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TF30-P-7 INSTALLED TRIM CORRECTION.(U)
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HEADQUARTERS STRATEGIC AIR COMMAND

DIRECTORATE OF AIRCRAFT MAINTENANCE

AIRCRAFT ENGINEERING DIVISION
(Hq SAC/LGME)

OFFUTT AIR FORCE BASE, NEBRASKA 68113

AD A047023

ENGINEERING REPORT NO. P-206

TF30-P-7 INSTALLED TRIM CORRECTION

14 January 1977

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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

This report summarizes the findings from engineering tests conducted to determine causes of observed TF30-P-7 engine performance shift during operation of the FB-111A aircraft. Details of the test conducted at Pease AFB during September 1974 are given along with analysis of the data by P&WA, GD/FW, and Hq SAC/LGME. Measurement of ambient temperature, instrument uncertainty in the trim procedure, and assumption of constant inlet operation for simplification were found to be the prime causes of the apparent performance or trim shift. Recommendations for improvement are given.

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1. **PURPOSE:** This report summarizes the findings from engineering tests to determine the cause of observed engine performance shifts of TF30-P-7 engines installed in FB-111A aircraft.

2. **FOREWORD:**

a. Operational trim shifts reported by field units in 1972 were verified and documented by trim tests performed by Hq SAC Aircraft Engineering Division on FB-111A aircraft at Carswell, Eglin and Edwards AFBs in varying ambient conditions. Based on those observed and documented engine performance deviations from published performance data, Hq SAC/LG message 242004Z May 1973 to the F/FB-111 SPO requested correction of this deficiency.

b. The F/FB-111 SPO tasked Pratt & Whitney Aircraft (P&WA) to work the TF30-P-7 installed trim shift problem. P&WA engineers directed the trim shift investigation during the period 27 August through 2 September 1974 at Pease AFB, NH. Qualified 509BMW engine conditioning specialists operated the engines and took data by technical order procedures. Personnel from Oklahoma City ALC/MMTTFA/MMEPS, General Dynamics/Ft Worth, and ASD/SD-1110-LJ observed and assisted with the testing. The test produced large quantities of data useful for general engine trim repeatability studies as well as for the specific objectives of the test.

c. As a result of the Pease AFB test, General Dynamics/Ft Worth submitted recommended revisions to FB-111 trim procedures. The recommended trim procedures incorporate:

(1) The philosophy of a narrow tolerance for initial trims and wider tolerance for trim checks (essentially a mid-band trim).

(2) Revised Z-5 trim check curves (slightly decreases the amount of allowable A/B suppression which decreases the probability of critical oversuppression during trim).

(3) A functional check of the 7th stage bleed system to be performed on each engine trim (verify operation to prevent trim with bleed open).

(4) The requirement to repeat the trim procedure if the ambient pressure (P_{BAR}) variation between the beginning and end of the trim run exceeds ± 0.03 inch Hg.

d. The Pease AFB test indicated a need for improved OAT measurement capability and for restrictions on use of the sound suppressor when recirculation occurs. General Dynamics/Ft Worth (GD/FW) did not include these in their recommended revision. GD/FW report FZA-12-11001 stated that OAT measurement is a local trim site problem and GD/FW has no responsibility for the sound suppressor; therefore, they would make no recommendation in these areas.

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3. CONCLUSIONS:

a. TF30-P-7 engine trim may repeat on a recheck more than a trim band away from the original trim point when trimmed by technical order procedures with PMEL certified test equipment. This variance is a primarily measurement phenomenon and not caused by actual engine performance changes.

b. The observed trim shift results from several causes. The largest contributor is apparently an inability to accurately determine the ambient air temperature and humidity with specified trim pad instrumentation. Trim rechecks showed less variance in the engine performance when tower ambient temperature and dew point were used in the analysis of the run data.

c. Ambient air temperature and humidity measurement variations observed during the Pease test were traced to:

(1) Radiation effects on the temperature measuring instrument (heat added to the shaded thermometer by radiation and reflected energy from the sunlit ramp).

(2) Changes occurring after the temperature measurements are taken but before the actual engine trim (using temperature observations that are taken sometime before the engine fuel control is adjusted).

(3) Non-homogenous character of the air mass caused by:

(a) Surface conditions (concrete, grass/lakes).

(b) Introduction of hot/humid air source (recirculation).

(c) Measuring in stagnant air heated by the ramp which cools after engines are operating.

d. The ML-24 psychrometer and the temperature-humidity measuring set, AN/TMQ-11(V) used at air weather service facilities are designed to minimize the common errors in temperature measurement. Therefore, either of these methods provides a more accurate air temperature-humidity measurement than the currently specified glass thermometer.

e. Outside air temperature instrumentation specified by P&WA instructions 504 for development of installed trim curves is subject to significant errors from direct radiation and reflected solar energy. (The instructions specify a ± 1°F thermometer hung in a shaded area free from hot gas recirculation near the test stand or airplane.) Errors in the measurement of outside air temperature cause unwanted variation in the developed trim curves.

f. Tolerances are allowed with each PMEL transfer of NBS standards. Therefore, each instrument has an allowable calibration inaccuracy.

Because of these allowable calibration errors, engine performance cannot be measured to a point but within an uncertainty band or range. The P_{t7} entered on the trim sheet really means that value plus or minus some instrument uncertainty.

g. Trimming to the mid-band in both military and ENC suppression should result in the least deviation outside trim bands. If improved methods are used to obtain ambient temperature, trim deviations should remain below critical suppression levels giving reliable FB-111A engine operation (though not always assuring engine operation within the recommended trim check band on repeated trim runs).

h. Effective engine condition evaluation techniques are not being used on installed engine trims. Test cell engine evaluations to determine compressor and turbine deterioration can be adapted to installed trim runs with little additional cost (run time, man-hours, or instrumentation). These procedures should be developed for installed trims and used to prevent covering up engine deterioration by up-trim.

4. RECOMMENDATIONS: Hq SAC/LGME recommends that:

a. Hq SAC/LGMSP request Sacramento ALC/MMSRBC to change TO 1F-111 (B)A-2-6-1 to include:

(1) Use of the ML-24 psychrometer for on-site measurement of ambient temperature. After the engines have been operating, but before trim, compare the ML-24 psychrometer reading with the current OAT obtained from the tower/weather station to verify accuracy of the ML-24. (If more than 3°F different, use a second ML-24 to verify on-site OAT.)

(2) Provide procedures for identifying deteriorated engines during installed trims. (Limits for low pressure compressor pressure ratio, corrected N_1 % RPM vs N_2 % RPM, and P_{s3}/P_{t2} vs EPR, referred to ambient barometric pressure considering inlet recovery.)

(3) Restrict trims in the sound suppressor when winds are from the direction which causes recirculation of exhaust gases (any tail winds or visible recirculation in calm or light wind conditions).

(4) Add functional checkout procedures for the engine nacelle vent air ejector cooling valve to assure regulation at 24 ± 5 psi with engine operating at military power prior to attempting an engine trim.

(5) The GD/FW, 15 Dec 1975, recommendations prepared for SM-ALC/MME under contract F04606-75-D-0114-0052-01, Task 76-10-28 (Atch 1). [Except the maximum A/B thrust trim curve (GD/FW No. 75PA-2552-007) which by current trim procedures will require an A/B reset instead of a decrease in A/B suppression.]

(6) Incorporation of the intent of GD/FW curve No. 75PA-2552-007 into a Zone 3 adjustment which will reduce trim suppression level and move normal engine operation further away from the critical stall conditions.

b. Hq SAC/LGME develop and evaluate a continuous reading temperature measuring instrument which is not subject to thermal radiation errors and can be used in the trim trailer during the engine trim run.

c. P&WA review their current instruction 504 instrumentation requirements for measurement of outside air temperature to assure that potential radiation errors associated with a glass thermometer in a free convection field are insignificant enough to be neglected in the development of installed engine trim curves.

5. DISCUSSION:

a. LGME Project P-152, TF30-P-7 Engine Trim Status, investigated reported trim problems and in-flight power losses associated with A/B blowouts/compressor stalls. The reported operational trim shifts were verified and documented by LGME trim tests performed on FB-111A aircraft at Carswell, Eglin, and Edwards AFBs in varying ambient conditions. The SAC/LG, based on the observed and documented engine trim shifts, sent Hq SAC/LG message 242004Z May 1973 to the F/FB-111 SPO requesting the complete and expeditious solution to this in-service revealed engine deficiency.

b. Potential causes of the observed performance deviations/trim shifts identified under LGME Project P-152 included the following:

(1) Installed engine trim curves may have slightly incorrect shapes caused by assuming a constant inlet recovery factor which in fact may vary with wind, air temperature, and/or humidity caused by averaging out OAT errors from use of a glass thermometer.

(2) Actual effects of humidity on engine trim performance may be different from the published corrections because of the short length of the FB-111A triple plow inlet when compared to the Navy A-7 inlet. The A-7 inlet was used by P&WA engineers as the model for developing the humidity corrections.

(3) The T_{t2} fuel control temperature probes may sense temperature rise in the inlet caused by condensation of entrained water vapor (in opposition to the assumption that the air stagnates at the T_{t2} probe and the water vapor re-evaporates).

(4) Different pressure recovery factors at the locations of the fuel control temperature probes in the left and right inlet locations may cause differences in the sensed temperature.

(5) Instrument uncertainty and human errors may cause imprecision and bias in the measurement of trim parameters. Trim targets calculated from incorrect measurements of test conditions may cause apparent trim shifts when engine performance is, in fact, satisfactory.

(6) Actual engine performance may change because of hot section parts deterioration, modifications which change the physical shape of

the gas path area, build-up variations in physical turbine nozzle areas and turbine wheel spacing, or unmeasured variations in bleed air extraction during the trim operation.

c. The F/FB-111 SPO tasked P&WA under their TF30 Product Support Program (PSP) to work the TF30-P-7 installed trim shift problem (Item M-6). Details of a proposed test to determine the cause or causes of reported trim shifts apparent on TF30-P-7 engines installed on FB-111A aircraft were presented to SAC/LGMSP/LGME in September 1973. The final details of the required testing were worked out at Oklahoma City ALC 7 June 1974.

d. The planned testing was completed at Pease AFB during September 1974. It confirmed that a high probability exists that a recheck of FB-111A engine trim data will indicate a performance shift outside acceptable tolerance bands. The primary cause of the observed variability was attributed to instrument uncertainty, inaccuracy, or error. See Atch 5 for a discussion of how simplifying assumptions and instrument uncertainty can introduce variations in observed engine performance under trim conditions. The details of the Pease AFB testing are given in Atch 2, test log. Analysis of the data made by P&WA and GD/FW are given in Atch 3 and 4.

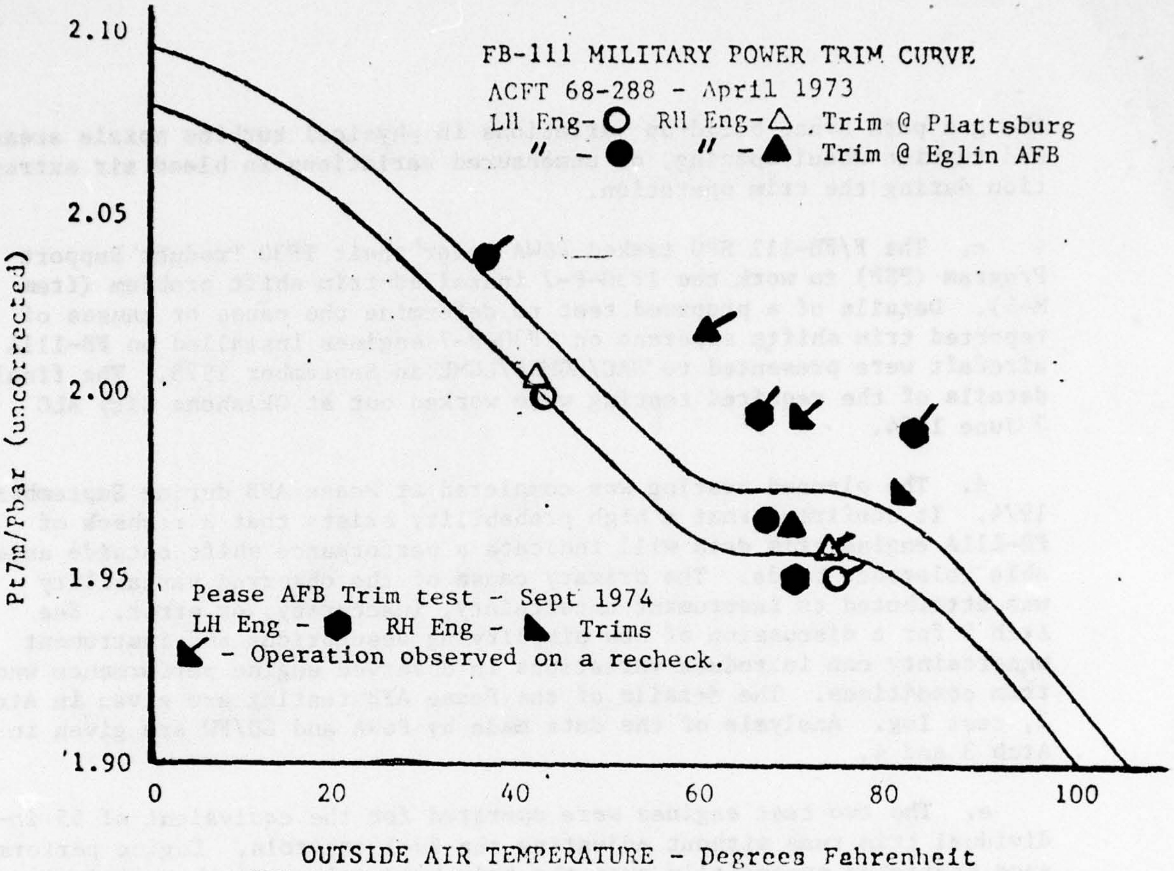
e. The two test engines were operated for the equivalent of 55 individual trim runs without adjusting the fuel controls. Engine performance scattered essentially over the trim band tolerance when evaluated using data obtained from test cell quality instruments supplied by P&WA. The observed performance scatter confirmed that engines trimmed to mid-band will have an apparent shift out of the trim band on subsequent trim checks with a significant but random frequency. See Figure 1 for a comparison of shifts observed in the 1973 Eglin AFB test and in the Pease AFB test.

f. During the operation of engines for the Pease AFB test, the following significant phenomena were observed:

(1) The performance scatter could be reduced to essentially a trim band width (1.1 bands) by selectively choosing the data sources used to evaluate performance.

(2) Engine operation varied more than a half trim band between individual runs and later checks. In each case where the variation was more than 1/2 trim band, engines adjusted on that run to the mid-point in the trim band would have been out of trim on the recheck.

(3) Significant differences were noted between temperature and dew point readings recorded at the base weather observation point and those recorded at the power check pad. See Figures 2, 3, 4, and 5 for examples. The desired engine performance is calculated based on ambient conditions existing at the time of the engine trim run. A deviation of 5°F temperature between what is measured and what goes into the engine



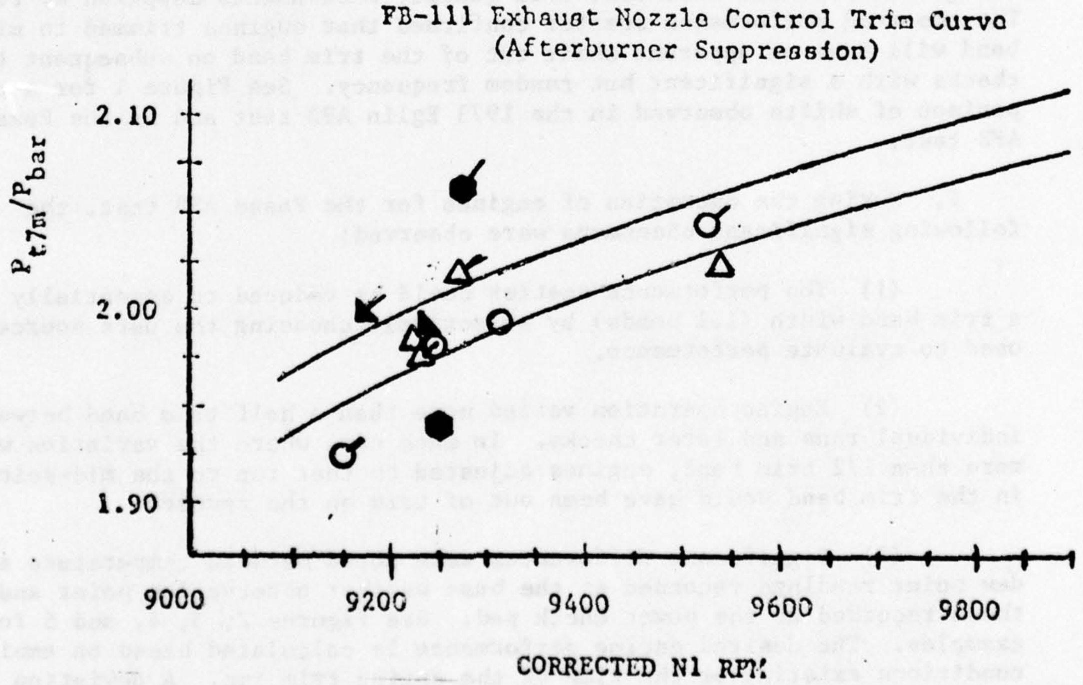


Figure 1 -- Comparison of FB-111A observed engine performance from April 1973 Eglin AFB trim test and from September 1974 Pease AFB trim test.

