | 14 | 6.767 | 36 | 6.633 | 29 | 6.675 | 18644 | 1.0004 |
| 27-Mar | 16 | 6.755 | 35 | 6.639 | 30 | 6.670 | 18702 | 1.0035 |
| 30-Mar | 12 | 6.780 | 29 | 6.673 | 23 | 6.711 | 18625 | 0.9994 |
| 30-Mar | 18 | 6.746 | 33 | 6.653 | 28 | 6.685 | 18661 | 1.0013 |
| 2-Apr ³ | 10 | | | | | | | |
| 2-Apr | 13 | 6.779 | 31 | 6.669 | 27 | 6.694 | 18648 | 1.0006 |
| 3-Apr | 13 | 6.781 | 32 | 6.665 | 26 | 6.700 | 18647 | 1.0006 |
| 3-Apr | 18 | 6.750 | 33 | 6.657 | 28 | 6.688 | 18666 | 1.0016 |
| 6-Apr | 13 | 6.779 | 32 | 6.665 | 27 | 6.695 | 18623 | 0.9993 |
| 7-Apr | 13 | 6.784 | 30 | 6.678 | 24 | 6.716 | 18593 | 0.9977 |
| 8-Apr | 13 | 6.785 | 33 | 6.660 | 24 | 6.717 | 18596 | 0.9978 |
| 9-Apr | 12 | 6.792 | 33 | 6.661 | 30 | 6.680 | 18582 | 0.9971 |

¹ Lower Heating Value Ratio=LHV/18,636 (LHV average=18,636 Btu/lb)

² Due to DAS failure during the sortie sample not used nor delivered to Phillips Laboratory

³ Refueled following aborted takeoff attempt; data not recorded

Table G2: Fuel Density and Lower Heating Values

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

| <u>Abbreviation</u> | <u>Definition</u> | <u>Units</u> |
|---------------------|--|---------------|
| AFB | Air Force Base | --- |
| AFFTC | Air Force Flight Test Center | --- |
| AOA | angle of attack | units |
| a_o | speed of sound, sea level standard day | ft/sec |
| Btu | British thermal unit | --- |
| C_D | total aircraft drag | dimensionless |
| C_{Db} | coefficient of base drag | dimensionless |
| C_{Df} | coefficient of skin friction drag | dimensionless |
| C_{Di} | coefficient of drag due to lift | dimensionless |
| C_{Dp} | coefficient of pressure drag | dimensionless |
| cg | center of gravity | pct MAC |
| DAS | data acquisition system | --- |
| EGT | exhaust gas temperature | --- |
| Eq | equation | --- |
| F_{ex} | excess thrust | lb |
| FF_{corr} | corrected fuel flow | lb/hr |
| FFm_{corr} | corrected mass fuel flow | lb/hr |
| $FFm_{corr,s}$ | standardized corrected mass fuel flow | lb/hr |
| FF_{ec} | energy corrected fuel flow | lb/hr |
| FF_{ex} | excess fuel flow | lb/hr |
| FF_m | mass fuel flow | lb/hr |
| FF_v | measured volumetric fuel flow | lb/hr |
| FHVR | fuel heat value ratio | dimensionless |

**LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS
(Continued)**

| <u>Abbreviation</u> | <u>Definition</u> | <u>Units</u> |
|---------------------|---------------------------------------|-----------------------|
| FTT | flight test technique | --- |
| ft | feet | --- |
| GW | gross weight | lb |
| g | acceleration due to gravity | 32.2 fps ² |
| gal | gallon(s) | --- |
| H | pressure altitude | ft |
| HAZMAT | hazardous material | --- |
| Hc | pressure altitude | ft |
| Hc _s | standardized day pressure altitude | ft |
| Hdot, \dot{H} | time rate of change in altitude | feet/sec |
| Hi | initial altitude | ft |
| Hs | standardization altitude | ft |
| H _f | final altitude | ft |
| hr | hour | --- |
| KIAS | knots indicated airspeed | --- |
| LHVt | lower heating value | Btu/lb |
| LHV _s | standard lower heating value | Btu/lb |
| lb | pound(s) | --- |
| M | Mach number | dimensionless |
| MAC | mean aerodynamic chord | --- |
| min | minute(s) | --- |
| NAM | nautical air mile | --- |
| n _x | longitudinal flight path acceleration | g |
| OAT | outside air temperature | --- |

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS (Continued)

| <u>Abbreviation</u> | <u>Definition</u> | <u>Units</u> |
|---------------------|--|--------------|
| P | ambient pressure | psia |
| PA | pressure altitude | --- |
| Ps | specific excess power | ft/sec |
| P _t | total pressure | psia |
| psi | pounds per square inch | --- |
| ρ | fuel density | lb/gal |
| ρ _s | fuel sample density | lb/gal |
| RF | range factor | NAM |
| RPM | revolutions per minute | --- |
| r _f | fuel density, as a function of fuel temp | lb/gal |
| S/N | serial number | --- |
| SR | specific range | NAM |
| SR _s | standardized specific range | NAM |
| sec | second(s) | --- |
| TM | trademark | --- |
| TPS | Test Pilot School | --- |
| TR | technical report | --- |
| TSFC | thrust specific fuel consumption | lb/hr |
| T _a | ambient air temperature | deg K |
| T _{as} | standardized ambient air temperature | deg K |
| T _f | fuel temperature | deg C |
| T _{fs} | fuel sample temperature | deg F |
| T _r | recovery temperature | deg K |
| T _s | standard ambient air temperature | deg K |

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS (Concluded)

| <u>Abbreviation</u> | <u>Definition</u> | <u>Units</u> |
|---------------------|--|---------------|
| USAF | United States Air Force | --- |
| U_{∞} | free stream velocity | ft/sec |
| V_t | true airspeed | ft/sec |
| $V_t \text{dot}$ | time rate of change in true airspeed | (ft/sec)/sec |
| V_{tf} | final true airspeed | ft/sec |
| V_{ti} | initial true airspeed | ft/sec |
| ν | viscosity | cinestokes |
| W | aircraft gross weight | lbs |
| Wf_s | standardized average normalized fuel flow | lbs/hr |
| W/δ | aircraft gross weight/ambient air pressure ratio | lbs |
| W_s | standard weight | lbs |
| δ_s | standard altitude ambient air pressure ratio | dimensionless |
| δ_t | test altitude ambient air pressure ratio | dimensionless |
| θ_s | standard ambient air temperature ratio | dimensionless |
| θ_t | test ambient air temperature ratio | dimensionless |

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