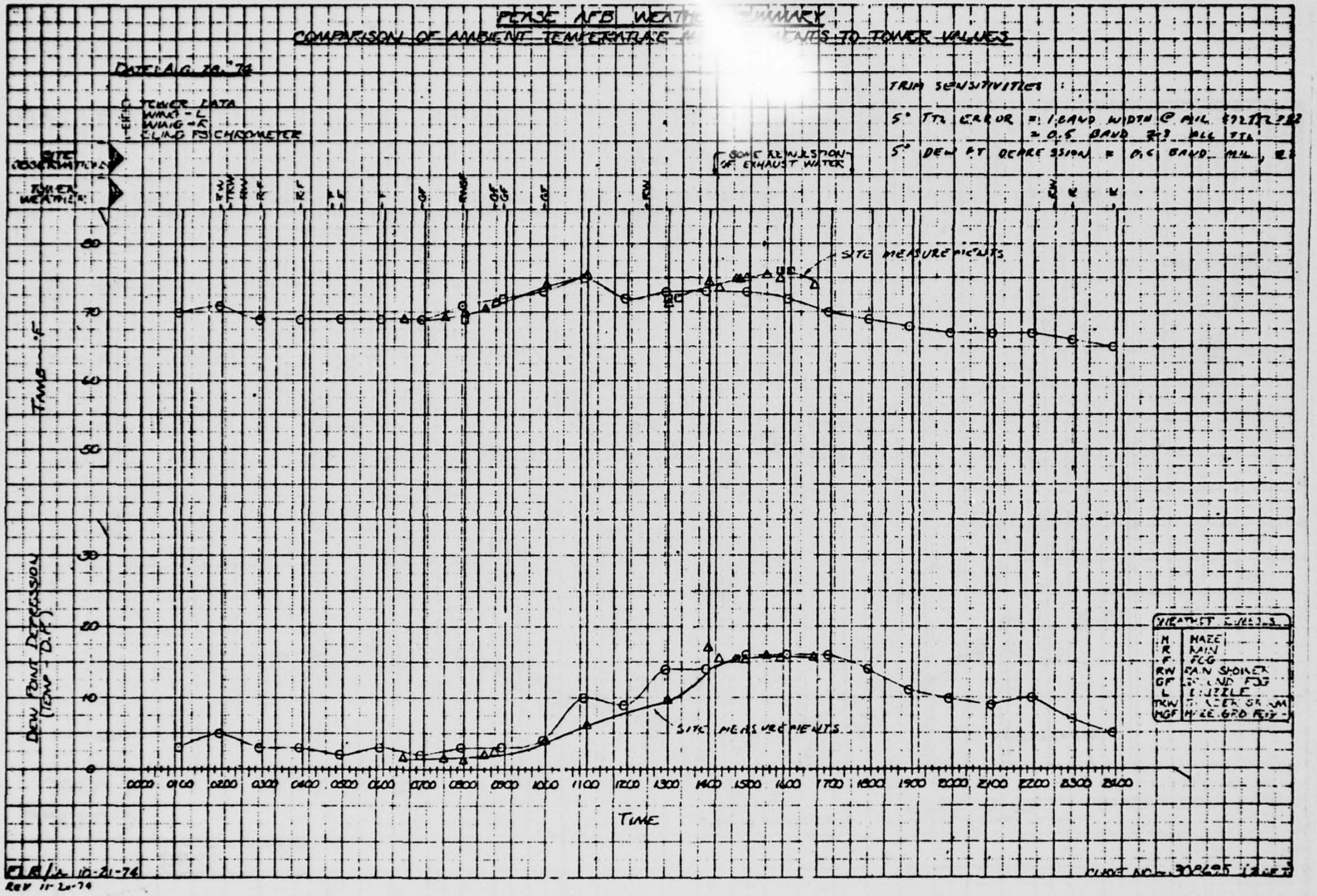

PEASE AFB WEATHER SUMMARY
COMPARISON OF AMBIENT TEMPERATURE MEASUREMENTS TO TOWER VALUES
DATE: AUG. 28, '74
○ TOWER DATA
WMAT - L
WMAG - R
SLING PSYCHROMETER
SITE OBSERVATIONS
TOWER WEATHER
RW
TRW
RW
R-F
R-F
L
L
F
GF
HGF
GF
GF
GF
RW
RW
R
R
SOME REINJESTION OF EXHAUST WATER
TRIM SENSITIVITIES:
5° TT2 ERROR = 1 BAND WIDTH @ MIL
≈ 0.5 BAND ALL TT2
5° DEW PT DEPRESSION = 0.5 BAND MIL
SITE MEASUREMENTS
SITE MEASUREMENTS
TEMP - °F
DEW POINT DEPRESSION (TEMP - D.P.)
80
70
60
50
30
20
10
0
0000
0100
0200
0300
0400
0500
0600
0700
0800
0900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
TIME
WEATHER SYMBOLS
H HAZE
R RAIN
F FOG
RW RAIN SHOWER
GF GROUND FOG
L DRIZZLE
TRW THUNDER STORM
HGF HAZE, GRD FOG
FLR 10-21-74
REV 11-20-74
CHART NO. 302695

Figure 2

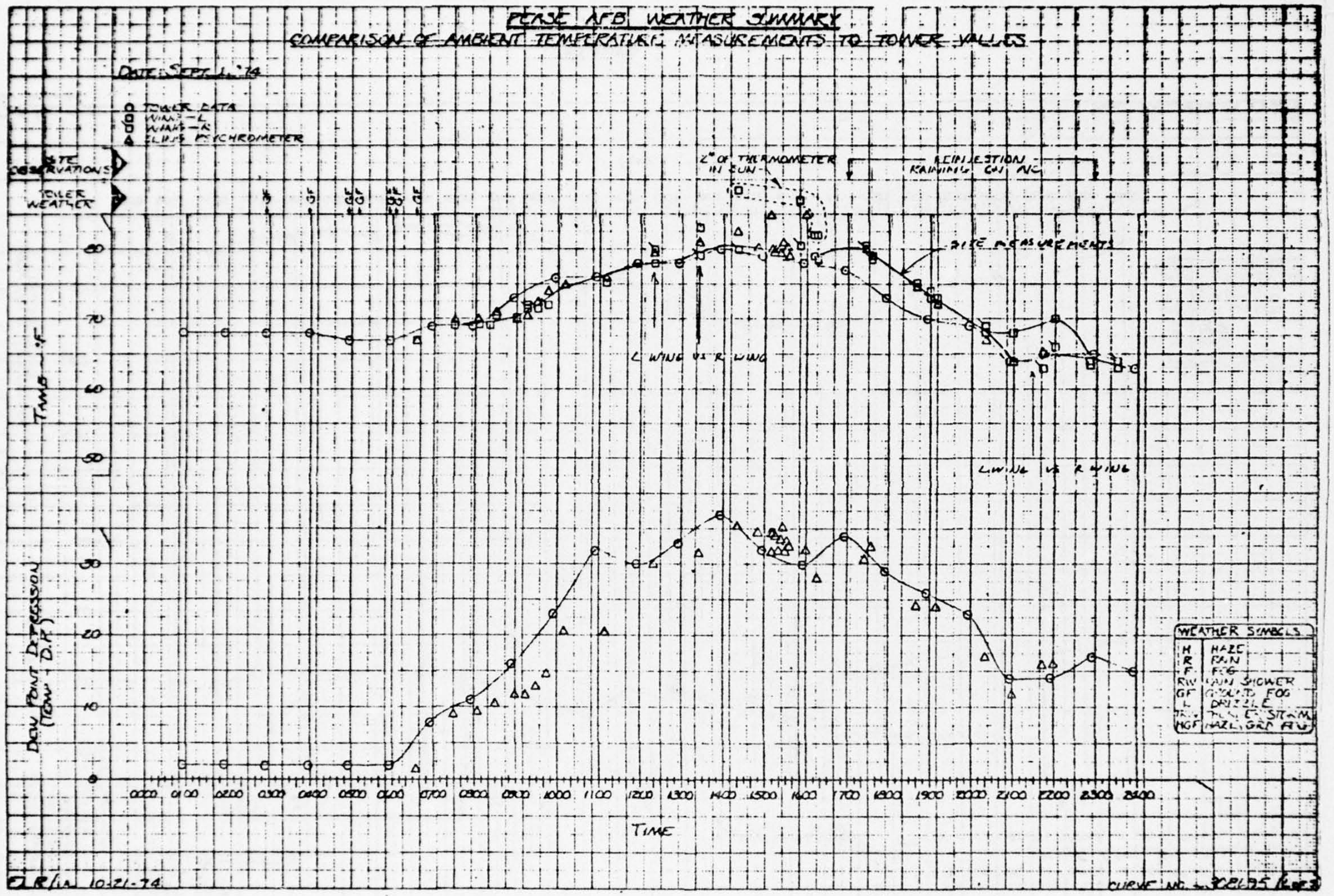

PEASE AFB WEATHER SUMMARY
COMPARISON OF AMBIENT TEMPERATURE MEASUREMENTS TO TOWER VALUES
DATE: SEPT. 1, '74
○ TOWER DATA
□ WING - L
□ WING - R
△ ELLIS PSYCHROMETER
SITE OBSERVATIONS
TOWER WEATHER
H
GF
GF
GF
HL
GF
GF
2" OF THERMOMETER IN SUN
REINJESTION - RAINING ON A/C
SITE MEASUREMENTS
L WING VS R WING
L WING VS R WING
TAMB - °F
80
70
60
50
30
20
10
0
DEW POINT DEPRESSION (TAMB - D.P.)
0000
0100
0200
0300
0400
0500
0600
0700
0800
0900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
TIME
WEATHER SYMBOLS
H HAZE
R RAIN
F FOG
RW RAIN SHOWER
GF GROUND FOG
L DRIZZLE
HGF HAZE, GRD FOG
ELR/LA 10-21-74
CURVE NO. 308695

Figure 3

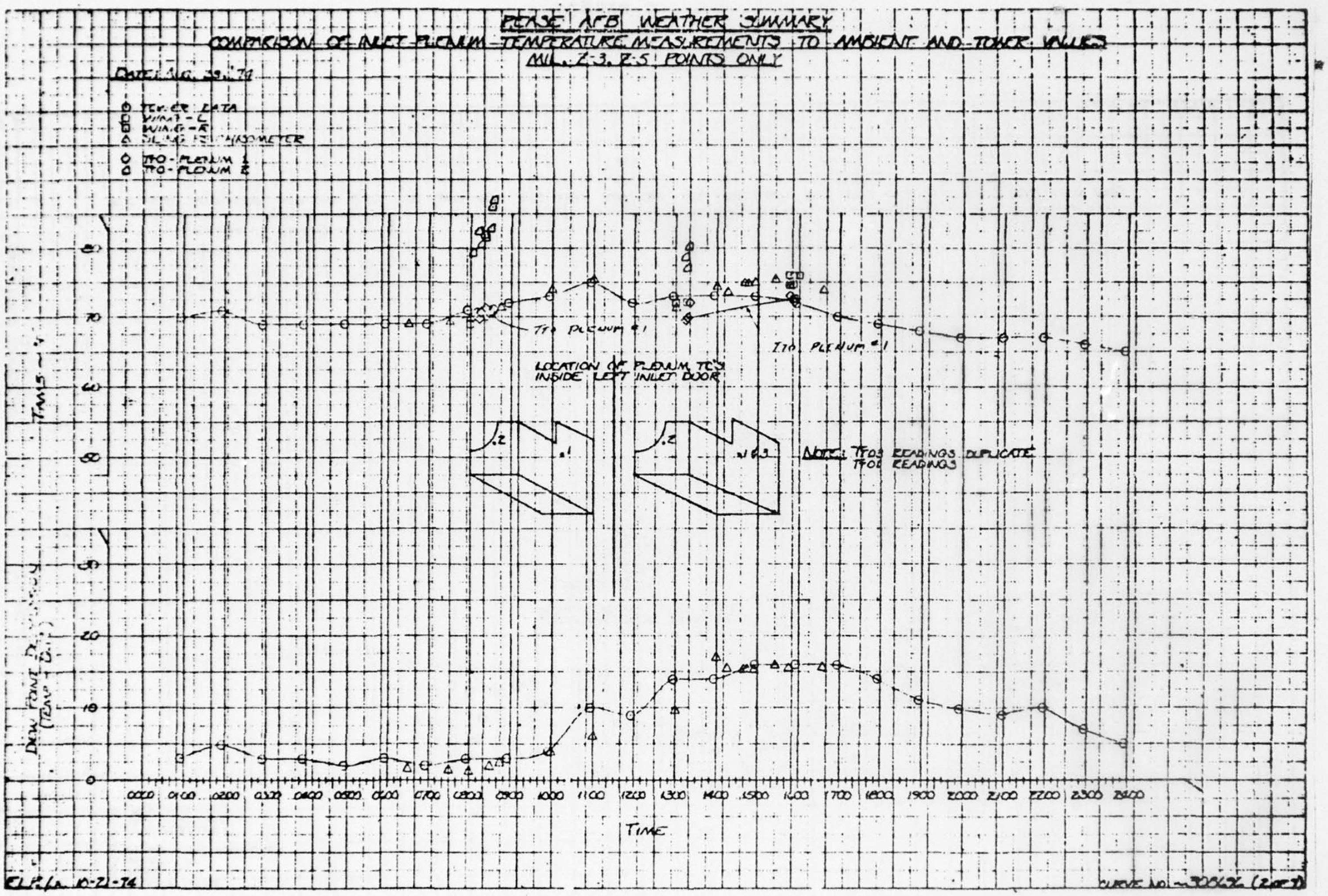

PEASE AFB WEATHER SUMMARY
COMPARISON OF INLET PLENUM TEMPERATURE MEASUREMENTS TO AMBIENT AND TOWER VALUES
MIL, Z-3, Z-5 POINTS ONLY
DATE: AUG. 29, 74
TOWER DATA
WING - L
WING - R
SLING PSYCHROMETER
TTO - PLENUM 1
TTO - PLENUM 2
TTO PLENUM #1
TTO PLENUM #1
LOCATION OF PLENUM TC'S INSIDE LEFT INLET DOOR
.2
.1
.2
.1 & .3
NOTE: TTO3 READINGS DUPLICATE TTO1 READINGS
TAMB ~ °F
DEW POINT DEPRESSION (TEMP - DP)
80
70
60
50
30
20
10
0
0000
0100
0200
0300
0400
0500
0600
0700
0800
0900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
TIME
ELP/la 10-21-74
CURVE NO. -30692 (2 of 3)

Figure 4

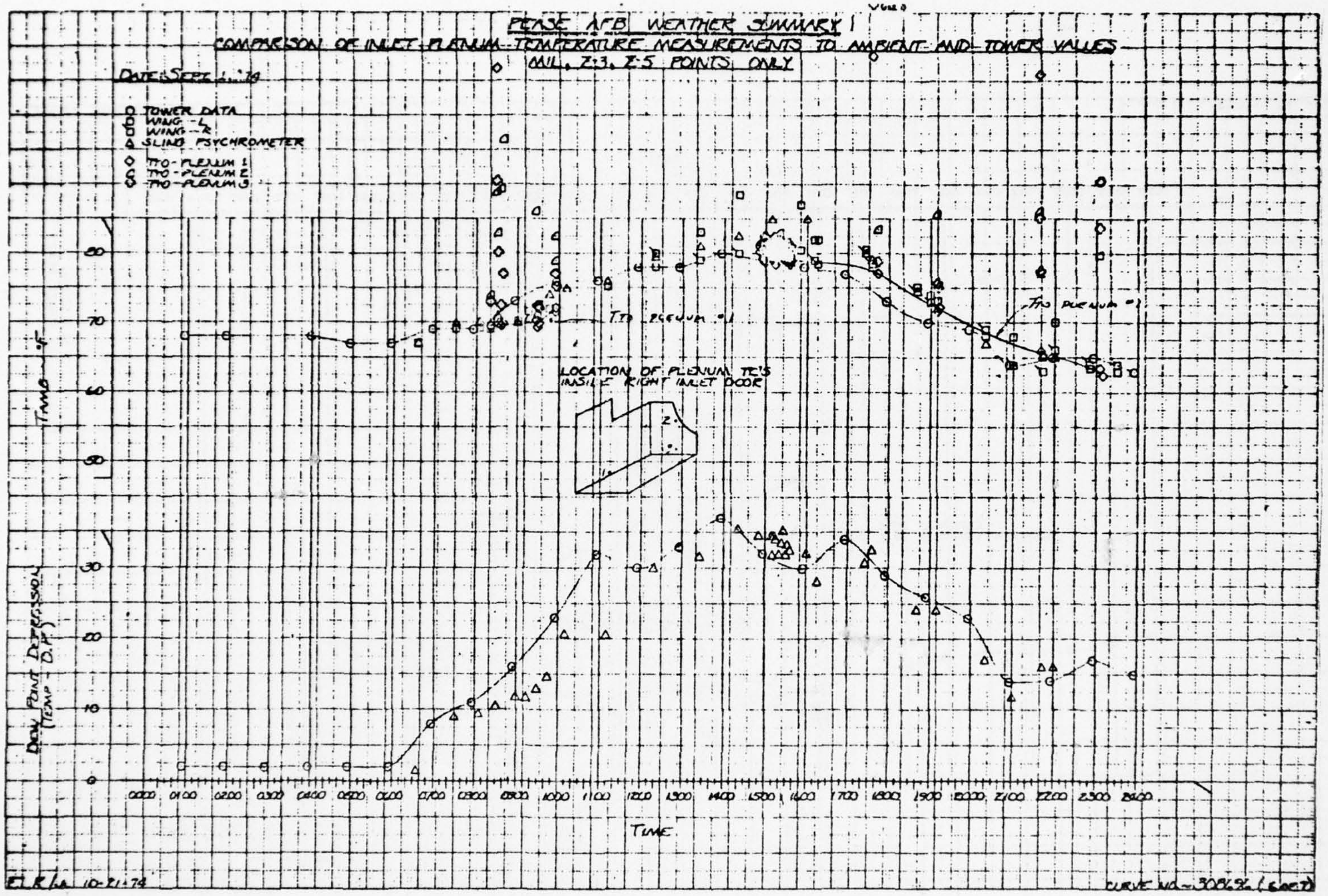

PEASE AFB WEATHER SUMMARY I
COMPARISON OF INLET PLENUM TEMPERATURE MEASUREMENTS TO AMBIENT AND TOWER VALUES
MIL, Z-3, Z-5 POINTS ONLY
DATE: SEPT. 1, '74
TOWER DATA
WING - L
WING - R
SLING PSYCHROMETER
TTO - PLENUM 1
TTO - PLENUM 2
TTO - PLENUM 3
TTO PLENUM #1
TTO PLENUM #1
LOCATION OF PLENUM TC'S INSIDE RIGHT INLET DOOR
TAMB - °F
DEW POINT DEPRESSION (TEMP - D.P.)
80
70
60
50
30
20
10
0
0000
0100
0200
0300
0400
0500
0600
0700
0800
0900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
TIME
E.L.R/ua 10-21-74
CURVE NO. - 30869 (5 OF 7)

Figure 5

will cause an apparent performance change of a military trim band magnitude. A 5°F dew point deviation will cause a change of 1/2 military trim band magnitude.

(4) A large shift in military and afterburner suppression trim was observed on the left hand engine during the repeated check operation. The A/B suppression shift was approximately 7%, which P&WA says has an 80% probability of causing an engine stall and power loss when selecting military power after A/B operation. Continued testing traced the cause of this observed performance shift to initially adjusting the fuel control trim with the 7th stage inter-compressor bleed in the open position. This 7th stage bleed had failed to close because of an engine Mach trim actuator system malfunction. Checks of the 7th stage bleed system during each trim are included in the GD/FW recommended changed to TO 1F-111(B)A-2-6-1.

(5) An assumption in the current trim charts is that the engine face total temperature probe (T_{t2}) operates with a constant 7°F recovery factor. The recovery values observed during the test varied between 3 and 9°F. P&WA concluded that the assumption of a 7°F recovery was valid since the average recovery was 7°F. Use of the average T_{t2} probe recovery in calculating installed trim curves can cause more than a trim band of apparent shift at the fuel control T_{t2} bias break points (60 and 80°F ambient temperature) on the trim curve.

(6) The exhaust plume from the sound suppressor was observed to re-circulate and to enter the inlets under near calm wind conditions. The recirculating air is warmer and it contains higher humidity than surrounding air because of cooling water sprayed into the sound suppressor. The recirculation on a couple of occasions was observed to add sufficient water to cause rain to fall on the aircraft with an intensity equal to that often seen in a summer rain shower.

(7) Measures of engine performance were most consistent when the data was analyzed using ambient temperature and dew point as measured by the base weather facility. The measuring equipment used by the weather station is specially designed to eliminate radiation errors and localized ground heating. The readings from this specially designed equipment should be the best available except when exhaust recirculation is occurring. Measuring OAT at the trim site will not detect recirculation or localized heating if it is done before the engine is started and air is moved by high power operations. Only continuous temperature monitoring during trim runs has the potential for detecting temperature errors caused by exhaust recirculation and local trim pad temperature abnormalities. The air flows (2000 cubic feet per second) required during high power operation will tend to minimize local temperature effects.

g. Ambient temperature measurement, which is one of the prime parameters required for calculation of jet engine performance targets for trim, can be influenced by radiation. Basically, measured ambient temperature is the result of a heat balance on the instrument between the three primary modes of heat transfer thru convection, radiation, and conduction. Technical orders require trim crews to suspend the thermometer in the shade of the aircraft away from hot air sources and obtain a reading prior to engine start. If a string is used to suspend the thermometer, then conduction can be assumed neglible in the heat balance. The indicated temperature on the suspended thermometer will be the result of a heat balance between convection and radiation. By observation, it is apparent that the surroundings are very large when compared to the size of the thermometer. Therefore, the following energy balance may be made:

$$hA\ (T_A - T_t) = \sigma Ae\ (T_t^4 - T_s^4)$$

Where h = convection heat transfer coefficient from the air to the thermometer, typical value = 2 BTU/hr(ft^2)°F.

A = Surface area of the thermometer.

e = Surface emissivity of the thermometer.

T_A = True temperature of air.

T_t = Thermometer temperature indicated.

T_s = Temperature of surroundings.

σ = Stefan-Boltzmann Constant. 0.1714 E-8 BTU/(hr)(sq ft)(deg R)^4

h. The influence of radiation is illustrated by this example of a trim crew using a thermometer to determine air temperature for trim target calculations. The sun is shining brightly on the ramp and has heated the surface to 86°F. The weather station reports 61°F. The thermometer is hung under the wing shaded from the sun as required by technical orders. The convective heat transfer coefficient for the thermometer is estimated at 2 BTU/hr(ft^2)deg R, and e = 0.9 for glass. What will be the temperature read on the thermometer by the trim crew? Using the energy balance, we can see the error in measurement introduced by radiant heat added to the thermometer.

$$h(T_A - T_t) = e\sigma\ (T_t^4 - T_s^4)$$

$T_s = 86°F = 545°R$ $\qquad$ $T_{air} = 61°F = 520°R$

$h = 2$ BTU/hr(ft^2)deg R (Assumed Typical Value)

$$(2)(520 - T_t) = 0.1714\text{ E-8 } (0.9)(T_t^4 - 545^4)$$

$$0.15426\text{ E-8 } T_t^4 + 2\ T_t - 1176.1 = 0$$

Trial and Error Solution - Assume 69°F.

$119.9 + 1056 - 1176.1 \simeq 0$ $\qquad$ $T_t \simeq 69°F$ vs $T_A = 61°F$

Measured temperature is 8°F higher than the actual air temperature because of heat radiated from the warm ramp.

i. Since radiation heat is transferred as a function of the fourth power of the absolute temperature, thermometers depending on free convection for heat transfer will be influenced more by the temperature of surrounding surfaces as the difference between the air temperature and the surrounding surfaces increases. A thermometer in a free convection field will experience errors in measured temperature as shown in Figure 6 for differences in the temperature of surrounding surfaces and the air. Figure 6 is based on a free convection heat transfer coefficient given by:

$$hc = 0.25[(T_A - T_t)/D]^{1/4}$$

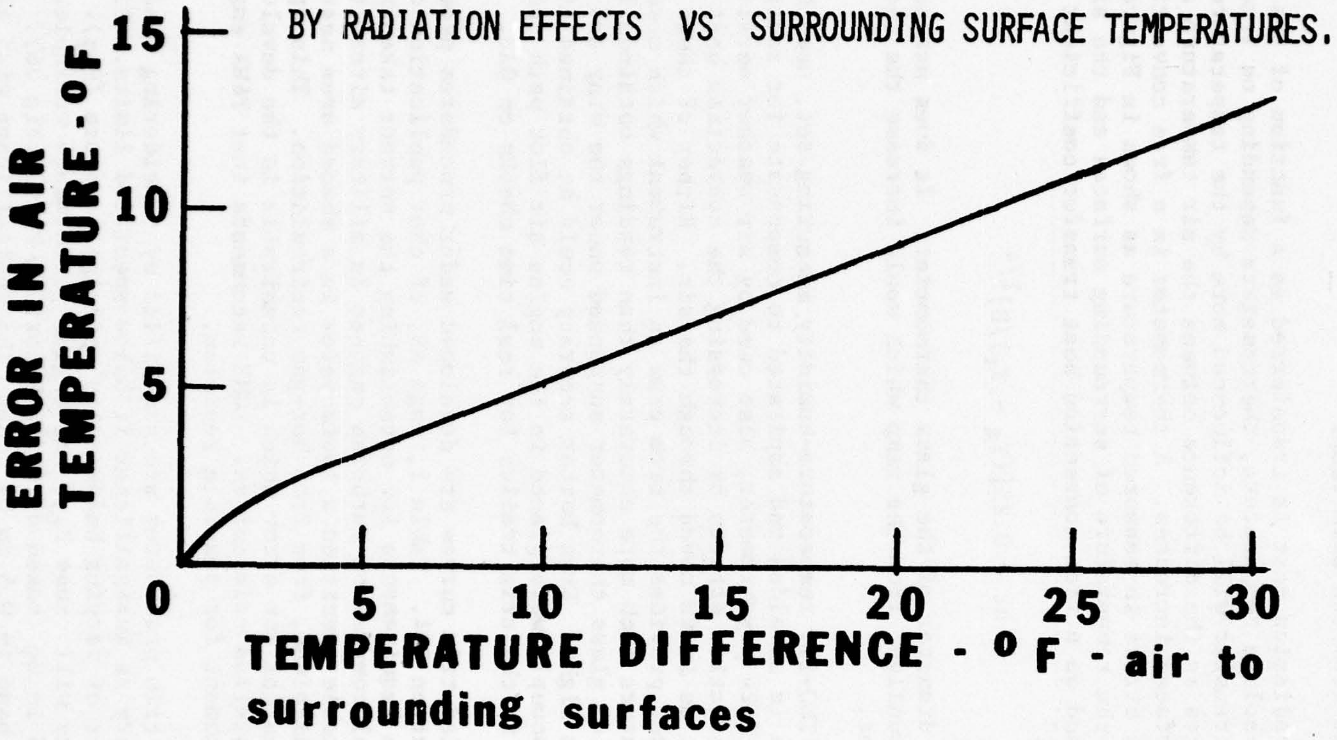
where D is the diameter of the glass thermometer. It does not account for reflected sunlight from the ramp which would increase the thermometer error if present.

j. The AN/TMQ-11, temperature-humidity measuring set, used by air weather service is shielded and aspirated to compensate for radiation effects. The ML-24 psychrometer, also used by air weather service, compensates for radiation effects by increasing the convection heat transfer coefficient as it is moved through the air. Either of these instruments, therefore, provides the trim crew an instrument which measures ambient temperature much more accurately than readings obtained from a free convection glass thermometer suspended under the wing and shaded from direct sun light. Even better accuracy could be obtained if a shielded thermocouple were placed in the engine air flow path and a remote readout placed in the trim trailer for real time checks on OAT.

k. Installed trim curves are developed under procedures provided by P&WA Instruction 504. Table 1, page A9, of that publication specifies instrumentation requirements for establishing the correct takeoff thrust and trim of dual compressor turbofan engines in military aircraft installations. The table specified a thermometer in a shaded area near the test stand or airplane, free from hot-gas recirculation. This specified method has potential for error which is undesirable in the development of accurate installed trim curves. LGME recommends that P&WA engineers review this document for possible revision.

l. Engine trim procedures are simplified by considering wind effect on inlet recovery as insignificant if below specified limits. Figure 7 shows the effect of varying headwind on tailpipe pressure (P_{t7}). A headwind of 15 knots will cause P_{t7}, the engine performance variable, to increase by 0.5 in Hg (based on GD/FW Report MR-P-293, Fig 26). The allowable trim band in 0.5 in Hg wide. The insignificant wind effect assumption is necessary to provide an acceptable maintenance procedure and is justified by the fact that it produces an undertrim. Cross wind effects, however, can cause decreases in inlet recovery which, theoretically, will cause overtrims. The relative effects of crosswind on inlet recovery are presently undefined.

ERROR IN OAT MEASUREMENT WITH A GLASS THERMOMETER CAUSED BY RADIATION EFFECTS VS SURROUNDING SURFACE TEMPERATURES.



JLP 20 Sep 1976

FIGURE 6. RADIATION EFFECTS ON A GLASS THERMOMETER HUNG IN THE SHADE FOR THE PURPOSE OF MEASURING AMBIENT AIR TEMPERATURE. REFLECTED SOLAR ENERGY IS ASSUMED TO BE ZERO. NATURAL CONVECTIVE HEAT TRANSFER COEFFICIENT IS OBTAINED FROM

$$H_C = 0.25 \left[(T_{\text{THERMOMETER}} \div T_{\text{AIR}})/D_{\text{IA}}\right]^{1/4}$$

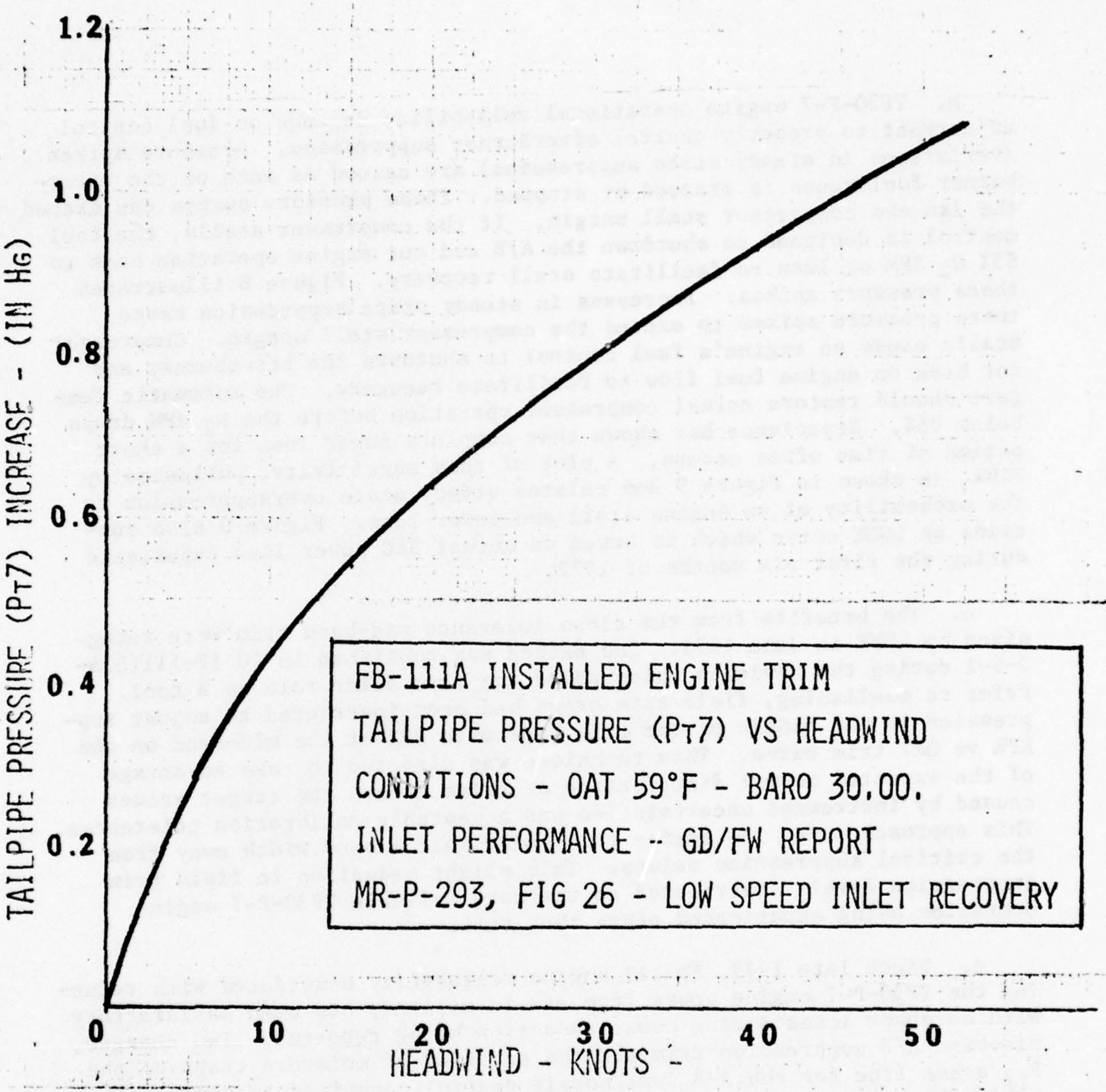


FIGURE 7

A Trimshift of one band width will be apparent between zero wind and 15K headwind conditions. Current trim procedures are simplified by assuming that wind effects are negligible and can, therefore, be neglected. This curve shows the change in tailpipe pressure in inches of mercury that headwinds will cause. The effect of crosswinds on inlet recovery is not presently defined.

m. TF30-P-7 engine operational reliability depends on fuel control adjustment to properly control afterburner suppression. Pressure spikes (variations in steady state suppression) are caused as each of the afterburner fuel zones is started or stopped. These pressure surges can exceed the fan and compressor stall margin. If the compressor stalls, the fuel control is designed to shutdown the A/B and cut engine operation back to 85% N_2 RPM or less to facilitate stall recovery. Figure 8 illustrates these pressure spikes. Increases in steady state suppression cause these pressure spikes to exceed the compressor stall margin. Compressor stalls cause an engine's fuel control to shutdown the afterburner and cut back on engine fuel flow to facilitate recovery. The automatic feature should restore normal compressor operation before the N_2 RPM drops below 85%. Experience has shown that complete power loss for a short period of time often occurs. A plot of this sensitivity, published by P&WA, is shown in Figure 9 and relates steady state oversuppression to the probability of an engine stall and power loss. Figure 9 also contains an LGME curve which is based on actual SAC power loss experience during the first six months of 1972.

n. The benefits from the close tolerance mid-band trim were recognized by LGME in June 1973. The method was published in TO 1F-111(B)A-2-6-1 during the revision which added the trim slide rule as a tool. Prior to publishing, field trim crews had been instructed to adjust suppression in the middle of the trim band with EPR at the mid-band on the EPR vs OAT trim curve. This technique was directed to take advantage of the expected normal distribution of trims around the target values caused by instrument uncertainties and acceptable calibration tolerances. This approach moved the engine trim point half a band width away from the critical suppression values. This slight reduction in field trim suppression levels contributed to the more reliable TF30-P-7 engine operation being experienced since that time.

o. Since late 1973, FB-111 engine reliability associated with reducing the TF30-P-7 engine power from A/B to military has been satisfactory with no power loses during power reduction being reported. Two changes, mid-band A/B suppression trim and the addition of moisture traps on the P_{t7} sense line for the A/B fuel/nozzle control, combined to give this reliability improvement. TCTO 2J-TF30-729J, Installation of Condensate Trap for P_{t7} Sense Manifold (ECP 197945F), was issued 15 March 1973.

p. Since SAC is experiencing operationally reliable TF30-P-7 engine operation, LGME can accept with the reservations noted in Paragraph 5f the P&WA conclusion that current trim procedures are satisfactory. Instrumentation uncertainty may allow engines to be accepted when they are actually operating slightly outside the tech order bands and will cause trim shifts to be observed on rechecks. Recommended changes in trim procedures as the result of the Pease test data will reduce this instrument uncertainty and should be made as soon as possible in the applicable technical orders. The action recommended in Paragraph 4a above will provide, for field use, the improved procedures developed

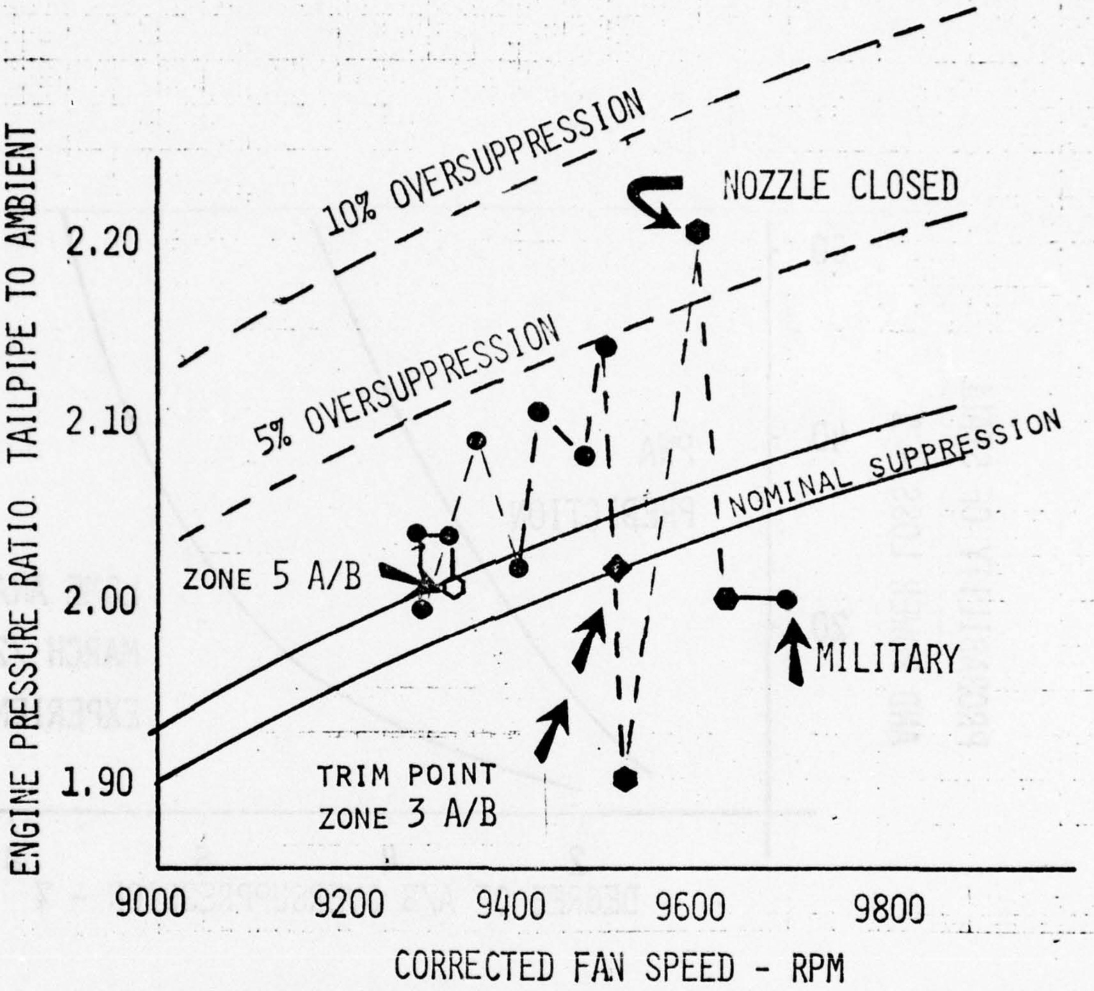


FIGURE 8. EPR and RPM dynamics during snap throttle retard from maximum A/B to military power for a TF30-P-7 engine trimmed to the bottom of the suppression band.

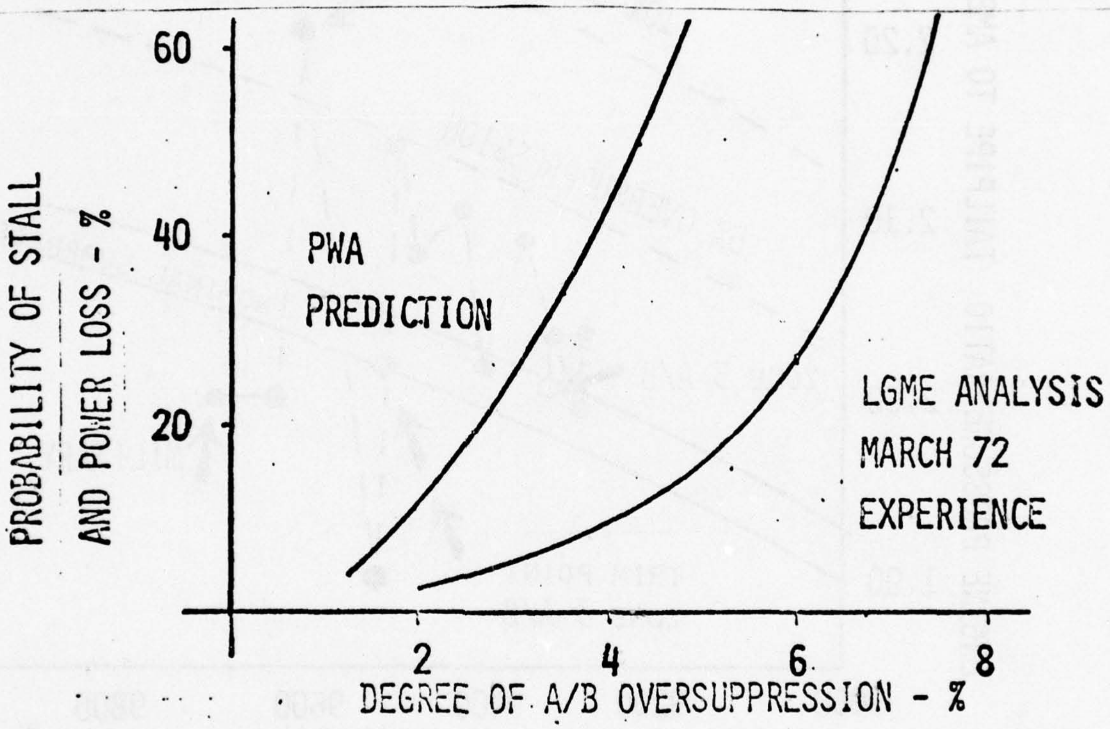


Figure 9. Comparison of power loss probability associated with the degree of A/B oversuppression predicted by P&WA and SAC FB-111A experience during the winter of 1971 - 1972.

as the result of this trim improvement effort and should further improve confidence that oversuppression on A/B trim will not contribute to unreliable TF30-P-7 engine operation.

q. The Pease AFB test invalidated a common engine trim assumption among field propulsion experts. It proved without a doubt that engine performance does not repeat to a line but rather varies randomly within a band. No matter how precise a trim crew works, engine performance cannot be controlled inside this uncertainty band. Actual engine performance as located by the precise trim operation is being certified at a point when it is operating somewhere within the width of this uncertainty band. This band width is established by the uncertainty in each element of the trim instrumentation and operation. The normally experienced magnitude of the uncertainty band will be the root-sum-square of each contributing element. However, when the consequence of oversuppression is as critical as it is with the TF30-P-7 engine, the maximum error band (the sum of each contributing element) must be controlled below the critical value. Routine trims must consider that the operating point can move the width of the total uncertainty band closer to the critical value. If additional operational engine power losses are experienced, it may be necessary to trim to the lower tolerance of the trim band less half of the known trim performance variation to assure that critical overtrims are not experienced because of normal uncertainty of the trim point. Attachment 5 gives an in-depth discussion of the effect of instrument uncertainty on the trim point.

r. Evaluation technique used with test cell engine runs is capable of providing a more thorough analysis of engine condition if used with installed engine trim runs. Some of the test cell procedures which could easily be adapted to installed trim runs are low pressure compressor ratio check, maximum corrected N_1 % RPM vs N_2 % RPM, P_{s3}/P_{t2} vs EPR, etc. The inlet performance effects would have to be computed and applied in order to use the techniques for installed engines. If correct limits were available, little additional cost (man-hours, fuel, or instrumentation) would be required to evaluate engine condition along with routine installed trims. Current trim procedures can easily overlook engine deterioration and turn up the wick (up-trim the fuel control) to overcome existing engine deterioration. Deterioration of first stage turbine outer air seals or low pressure compressors will make engines more prone to in-flight engine stalls. All methods for evaluating engine condition which can be developed for installed engines should be used on each trim to spot deterioration before in-flight problems arise.

5 Atch
1. GD/FW Report
2. Log of Engine Test Program
3. TF30-P-7 Trim Repeatability Investigation
4. SA-ALC Report
5. Trim Point Uncertainty Paper

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GENERAL DYNAMICS
FORT WORTH DIVISION

15 DECEMBER 1975

FB-111A GROUND ENGINE TRIM PROCEDURE

REVISION

THIS PROPOSED REVISION TO THE 1F-111(B)A-2-6-1 TECHNICAL MANUAL WAS PREPARED FOR SM/ALC (MME) UNDER CONTRACT F04606-75-D-0114-0052-01, TASK 76-10-28.

PAGE 1 OF 7

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P1 of 7

GENERAL DYNAMICS
FORT WORTH DIVISION

15 DECEMBER 1975

FB-111A GROUND ENGINE TRIM PROCEDURE

REVISIONS

THE FOLLOWING REVISIONS (ENCLOSURE A) TO THE FB-111A TRIM PROCEDURES WERE PREPARED TO INCORPORATE (1) THE PHILOSOPHY OF SEPARATE TOLERANCES FOR INITIAL TRIM AND TRIM CHECKS, (2) REVISED TRIM CURVES, (3) PROCEDURE IMPROVEMENTS, AND (4) FUNCTIONAL CHECK OF 7TH STAGE BLEEDS. THESE REVISIONS ARE SIMILAR TO THE RECENT F-111E TRIM PROCEDURE REVISIONS WHICH WERE RELEASED BY T.O. 1F-111E-2-6-1S-5. THE ATTACHED TRIM PROCEDURE REVISIONS SHOULD BE INCORPORATED BY T.O. 1F-111(B)A-2-6-1,

IT SHOULD BE NOTED THAT THE ENGINE TRIM SLIDE CALCULATOR SHOULD BE REVISED TO AGREE WITH THE TRIM TOLERANCES STATED IN PARAGRAPHS 3, 4, 12, AND FIGURE 2. THIS MAY POSSIBLY BE ACCOMPLISHED BY REVISING THE CALCULATOR SLIDE TRIM TOLERANCE INDEX MARKINGS.

THE REVISED TRIM CURVES WERE DEVELOPED FROM P&WA CURVES INST. 36799 AND INST. 36800, REV. 3-6-75. ESTABLISHED PER PSP ITEM M-6.

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ATCH 1

GENERAL DYNAMICS
Fort Worth Division

ENCLOSURE (A)
Page 1

12 December 1975

FB-111A GROUND ENGINE TRIM PROCEDURE REVISIONS

Revisions to the FB-111A trim procedures were prepared to incorporate (1) the philosophy of separate tolerances for initial trim and trim checks, (2) revised trim curves, and (3) procedure improvements. These revisions are similar to the recent F-111E trim procedure revisions which were released by T.O. 1F-111E-2-6-1S-5. The attached trim procedure revisions should be incorporated in T.O. 1F-111(B)A-2-6-1.

FB-111A GROUND ENGINE TRIM PROCEDURE REVISIONS FOR FB-111A WITH TF30-P-7 ENGINES

Reference: T.O. 1F-111(B)A-2-6-1 dated 29 May 1970,
Change 19, dated 2 May 1975.

1. On page 3-67, paragraph 3-74, a note is added following subparagraph e:

NOTE

For initial engine trim the P_{t7_m} tolerance listed on trim curves for "trim" must be achieved. For trim checks during troubleshooting (after engine has been flown) the values of P_{t7_m} listed on trim curves as "check" tolerance will indicate satisfactory engine trim.

2. On page 3-69, paragraph 3-76.f., the note following step 9 is changed to read:

NOTE

Obtain uncorrected barometric pressure (inches of mercury) and dew point temperature (^{o}F) from base operations or base weather forecaster. Record these data.

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3. On page 3-72, paragraph 3-78.a., the note following step 2 is changed to read:

NOTE

> Tolerance on military power target P_{t7_m} is ±0.10 in. Hg for initial engine trim. Tolerance on trim checks (after engine has been flown) is $^{+0.50}_{-0.20}$ in. Hg.

4. On page 3-72, paragraph 3-78.c., the note following step 2 is changed to read:

NOTE

> Normal tolerance on Max. AB P_{t7_m} is $^{+0.90}_{-0.20}$ for initial engine trim. (A tolerance of -0.9 is acceptable only if required to avoid exceeding AB TIT limit.) Tolerance on Max AB trim checks (after engine has been flown) is $^{+0.90}_{-0.20}$ in. Hg.

5. On page 3-72, paragraph 3-78.i., is changed to read:

   i. Perform operational checkout of nacelle vent/ejector regulating and shut-off valve per paragraph 15-9a through h.

6. On page 3-72, paragraph 3-78.d. is revised as follows:

   d. Determine cockpit indicated MAX A/B EPR band by entering MAX A/B engine pressure ratio card (figure 3-30) at existing OAT.

7. On page 3-73, Figure 3-24, Note 1 is revised as shown below.

Note 1. P_{t7_m} TOLERANCE

TRIM ±0.1 IN. Hg.

CHECK $^{+0.5}_{-0.2}$ IN. Hg.

8. On page 3-81, Figure 3-30 is revised per Figure 1 attached.

9. Page 3-79, Figure 3-29 is revised per Figure 2 attached.

10. On page 3-76, paragraph 3-78.s., is changed to read:

s. Adjust the main fuel control maximum rpm ground trim adjustment screw (figure 3-20) to set turbine discharge pressure P_{t7_m} within the normal target value determined in step a. Make the final trim adjustment in the increasing P_{t7_m} direction.

11. On page 3-76, paragraph 78.t.1. is changed to read:

1. Advance throttle to 88(±1) degree throttle lever angle (midzone 3) as measured on engine cross-shaft protector. Make the final zone 3 throttle adjustment in the increasing P_{t7_m} direction.

12. Page 3-76A, paragraph 3-78.t.5., the note following step 5 is revised as follows:

NOTE

Tolerance on Zone 3 P_{t7_m} is ±0.30 in. Hg for initial engine trim. Tolerance on Zone 3 trim checks (after engine has been flown) is ±0.60 in.Hg.

13. On page 3-76A, revise paragraph 3-78.t.6. as follows:

6. Repeat substeps 1 through 5 as necessary. Make the final trim adjustment in the increasing P_{t7_m} direction.

NOTE

Observe engine operating time limit. Refer to Organizational Maintenance Manual, GENERAL AIRCRAFT INFORMATION.

14. On page 3-76A, add paragraph 3-78.t.6.1. as follows:

6.1 After completing final Z-3 suppression trim, perform functional check of the 7th stage bleed system as follows:

(a) Advance throttle to 88° ±1° and stabilize 30 seconds. Record nozzle reading.

14. continued:

(b) Operate the CADC Self-Test Switch to HIGH: hold until Mach 2.3 indication, and release. Observe the step change in nozzle indication on both Mach sweeps, and the Mach number at which the step change occurs.

(c) Retard PLA to idle.

NOTE

Correct bleed operation and Mach lever rigging will result in a 0.6 unit step increase in nozzle indication at 1.75 Mach ±0.1 on Mach increase, and a 0.6 unit step decrease at 1.65 Mach ±0.1 on Mach decrease.

At OAT $>$ 60°F, a gradual upward drift in nozzle indication of up to 0.2 units may occur between 1.6 and 2.0 Mach; however, this is not related to and should not be confused with the 0.6 unit step nozzle change associated with bleed opening.

If no or very little change ($<$ 0.2 unit) is observed, or if the bleed opening or closing point exceeds the tolerance band given above, several problems may exist and further troubleshooting should be scheduled.

15. Page 3-77, Figure 3-27, revise note 1 as follows:

1. P_{t7_m} TOLERANCE

TRIM ±0.3 IN. Hg.

CHECK ±0.6 IN. Hg.

16. On page 3-76A, paragraph 3-78.t.12.c. is changed to read:

(c) Determine the required trim adjustment from trim adjustment table (figure 3-29A). If AB reset adjustment is required, repeat steps 8 through 12. Make the final trim adjustment in the increasing P_{t7_m} direction.

17. On page 3-76B, paragraph 3-78.t.13, a new subparagraph 13-1 is added to read:

13-1 Obtain uncorrected barometric pressure (inches Hg.) from base operations or base weather forecaster. Record this data.

(1) If uncorrected barometric pressure has changed more than 0.03 inch Hg. from the value obtained before trim (Step 3-76.f-9), repeat the trim procedure (Step 3-78).

NOTE

Engine trim accomplished with a change in barometric pressure more than 0.03 inch Hg. may result in abnormal engine operation. However, when operational necessity dictates that engine trim be accomplished under these conditions, an entry shall be made in the AFTO Form 781 to reflect that No. ___________ engine has been trimmed under adverse weather conditions and shall be retrimmed as soon as weather conditions permit an accurate trim.

18. On page 3-78B, revise paragraph 3-78.t.20. to read:

t. Close engine access doors.

19. T.O.1F-111(B)A-2-1 also requires a change to incorporate the revised Max A/B EPR check data per attached Figure 3.

20. T.O. 1F-111(B)A-2-6-1-1 will require the same revisions as prepared for the corresponding T.O. 1F-111(B)A-2-6-1.

21. Revisions to trim data makes the slide calculator out of date.

MAXIMUM AB EPR CHECK

OAT ^{O}F	MINIMUM NOZZLE AREA	EPR MINIMUM	EPR MAXIMUM
120	7.90	1.88	2.04
110	8.02	1.91	2.07
100	8.15	1.95	2.11
90	8.30	1.99	2.15
80	8.47	2.00	2.16
70	8.65	2.00	2.16
60	8.80	1.99	2.15
50	8.96	2.02	2.18
40	9.14	2.05	2.21
30	9.30	2.07	2.23
20	9.46	2.09	2.25
10	9.63	2.11	2.27
0	9.70	2.13	2.29
-10	↑	2.14	2.30
-20		2.15	2.31
-30		2.16	2.32
-40		2.16	2.32
-50		2.16	2.32
-60	↓	2.17	2.33
-65	9.70	2.17	2.33

Figure 1: FB-111A Engine Pressure Ratio Card

TF-30 P-7 Engine Trim Shift Investigation Program
Pease AFB, New Hampshire August 6 - September 3, 1974

Log of Engine Test Program

August 26

Program personnel began arriving at Pease AFB around noon. An update was received on the aircraft status and the progress of the installation of two main fuel controls supplied by P&WA. These fuel controls were benched at P&WA and preset. They also had the T_{T2} service probes instrumented with kielhead thermocouples (4 each) across the front face of the sensor. P&WA had also supplied special N_1 and N_2 tach generators for precise RPM measurement and two fuel coxmeters for accurate fuel flow measurement. PWA personnel proceeded to assist in the installation of the Fuel Control T_{T2} sensors in the inlet case and the installation of the N_1 tachometers within the aircraft nose cone area. Difficulty was encountered in routing two sets of wires through the inlet case vane cavity. Attempts at routing the N_1 wire was postponed in order to allow the aircraft to be towed to the trim pad during the night shift. Meanwhile the van had been positioned at the trim pad and was in process of being set up. The aircraft assigned for this test was No. 68-256. Fuel control S/N 202020 was installed in the #1 engine (left engine) P-675616. Fuel control S/N 202008 was installed in #2 engine (right engine) P-675610. P-675616 had 865 hours and P-675610 had zero hours.

August 27

Aircraft had not been transferred to trim pad during night shift as expected. It was released from the Hanger at 9:00 A.M., transferred to a refueling station and delivered to the trim pad. It was secured by 12 noon. The total fuel load at this time was 37,000 lbs. The plane utilized two external wing tanks. The air force crew proceeded with the instrumentation installation on the aircraft and hookup to the P&WA instrument van. All installation was assisted by or supervised by P&WA personnel. The following instrumentation of the engines was performed.

No. 2 Engine - N_1 tachometer (PWA) with aircraft tachometer.
No. 1 Engine - N_1 tachometer (PWA) with aircraft tachometer.
N_2 tachometer (PWA) with aircraft tachometer.
(2) Wf ,(2)Wf_T, P_b, P_{T2}, P_{S3}, P_{S3} enc., P_{T7} enc, P_{T7} mix,
P_s Nacelle, T_{T2} Harness, T_{T5}Harness, (4) T_{T2} keilhead on Fuel Control T_{T2} sensors, (2) T_T ECS Valve (upstream and downstream).

External Instrumentation

Pambient, Tambient in suppressor inlet plenum,
T dew point (sling cyclometer)
T ambient (thermometer under wing and weather station monitoring)

Instrumentation setup was completed at 9:00 P.M. engines were started and proceeded with leak checks at idle, mil, and A/B zones. All passed leak checks with no problems. Ground Crew prepared for engine time by computing trim targets. The No. 1 engine was set at mil PLA and a visual check showed it to be only very slightly below required trim level for ambient temperature conditions. Within 5 seconds of the engine accel to mil condition, a complete data point was taken. 5 more data points were taken at 1 minute intervals in order to monitor and record the stabilization

ATCH 2

time of the engine. The engine was then advanced to mod Z-3 setting and within 5 seconds a data point was recorded. Four more data points were recorded at 30 second intervals in order to monitor the stabilization time in Z-3. The engine was then advanced to max Z-5 and within 5 seconds, a data point was taken. Two more points were recorded at 30 second intervals. A fourth point was not completed due to failure of the ejector cooling water supply and necessity for PLA retard out of A/B. This fourth point was deleted. The engines were cooled and shut down. Testing was terminated for the day at 11:45 P.M. Tentative resumption of testing was scheduled for 5:00 A.M. next day for expected cold temperature weather conditions.

August 28

Crew and PWA personnel assembled at 5:00 A.M. for resumption of program, however the necessary ground support equipment had been commandeered during the night shift by some other trim crew. The cold front expected did not arrive at this time. Ground support equipment was acquired by 8:00 A.M. Engines No. 1and 2 were started and the following program was run on engine No. 1. Repeatability of the data point settings: Set mil, stabilized 5 min and took full data point advanced to mil Z-3, stabilized 1 minute and took full data point, advanced to Z-5, stabilized to 30 seconds and took full data point. Returned to idle for 30 seconds duration. Repeated the above 3 data points in the same sequence twice except for stabilizing the mil point only 3 minutes.

The last 3 points taken above were set as the base data points for evaluating very high humidity conditions. The weather at this time was cold light rain. Prior to engine shutdown; an inlet vortex was observed on the No. 1 engine above idle conditions. Engines were shut down to await arrival of a base photographer called to photograph the inlet vortex. While the engine was shut down, the tail feathers were manually spread to the open position on engine No. 1. The purpose was to gather information on the engine operating level at which the tailfeathers would close due to air loading. Photographer arrived and engine No. 1 was started. A slow accel revealed that the tailfeathers started to close around 75% N_2 RPM setting and were fully closed at 85% N_2 RPM. The accel rate through this region was slow and the tailfeather closing rate was also slow and smooth. Photographs were then taken of the inlet vortex. A light rain was still falling at this time. The engine was shut down to await a weather change.

At noon a change in humidity level was verified and the engines were started. Took 3 data points on engine No. 1 at the following settings, military, mid Z-3 and max Z-5. A standard stabilization time for all data points was inspected for the duration of testing unless otherwise specified, these were 5 min. - mil; 1 min. - mid Z-3, 30 sec. - max. Z-5.

Another change in humidity was verified after 3:00 P.M. and another 3 points were taken at mil, mid Z-3, and max Z-5.

The plane was removed from the suppression refueled and reinstalled. Desired weather change did not materialize and testing was terminated for the day.

August 29

Team gathered at 7:00 A.M. Due to adverse weather the team met to establish alternate fill in programs for the day which would be beneficial to the program. Weather was cool with light to moderate rainfall. At noon the engines were started, program was to evaluate ECS valve operation and leakage. With ECS on right engine No. 2, the No. 1 engine was stabilized at 1700°F T_{T5}. ECS transfer checks were made. ECS valve operation appeared satisfactory. ECS reset on No. 2 engine. Following points taken on No. 1 engine: 1700°F T_{T5}, 1800°F T_{T5}, 1900°F T_{T5} and mil. Shut down and removed ECS valve from No. 1 engine. Installed blocker plates in ECS valve location on No. 1 engine. Started engines and repeated the above 4 point program. Shut down and left blocker plates in position. Reversed the location in the inlet case of the instrumented main fuel control T_{T2} probe. Started engines and ran the following points on engine No. 1: mil and mid Z-3. Shut down.

Removed the instrumented fuel control probe from the inlet case and installed a dummy probe to close up the port. Left the dial indicator T_{T2} probe in the inlet case main fuel control T_{T2} probe location. The blockage plates were still left in the No. 1 engine ECS valve location. Prepared to run a false varying T_{T2} program for the No. 1 engine main fuel control. This was done by immersing the T_{T2} probe in a container of glycol preheated to 85°F. Then placing this container in an ice-water bath in order to steadily decrease the glycol temperature. Started engine No. 1 and ran program. Took 17 data points at mil setting with decreasing false T_{T2} sense temperatures from 85°F down to 43°F. The time required for the total temperature change was 45 minutes and was close to linear. Shut down.

Removed dummy T_{T2} probe from inlet case. Switched the dial indicator T_{T2} probe to the original A/B T_{T2} probe location on the inlet case. Reinstalled the instrumented main fuel control T_{T2} sense probe in its original MFC probe location in the inlet case. Removed the blockage plates from the ECS valve location and reinstalled the valve in the No. 1 engine. Started both engines and set No. 1 engine at mil power and No. 2 engine at 75% N_2 RPM. Cycled ECS between No. 1 and 2 engines for on the spot inspection of General Dynamics representative. Took data points at less than mil power on No. 1 engine with ECS selection alternately left and right for each of the power settings. Low fuel level caused end to this program run. Shut down and removed aircraft from suppressor, refueled, and reinstalled. This terminated testing for the day.

August 30

Crew reported at 5:00 A.M. for cold day program but temperatures did not drop sufficiently. Weather was very high humidity with light rain. Selected the cold day gas generator program to run next with slight modification. Ran mil, mid Z-3 with standard stabilization. Then using the power lever, set and took data points at decreasing N_2 RPM, 1% at a time down to 6% N_2 from mil. Stabilization times for these points was 2 minutes.

Because of questions concerning the data taken the previous day on the ECS valve program, the following points were set and recorded. Mil and mid Z-3 with ECS on No. 1 engine and mil and mid Z-3 with ECS on "Both" which is actually "ECS on No. 2 engine". As engine was sufficiently hot, stabilization time for ECS program was kept at 2 min.

mil P_{TS} and 20 sec - mil Z-3 P_{TS}. Engines were shut down. The inlet suppressor section was removed from the No. 1 engine location. Started engine and took data points on No. 1 engine at mil and mid Z-3; with ECS selection on No. 2 engine. Standard stabilization times were used.

Tried to acquire a 7th bleed open point but found the mach sweep check would not function properly on the No. 2 engine. The Mach motor would not operate. Tried moving the Mach lever at the main fuel control but was too stiff to move at all. Cancelled 7th B/O check at this time. Shut down and checked movement of MFC Mach lever. It would move easily by hand and was set at full rearward (7th B/C) position.

Removed ECS valve from No. 1 engine and installed blocker plates. Started engines and took the following points on No. 1 engine with ECS set for No. 2 engine. Mil, mid. Z-3, and max. Z-5 with standard stabilization. Brought engine to idle and vented the P_{T2} sense line to atmosphere at the main fuel control port location. Vented the main fuel control P_{T2} port to atmosphere also. Ran the following points with standard stabilization on No. 1 engine with ECS set for No. 2 engine: mil, mid Z-3, and max Z-5. Shut down and reconnected the P_{T2} line to the MFC. Removed the blocker plates and reinstalled the ECS valve. Started engines and ran the following on engine No. 1 with ECS on No. 2 engine: Mil, mid Z-3, and max Z-5 with standard stabilization.

Shut down and started process of moving instrumentation lines from engine No. 1 to engine No. 2. Halfway through the changeover a change in the running program was affected and all instrumentation was reconnected to the No. 1 engine. The following lines had been disconnected and reconnected. P_S Nacelle, P_{T7}, ENC, P_{S3} ENC, P_{T2} F/C, and P_{bFC}. The aircraft was removed from the suppressor, refueled and reinstalled. Testing terminated for the day.

August 31

Team reported to trim pad at 5:00 A.M. and set-up to run the cold day to hot day temperature tracking program. Started engines and took the following data points on the No. 1 engine (ECS No. 2 engine): mil, mid Z-3, and mil again. The first set of points was taken at a day's temperature of 58°F with very high humidity. A repeat of the above three points was taken throughout the day as possible with the following criteria. Every 2°F rise in the day's temperature or every 2°F increase in dew point depression from ambient temperatures. Tracked the weather with runs up to 72°F ambient temperature and dew point depression increase of 8°F. During this time, temperature sensing devices and weather tower readings were carefully monitored throughout the day for comparison and evaluation. This data was recorded and noting abnormalities, it was decided to keep monitoring and recording this relationship through the rest of the test duration. At end of cold day to hot day tracking program, attempts were resumed to try and check out operation and position of 7th bleeds in relation to a few previously recorded points which indicated 7th bleeds in the open position. Manually set Mach lever at fuel control in 7th B/O position and took the following points on No. 1 engine; mil, mid Z-1 with ECS No. 2 engine. cycled Mach lever several times and saw definite 7th bleed closing and opening shifts in engine parameters. Set 7th bleeds in closed position and with ECS still on No. 2 engine, took following points on No. 1 engine; mil, mil (repeat with 7th bleed cycled once), mid Z-3, and max Z-5.

Shut down and removed instrumentation from No. 1 engine and installed it on No. 2 engine. Removed aircraft from supressor, refueled, and reinstalled. Testing terminated for the day.

September 1

Crew reported to trim pad and completed instrumentation checkout on No. 2 engine. An additional pad trim kit was hooked up to the No. 1 engine. The purpose was to keep monitoring some parameters on the No. 1 engine and record from the trim kits on both engines at the same times and conditions for van instrumentation readings.

Started engines and checked the "as received" trim condition of the No. 2 engine in mil and mid Z-3. The mil trim was found to be at an acceptable level for the test purposes but the A/B supression was off. Performed 7th bleed check points for the No. 2 engine with each lever operation. The trim crew then proceeded to set suppression within the required band. This exercise was designated as an instruction for new trim crew members and progressed slower than normal. After suppression was set, the engines were shut down to await the day's hot temperature. During down time, the aircraft was refueled and the dial indicator T_{T2} sense probe was installed in the No. 2 engine inlet case at the A/B T_{T2} probe port location. The A/B T_{T2} probe was tied aside where it would sense only ambient temperature.

At the day's peak high temperature level, the engines were started and the hot day gas generator program was done on No. 2 engine as followers: Mil, mid Z-3, Z-5 with ECS No. 1 engine. Then with remote trimmer the mil N_2 setting was reduced by 200 RPM increments and points taken at mil throttle setting and mid Z-3 setting. Eight points were taken this way. The engine was then returned to the original N_2 RPM and T.I.T. level verified before the down trim sequence and another set of mil, mid Z-3, and mil were recorded. The No. 1 engine which had been running at 80% during the above test was then advanced to mil, ECS changed to No. 2 engine, then points were taken at mil and mid Z-3 with the trim kit on No. 1 engine. Engines were then shut down and restarted periodically as required to record mil, Z-3, mil for No. 2 engine and mil, Z-3, mil for No. 1 engine with trim kit only. ECS was always opposite of engine being tested. The points were selected for 2°F drop in ambient or 2°F dew point depression increase whichever occurred first. Testing terminated for the day at 11:00 P.M.

September 2

Crew reported to trim pad early in A.M. and ran the final cold day low temperature point from the previous night's program on both engines in the same manner. The engines were then shut down and the instrumented fuel control T_{T2} sense probe was removed from the No. 2 engine inlet case. A dummy probe was installed in order to cover the case probe port. A glycol probe both was prepared and the same false T_{T2} program run previously on No 1 engine, was repeated on the No. 2 engine at this time. Only the following parameters were recorded. P_b, P_{T7} ENC, P_{AMB}, P_{S3} ENC, N_1, N_2, Wfe1, Wfe2, T_{T2} T_{T5}, T_{T2} KH(1&2), T_{T2}Plenum, T_{T2}-1, T_{T2}-2, Pbar, cockpit readings, trim kit readings, T dry bulb, T wet bulb, and O.A.T. Shut down engine and reinstalled instrumented fuel control T_{T2} sense probe. Removed aircraft from suppressor, refueled, and reinstalled. Started engine No. 2 and ran hysteresis check on the throttle settings by utilizing the protractor used to set the engine throttle during trim operations. Procedure was to set the protractor at mil degrees or close to mil by advancing the throttle or decreasing the throttle with no allowable over shoot. Five points were recorded in this test (up to 65°, down to 65°, up to 66°, down to 65 1/2°, down to 66°) Hooked up the remote trimmer to engine No. 2 and run the cold day gas generator down trim by reducing mil setting N_2 in 100 RPM increments to full down trim position on fuel control and recording the mil points. Engine was then reset to the original

N_2 RPM and TIT for the start of this program, and then the program was repeated but this time only the mid Z-3 settings were recorded. Engine No. 2 was then reset to original N_1 and TIT trim conditions. One final mil point was recorded on both No. 2 and No. 1 engines. Engines were shut down and testing program closed out.

September 3

Final data evaluation and program discussions were held. Reocmmendations and conclusions were approved by team members and observers. A briefing session was held with the chief of maintenance of the base, with all crew members present. The recommendations and conclusions were presented and accepted.

TF30-P-7 TRIM REPEATABILITY INVESTIGATION PWA-5282 June 1975

This report presents the results of the trim investigation conducted under TF30 PSP Item M-6 on TF30-P-7 engines installed on an FB111-A aircraft at Pease AFB, NH. The tests were run during the period 27 August 1974 - 2 September 1974 under the direction of a P&WA engineering team and observed by representatives from Oklahoma City ALC, SAC/LGME, ASD/SD1110-LJ and General Dynamics/Ft. Worth.

3.0 CONCLUSIONS AND RECOMMENDATIONS

3.1 CONCLUSIONS

(1) Existing trim procedures, trim curves and humidity corrections for the TF30-P-7 are satisfactory and no revisions are required.

(2) Repeatability of trim checks made over the range of climatic conditions experienced during the 7-day test period, using P&WA instrumentation, was within one trim band width or less.

(3) The 7°F T_{t2} recovery loss factor assumed for the control T_{t2} sensor and used in the control schedule design, is valid. No changes to this factor are required.

(4) Rapid changes in or inaccurate readings of ambient pressure, temperature or dew point can result in incorrect trim target calculations and lead to engine mistrimming.

(5) A malfunctioning Mach lever actuator, causing inadvertent 7th-stage bleeds open during trim operations, can result in overtrimmed main engine and oversuppressed ENC trim conditions during subsequent engine running with normal bleed operation.

3.2 RECOMMENDATIONS

(1) The USAF should establish a procedure for accurately measuring temperature and dew point on-site during trim runs, preferably in the inlet sound suppressor plenum, to assure accurate trim target calculation.

(2) Ambient pressure, temperature and dew point should be recorded before and after engine trim. If ambient pressure variation exceeds ±0.3 in Hg or ambient temperature variation exceeds 4°F between start and completion of the trim, the trim should be repeated with new values.

(3) A one-time check of 7th-bleed valve and Mach lever operation should be made on all FB111A aircraft and a 7th bleed check incorporated in the trim procedure.

(4) Operational restrictions should be imposed to avoid trimming with the sound suppressor during wind conditions which can cause recirculation. If operational requirements dictate that an engine be trimmed during adverse conditions, the engine trim should be designated "interim" and a retrim performed as soon as possible.

(5) A narrow-trim/wide-check band trim tolerance system should be used for the TF30-P-7 which will assure satisfactory trim while limiting unnecessary retrim.

FZA-12-6022
7 October 1974

TF30-P-7 ENGINE INSTALLED TRIM SHIFT/REPEATABILITY TESTS

AT PEASE AFB, NEW HAMPSHIRE

FINAL ENGINEERING REPORT

FOR THE PERIOD 26 AUGUST TO 3 SEPTEMBER 1974

FOR

SACRAMENTO AIR LOGISTICS CENTER

CONTRACT F04606-74-D-0063
TASK 75-20-31

The investigation reported in this document was requested by Sacramento ALC (MME), McClellan AFB, California, under the above noted contract and task number. However, it does not necessarily bear the endorsement of the requesting agency.

Prepared by:

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Project Propulsion Engineer
Propulsion Analysis

Approved by:

R O Doughty

R. O. Doughty
Group Engineer
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JP McClain

J. P. McClain
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GENERAL DYNAMICS
Fort Worth Division

PAGE 1 OF 21

ATCH 4

1. FOREWORD

This report was prepared by General Dynamics' Fort Worth Division for the Sacramento Air Logistics Center, McClellan Air Force Base, California.

The contract specified the services of a propulsion engineer to participate in the TF30-P-7 installed trim shift/repeatability tests at Pease AFB, New Hampshire.

The General Dynamics representative was G. J. French, who was responsible for the preparation of this report.

2. ABSTRACT

The TF30-P-7 installed trim shift/repeatability test program was conducted at Pease AFB, New Hampshire, by Pratt & Whitney Aircraft (P&WA). The tests were conducted in accordance with the test plan established at the 6 June 1974 meeting at Oklahoma City ALC. Preliminary analyses, which were completed at Pease prior to termination of the test program, indicated that the engine operation was repeatable and generally consistent with the installed trim curves. Some inadequacies in trim curve tolerances and field operating procedures were discovered. Data analyses will be performed under the F-111E trim review call contract, Sacramento ALC Task No. MME 74-20-98.

3. TABLE OF CONTENTS

4. LIST OF ILLUSTRATIONS, TABLES, AND ABBREVIATIONS

4.1 List of Illustrations

4.2 List of Tables

4.3 List of Abbreviations

Symbol		Units
A/B	Afterburner	-
ECS	Environmental Control System	-

4.3 List of Abbreviations (Continued)

Symbol		Units
^{o}F	Degrees Fahrenheit	degrees
L/H	Left-hand	-
N_1	Low compressor rotor speed	rpm
OAT	Outside air temperature	^{o}F
P&WA	Pratt and Whitney Aircraft	-
$P_{T/M}$	Mixed turbine exhaust total pressure	in. Hg A
P_{AMB}	Ambient pressure	in. Hg A
R/H	Right-hand	-
T_{t2}	Compressor-Face total temperature (assumed equal to OAT for this report)	^{o}R
θ_{T2}	T_{t2} (^{o}R)/518.7	-

5. DISCUSSION

INTRODUCTION:

The FB-111A/TF30-P-7 Installed trim shift/repeatability test program was conducted at Pease AFB, N. H., on August 26 through September 3, 1974, in accordance with test objectives and plans. Tests were conducted on FB-111A No. 68-256 on the following engines:

Position	Serial No.	Time
Left	675616	865 hours
Right	675610	New (from overhaul)

All tests were run in the trim pad sound suppressor.

The members of the test team are listed in Appendix A.

DISCUSSION:

The run plan was prepared by P&WA based on the preliminary test plan prepared at Oklahoma ALC on 6 June 1974. The P&WA instrumentation van provided steady-state instrumentation very similar to the Convair 504 instrumentation trailer. Automatic or transient recording equipment was not used. The procedure was to take only one set of data at each run condition. A number of restrictions were not observed which would not have been allowed for engine trim determination, i.e., P&WA "504" testing. For example, some tests were conducted with exhaust gas recirculation and with rain falling.

An upward shift in operating level of the left engine was noted during bleed checks in the ~~thrid~~ THIRD day of testing. P&WA attributed the shift to ECS bleed valve (Item 5) malfunction; therefore, a number of tests were conducted with the ECS duct plugged. These tests verified that the Item 5 was operating properly.

A detailed analysis indicated that the magnitude of the shift in Zone 3 A/B was too large to be due to ECS bleed flow rates. It was determined that the shift was approximately the size that could be attributed to 7th stage compressor bleeds. Therefore, it was concluded that the 7th stage compressor bleeds were open during the first three days of testing. P&WA suggested that this was caused by a Mach lever malfunction; however, the Pease engine maintenance people insisted that the Mach levers were nulled prior to the test. Subsequent checks of Mach lever operation using the CADC test switch showed the 7th stage compressor bleeds to be operating at an indicated Mach 2.2 and 1.9 on the left and right engines, respectively. (The 7th stage bleeds should operate at Mach 1.75 ± 0.10 on the FB-111A.)

Measurement of ambient temperature and humidity conditions was noted to be very difficult on the trim pad. Differences in

OAT of up to 6°F were measured between four thermometers at different locations around the trim pad. Similar differences were noted in OAT and dew point temperature between control tower readings and results obtained using a sling psychrometer and psychrometric chart. Differences of up to 4°F in OAT were noted on the same thermometer during a 5-minute period. The temperature measurement difficulties are apparently due to wind patterns, thermal masses, radiation, cloud cover, and movement of weather fronts. Pease AFB personnel will gather temperature data for the next several months in an attempt to establish the best method for measuring ~~A/B~~ temperature for their trim operations.

An analysis of the trim data was performed at Pease AFB prior to termination of the test program. In general, the engines operated as predicted, and in accordance with the installed trim curves. A summary of the trim test results is presented in Table 1 and a more complete description of the analysis is presented in Appendix B.

The following observations were made regarding field trim operations during these tests:

1. SAC trim crews are performing extremely good trims. They understand what they are doing and are trimming to mid-band of the trim curve.

Table 1

SUMMARY OF TRIM DATA
TF30-P-7 TRIM TESTS @ PEASE AFB

POWER	ENGINE POSITION	OAT RANGE °F	DEW POINT DEPRESSION RANGE °F	$\Delta P_{T7M}/P_{AMB}$ OPERATING BAND	BLEED EFFECTS, $\Delta P_{T7M}/P_{AMB}$ ECS	BLEED EFFECTS, $\Delta P_{T7M}/P_{AMB}$ 7TH BLEEDS
MILITARY	LEFT	57-81	1-35	0.020 (1.19 bandwidth)	0.021	0.022
	RIGHT	57-80	2-33	0.018 (1.07 bandwidth)	0.047	0.031
ZONE 3 A/B	LEFT	59-72	1-35	0.027 (0.68 bandwidth)	$\simeq$ 0.030	0.11
	RIGHT	57-80	2-34	0.014 (0.35 bandwidth)	-	-
MAX. A/B	LEFT	63-80	1-34	0.016 (0.27 bandwidth)	-	-
	RIGHT	69-79	8-33	NIL	-	-

2. A better method of determining ambient temperature and dew point depression is required.
3. 7th stage bleed checks are needed during engine trim operations.
4. An FB-111A fleet check is needed for Mach lever rigging and 7th stage bleed operation.
5. T.O. 1F-111(B)A-2-6-1 includes a check of a 7th stage bleed throttle position switch in items j10-j13 of paragraph 11-62. This check should deleted.
6. Bench calibrated fuel controls do not yield acceptable initial engine trim. The bench calibrations should be revised.
7. The sound suppressor needs operating restrictions for both tailwind and near-calm operating conditions. These conditions can result in recirculation of engine exhaust gas and suppressor cooling water.
8. Instructions should be added to trim procedures to check OAT and dew point depression at the beginning and at the completion of trim runs to preclude improper trims due to rapidly changing weather conditions.

SUMMARY AND CONCLUSIONS:

The operation of the TF30-P-7 engine installed in the FB-111A is repeatable and generally consistent with the installed trim curves. However, trim tolerances should be reviewed because the measured engine repeatability is of the order of the allowable trim tolerance, without allowances for field instrumentation inaccuracies. The incorporation of the F-111F trim philosophy would relieve this problem somewhat. (F-111F Technical Orders require a very tight tolerance during the initial trim with a larger tolerance for subsequent trim checks.)

A more complete analysis of the trim data is needed and will be performed by General Dynamics under the F-111E Trim Review Task, Sacramento ALC Task No. MME 74-20-98. (Additional analysis will also be performed by P&WA under their Product Support Program.) The field trim observations discussed above will be evaluated further under the F-111E Trim Procedure Review Task, Sacramento ALC Task No. MME 74-20-77.

Appendix A

TEST TEAM MEMBERS

Attendees	Address
John J. Penney	Okla City ALC, Tinker AFB, OK/MMTIFA
Henry A. Calderon	P&W Acft, E. Hartford, CT
Ed Reynolds	Okla City ALC, Tinker AFB, OK/MMEPS
Jack Tarbox	P&W Acft, E. Hartford, CT
Floyd Evans, Jr.	ASD/SD1110-LJ, WPAFB, Ohio
Gerry J. French	General Dynamics, Fort Worth, Texas
Maj. J. L. Pettigrew	SAC/LGME, Offutt AFB, Nebraska
TSgt Richard Beal	509 FMS P/B, Engine Cond.
SSgt Robert Ritala	509 FMS P/B, Engine Cond.
A1C Alex Gerrard	509 FMS P/B, Engine Cond.
Chuck Eaton	P&W Acft, Fuel Controls, E. Hartford, CT
Norm Fish	P&W Acft, Instrumentation, E. Hartford, CT
Bruce A. Maclachlan	P&W Acft, Project Engineer, E. Hartford, CT
E. (Ted) Ralston	P&W Acft, Stability & Controls, E. Hartford, CT
SSgt William Conoly	509 FMS P/B, Engine Cond.
Sgt Carlos Martinez	509 FMS P/B, Engine Cond.
Sgt Byron Callahan	509 FMS P/B, Engine Cond.
A1C Byron Smith	509 FMS P/B, Engine Cond.

Appendix ~~B~~

1.0 Military Power Data Analysis

The military power data are compared to the mid-band trim curve as shown in Figures B-1 and B-2 for the left and right engines, respectively. All trim data were corrected to equivalent dry P_{T7M}/P_{AMB} using P&WA humdiity correction curves. Both engines generally operated in accordance with the trim curve slopes and tolerance except that the left engine repeatability slightly exceeded the trim tolerance of 0.017. It should be noted that neither of these engines were trimmed in military power prior to running these tests. All of the data points lower than the trim curve mid-band are either known bleed tests (ECS or 7th stage) or were taken early in the test program on the left engine when the 7th stage bleeds were believed to be open.

K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
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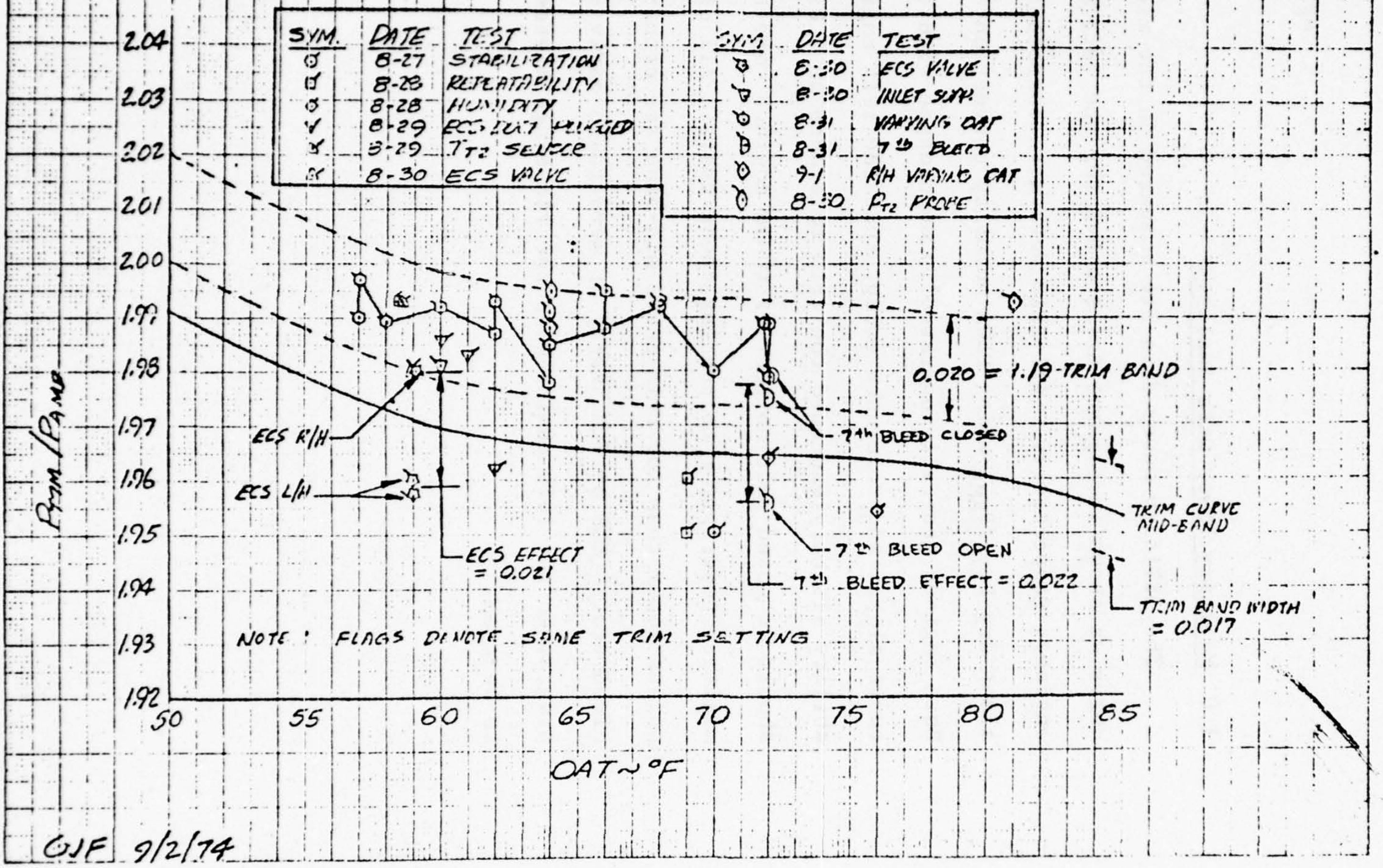
FIGURE B-1
MILITARY POWER TRIM SUMMARY
TF30-P7 TRIM TESTS @ PEASE AFB
L/H ENGINE



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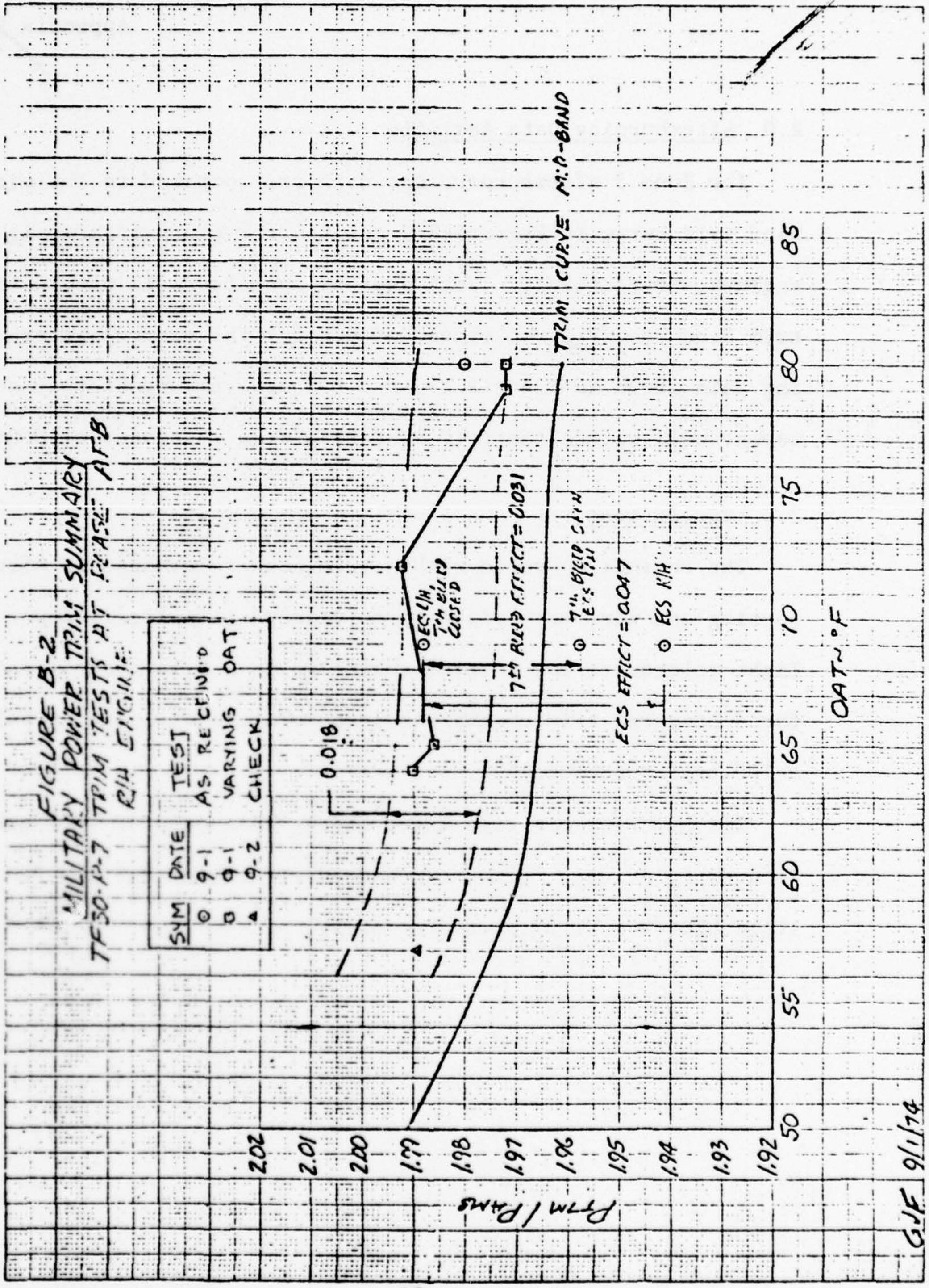

FIGURE B-2
MILITARY POWER TRIM SUMMARY
TF30-P-7 TRIM TESTS AT PEASE AFB
R/H ENGINE

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2.0 Afterburning Data Analysis

The Zone 3 afterburner test data are compared to the mid-band trim curve in Figures B-3 and B-4 for the left and right engines, respectively. Both engines operated well within the trim band P_{T7M}/P_{AMB} tolerance of 0.040. The maximum afterburning data shown in Figures B-5 and B-6 are very consistent and repeat well within the trim band P_{T7M}/P_{AMB} tolerance of 0.060.

3.0 Conclusions

The engines operated within trim band tolerances in afterburning and were very close to tolerances in military power. Tight tolerances for initial engine trims and larger tolerances for subsequent trim checks should be adopted (similar to F-111F/P-100 trim procedures).

The need for positive bleed checks as a part of trim procedures is evident from the measured effects of ECS and 7th stage bleeds on trim pressure ratio.

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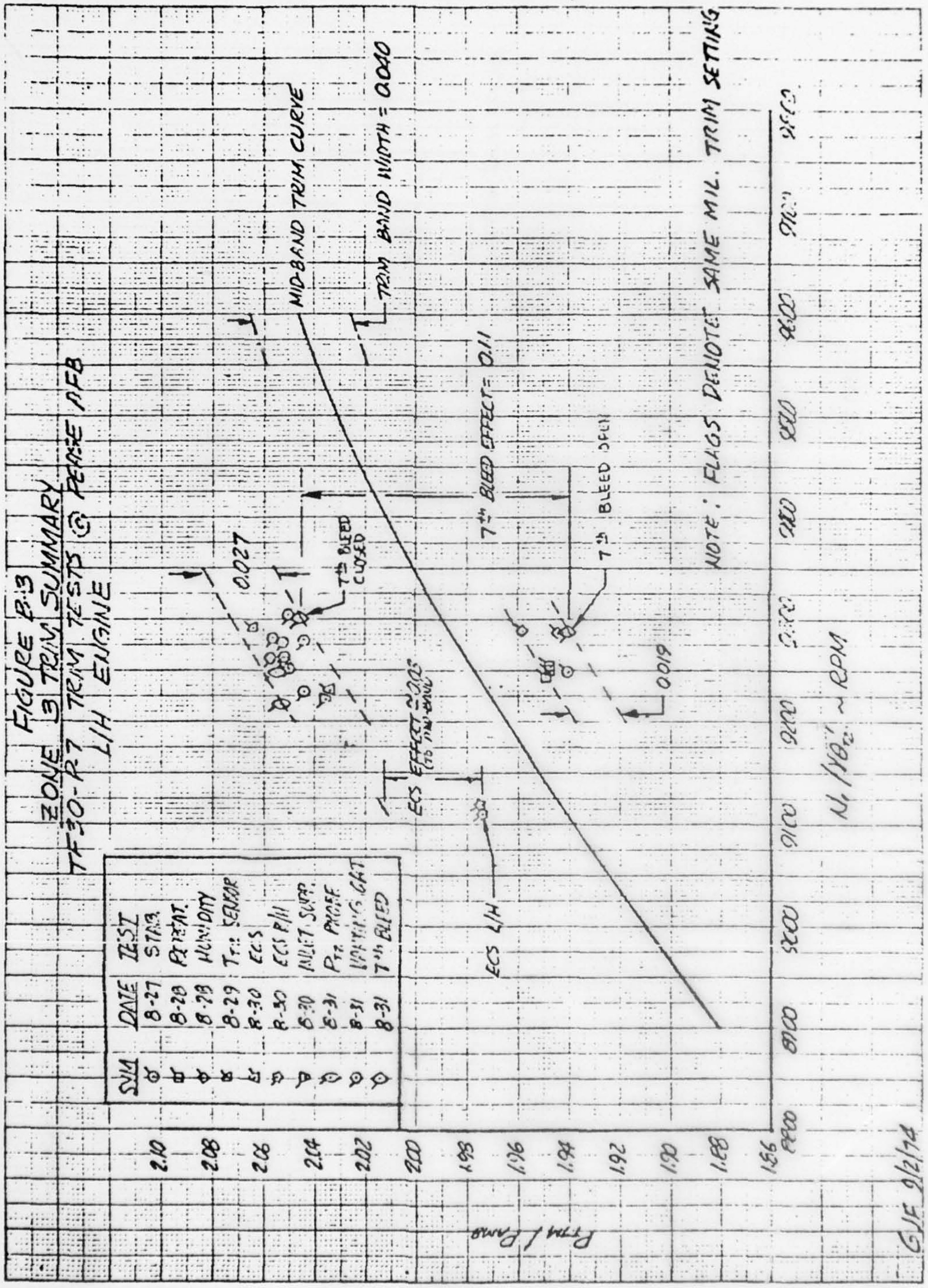

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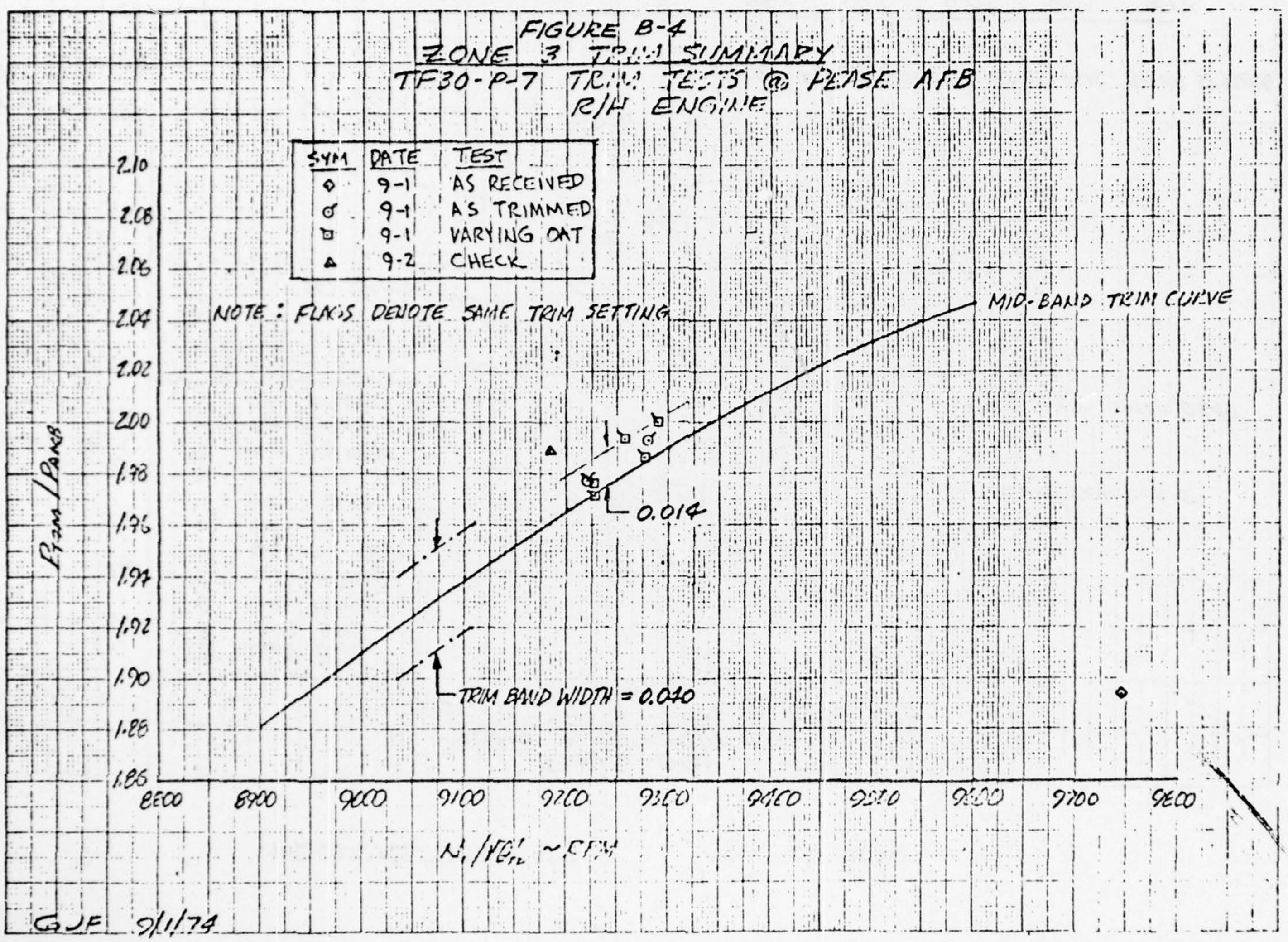

FIGURE B-4
ZONE 3 TRIM SUMMARY
TF30-P-7 TRIM TESTS @ PEASE AFB
R/H ENGINE

SYM	DATE	TEST
◇	9-1	AS RECEIVED
♂	9-1	AS TRIMMED
□	9-1	VARYING OAT
△	9-2	CHECK

NOTE : FLAGS DENOTE SAME TRIM SETTING

GJF 9/1/74

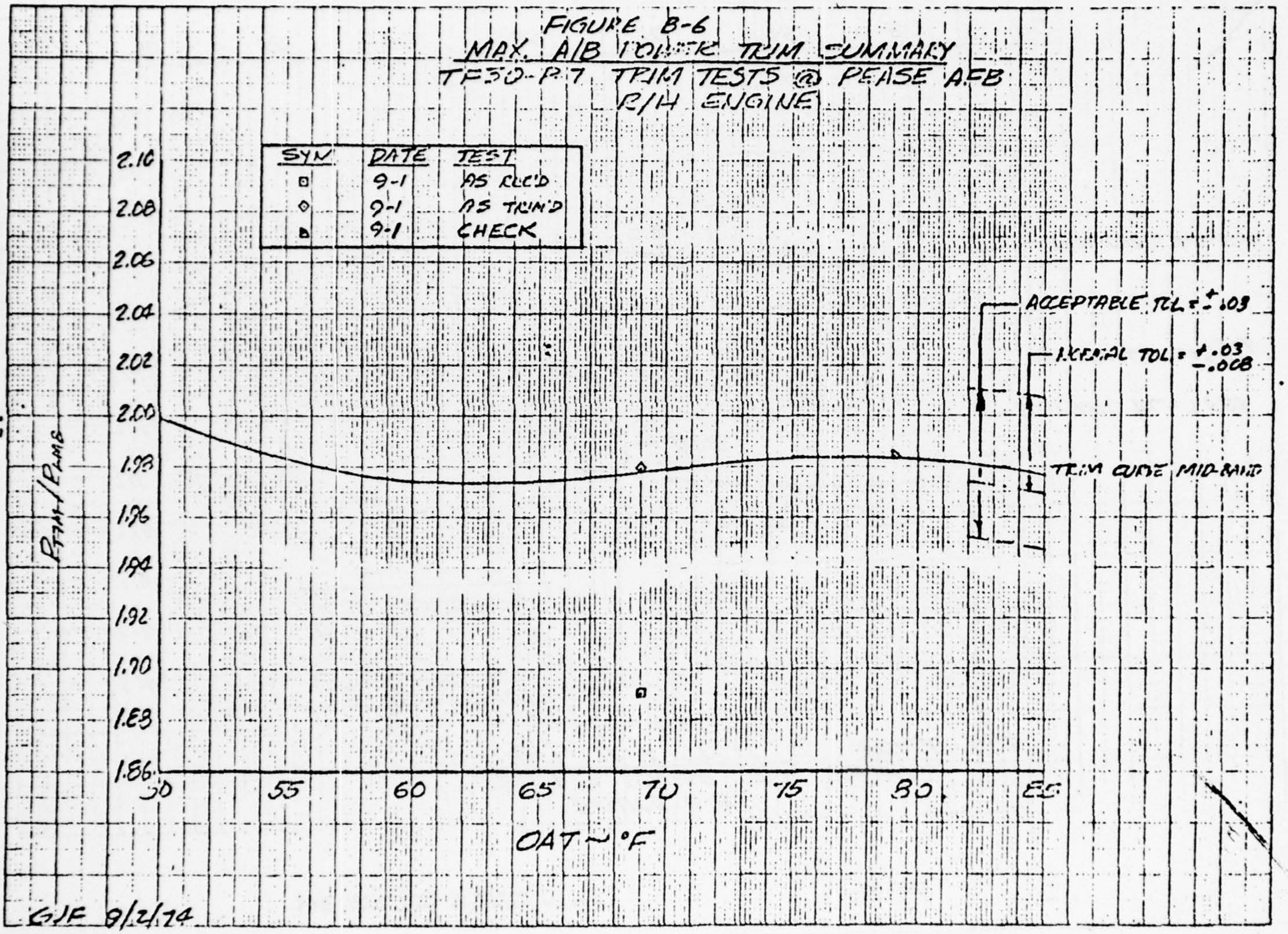

FIGURE B-6
MAX. A/B POWER TRIM SUMMARY
TF30-P7 TRIM TESTS @ PEASE AFB
R/H ENGINE

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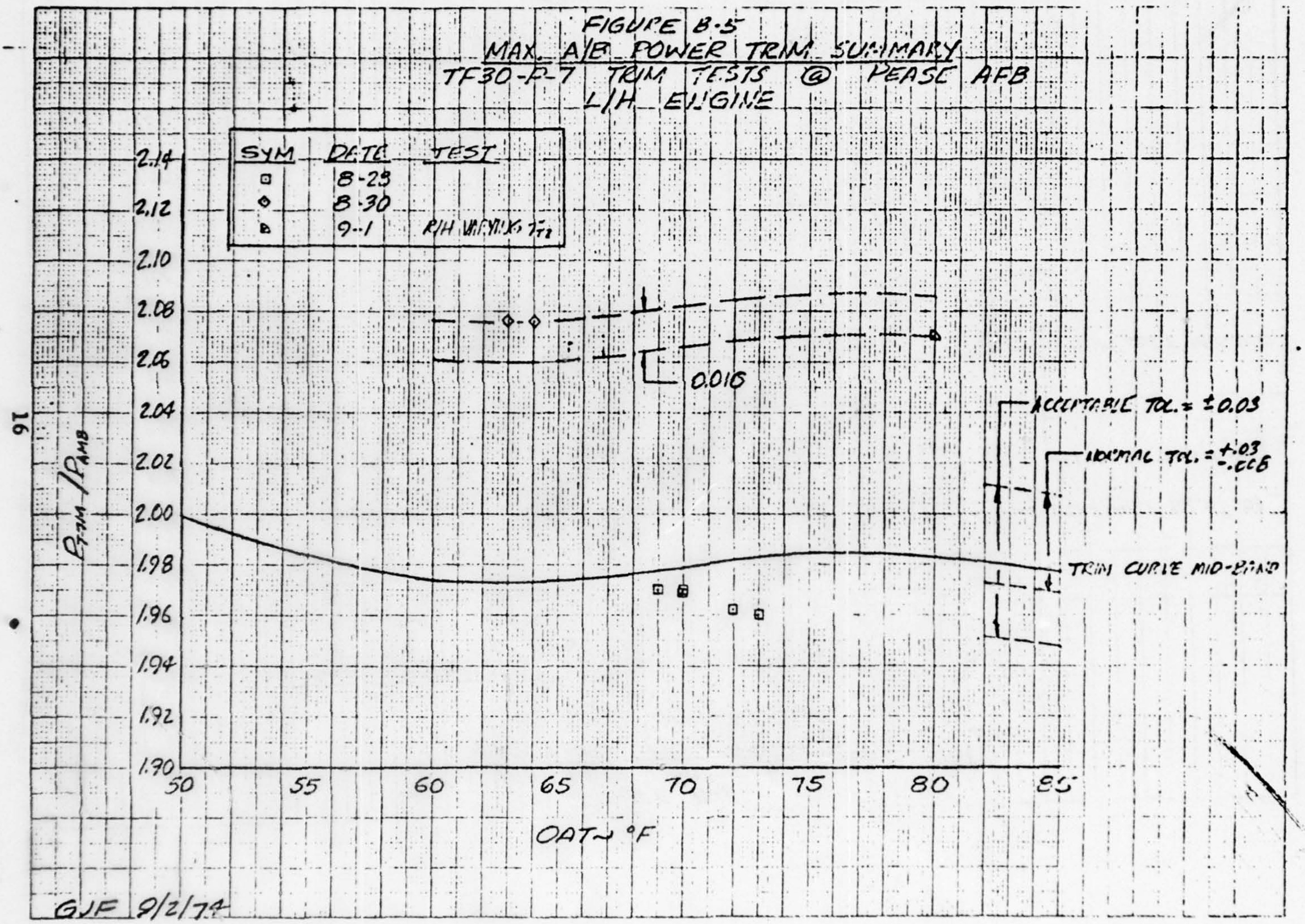

FIGURE B-5
MAX. A/B POWER TRIM SUMMARY
TF30-P-7 TRIM TESTS @ PEASE AFB
L/H ENGINE

GJE 9/2/74

THE EFFECT OF SIMPLIFYING ASSUMPTIONS AND INSTRUMENTATION ACCURACY ON JET ENGINE TRIMS

1. OPERATIONAL IMPACT OF ENGINE TRIM:

a. Proper trim is a prerequisite to satisfactory engine operation when full throttle (or a throttle stop) is routinely used as the maximum power setting. The FB-111A fighter bomber powered by P&WA's TF30-P-7 afterburning turbofan engines uses a throttle stop at the mid-point of throttle travel for military power. When the throttle is advanced (or retarded) past the military power detent, the afterburner automatically cuts in (or out).

b. At other than the throttle stops, the engine pressure ratio (EPR) is recommended as the best indicator of engine thrust. The cockpit EPR indicator compares the total turbine discharge pressure to the total pressure of the air entering the compressor, then indicates the ratio of these pressures. EPR is a valid measure of thrust only for engines which have a fixed exhaust nozzle area. The TF30 series engine has a variable exhaust nozzle area but it varies only while the afterburner is operating. The TF30 engine can, therefore, be operated as a fixed nozzle engine only when the throttle is positioned at or below the military detent. Pilots can monitor engine thrust while operating afterburner only by combining EPR and the position of the variable exhaust nozzle. At the same EPR, thrust will relate to nozzle area with a small nozzle area producing less thrust and a larger nozzle area producing more thrust.

c. Traffic avoidance by the "See and Be Seen Concept" in visual flight conditions requires a pilot's attention in the world outside the cockpit (especially single pilot aircraft). This requirement minimizes the amount of attention which the pilot can direct to monitoring engine instruments and setting engine power. Throttle detents, therefore, often substitute for pilot attention when setting engine power. When detents are used, adjustments made during engine trim set the maximum limits of engine operation. The pilot selects the detent and accepts the resulting engine performance. As his task load allows, he checks to see that in-flight limits are not being exceeded. The useful life of parts in the engine hot section depends on the time-temperature-RPM relationship seen during engine operation. Detents are used to set power on FB-111A engines, therefore the fuel control, not the pilot, sets the TIT and RPM at which the engine operates. TF30 engine life, therefore, depends on correct adjustment of the fuel controls during engine trim operations.

d. TF30-P-7 engine afterburning operational reliability also depends on fuel control adjustment and not on pilot actions. Start-up and shutdown of the afterburner causes pressure spikes as each of the five zones of afterburner fuel is started or stopped. As suppression increases, these pressure spikes approach the fan and compressor stall margin. Oversuppression by the afterburner nozzle causes these pressure spikes to be large enough to produce compressor stalls which may cause an engine to completely lose power for a short period of time.

e. For part throttle engines, trims assure that adequate throttle movement is available to reach the desired EPR and evaluate the suitability for continued service but will never affect engine performance under normal operation. Fuel control adjustment cannot cause an engine to produce the same thrust at a lower TIT. Accurate fuel control adjustment is therefore of critical importance only on full throttle engines where it limits engine performance. SAC engines (except TF30) are operated as part throttle engines which gives the pilot full responsibility for power management. Engine fuel control limits are set (trimmed) above rated power to assure adequate performance is always available.

2. PURPOSE OF ENGINE TESTS: Engine trim involves two separate and distinct functions--one is adjusting fuel controls to cause specified performance at the throttle stop and the other is evaluation of serviceability of the engine based on limits for pressure ratios, rotor speeds, and exhaust gas temperatures at rated thrust. Air Force field testing of jet engines has been simplified by deactivation of thrust measuring equipment in the field and substitution of engine pressure ratio (EPR) as the primary trim parameter. [EPR is turbine exhaust gas pressure (P_{t7}) divided by inlet total pressure P_{t2}.] A unique relationship is assumed to exist between EPR and thrust for each jet nozzle area. This relationship does actually vary less than other parameters which could be used as the primary indicator of engine thrust. Deterioration in the engine gas path does not cause a thrust loss as long as the specified EPR is developed (assuming no mass loss due to excessive air leaks or bleed and a constant tailpipe nozzle area).

3. SIMPLIFYING ASSUMPTIONS: Published trim procedures are simplified by assuming that three potentially variable parameters are constant enough to be neglected. Variations in these parameters which do occur in the real world are large enough to introduce varying degrees of uncertainty in engine performance evaluated by published procedures. One assumption is that area variation between engine exhaust (tailpipe) nozzles is small and, therefore, insignificant. Area variations do occur within allowable tolerances and produce different engine performance when an engine is tested with different tailpipes. The slave nozzles used during initial bare engine testing are replaced by quick engine change (QEC) kit exhaust nozzles during field build-up. Exhaust nozzle area is, however, assumed constant in development of performance data. Another assumption is that the EPR-thrust relationship is constant and unique. EPR for constant thrust is not unique but varies within a small band. (The width of this band is 0.05 EPR or 600 lbs of thrust for TF33 engines.) Field trim data is developed by assuming that this band is a unique line. Another assumption is constant inlet performance. EPR ratio of tailpipe to ambient uncorrected barometric pressures (P_{bar}) is the basis for field engine trim and performance evaluations. If the actual inlet recovery varies for some cause, a shift in engine trim EPR will be measured. One factor which causes inlet recovery variation is relative wind. The FB-111 inlet has a pressure recovery (total pressure at the engine face divided by ambient total pressure) of 90.4% with zero wind, its recovery goes up to 92.6% with a 30 knot head wind. This inlet recovery change will

cause the measured engine tailpipe pressure to increase by 0.8 in Hg while P_{bar} remains constant. Trim crews observe these wind effects as tailpipe (P_{t7}) pressure changes during engine operation in gusty winds. The JetCal pressure reading will roll or shift over a range (up to 1.0 in Hg) as the wind speed varies. Assuming that inlet recovery has a negligible effect on engine trim can easily introduce up to two trim band widths of error or uncertainty in an engine evaluation. Such simplifying assumptions are apparently necessary, but their use introduces significant uncertainty in the results obtained in the field evaluation of engines.

4. INSTRUMENT UNCERTAINTY: Uncertainty in field instruments used for engine testing is additive to the uncertainty introduced in the published performance data by the simplifying assumptions. The total field instrument uncertainty in an engine evaluation is the sum of that contributed by each instrument used to establish operating conditions. These instruments include P_{t7}, barometer, inlet loss, cell depression, ambient temperature, N_2 RPM, exhaust gas temperature, and dew point. Since test instruments do not give exact measurements, it is necessary that these characteristics be examined so that information derived from the readings can be properly evaluated. The readings obtained from test cell instruments only approximate the true jet engine performance values. Every measurement taken and every reading noted reflects the accuracy with which each individual measuring instrument was designed, manufactured, calibrated, as well as any human errors that may appear in the readings. The word "UNCERTAINTY" is used in engineering work to express or describe this error or variation from true values. When used with a measurement, it shows the probable reliability of the quantity involved. These errors are inherent in making any measurement and as such cannot be eliminated by any practical means. Often, they can be made smaller by care in making the measurements, by using more precise measuring instruments calibrated to higher quality standards and by performing repeated measurements to afford statistical accuracy. Statistical accuracy defines a region in which the true value probably will fall. Since the reliability of jet engine tests is of extreme importance, familiarity with the effect of instrument accuracy on probable error is essential.

5. ACCURACY, PRECISION, AND BIAS: A quick appreciation for the meaning of the words accuracy, precision, and bias (or systematic error) can be obtained by viewing Figure 1. The observations plotted in Figure 1(a) are precise and unbiased. In Figure 1(b) the observations are precise and biased. In Figure 1(c) the observations are imprecise but unbiased, and in Figure 1(d) the observations are both imprecise and biased. Precision has to do with the scatter of the observations about a point of central tendency. Bias is the difference, if any, between the true value (TV) and the mean of the observations. Accuracy is a more general term, encompassing both the concepts of precision and bias. The least accurate observations are those found in Figure 1(d), the most accurate in Figure (a).

6. INSTRUMENT VARIATION: The illustrations on Figure 1 show that an instrument usually does not repeat exactly on repeated observations.

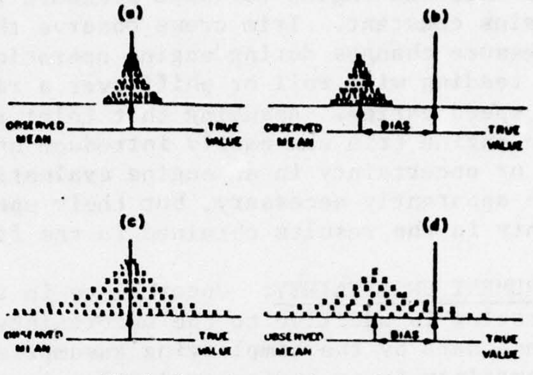

Fig. 1 Accuracy, precision, and bias

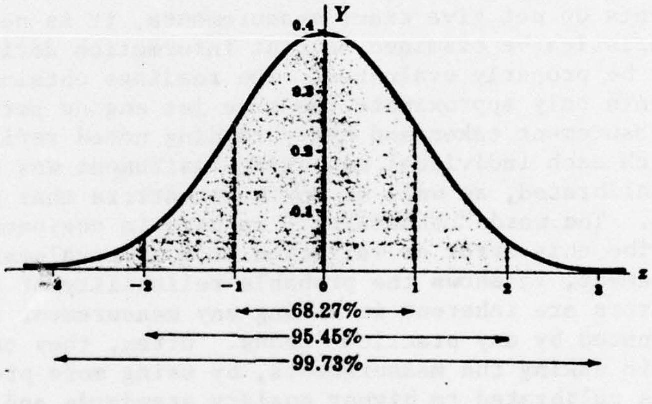

Fig. 2 THE NORMAL DISTRIBUTION

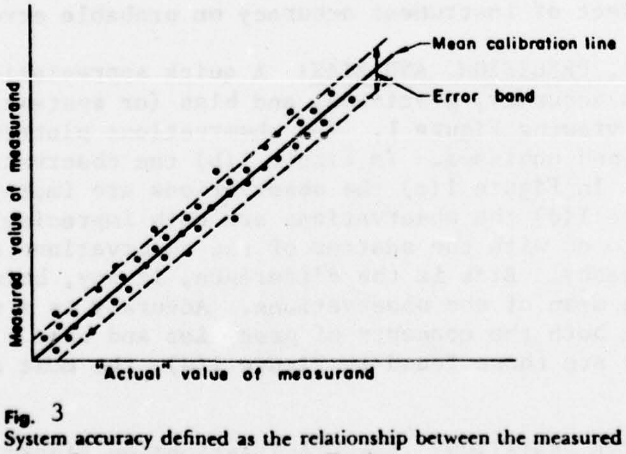

Fig. 3
System accuracy defined as the relationship between the measured value of a parameter and its "actual" value (see text).

What, then, is the true value (TV) of the measurand, given (n) unbiased measurements Y1, Y2, . . . Yn? The best estimate of TV is the average of the observations "Y-bar"; that is:

Y-bar = the sum of (Y1, Y2, . . . , Yn)/n

This average is recognized to be a statistic. It does not equal TV, but it is the best guess. Obviously, if a second set of (n) observations is recorded, the same set of values will not be recorded, nor will the second average likely equal the first. Repeated measurements do vary, of course, even when the circumstances surrounding the measurements are held as constant as possible. Thus it is believed that every recorded observed measurement equals the true value plus an error, or shock, or disturbance; that is:

Y = (TV) + E

In practice, the error (E) may be repeatable or random in nature. If the difference between the measurement and the true value is roughly the same each time, it is a repeatable type error. These type errors are called bias or systematic errors and are eliminated by the use of corrections. If the difference between the measurement and the true value varies from one occasion to the next in an unpredictable manner, it is a random type error. Random errors usually fall into a normal or Gaussian distribution about the true value. (Random error can generally be related to the precision of the instrument.)

7. <u>RANDOM ERROR DISTRIBUTION</u>: The Gaussian (or normal) distribution is the familiar bell shape curve of statistics which represents the frequency distribution function derived from study of a large number of random unrelated events (see Figure 2). It is used in statistics as the description of random events and, therefore, as the basis for establishing confidence intervals in sampling. (An engine trim represents a single sample of engine performance from the performance distribution for the engine and test instrumentation.) A statistical term, <u>standard deviation</u> (SD), associated with any distribution is the measure of the width of the bell curve about the mean for a given set of data. A measure of scatter or imprecision of repeated measurements is provided by the square of the standard deviation. This is the <u>variance</u> in a series of observations and defined as the mean of the sum of the squares of the deviations of observations from their average. The percent of total observations in the distribution that fall within a given amount or interval of the mean can be predicted if the standard deviation is known. For example, 68.3% of all readings in a normal distribution will fall between plus and minus one SD, 95.4% will fall between plus and minus two SDs, and 99.7% will fall between plus and minus three SDs. Likewise, knowing the standard deviation, we can also define the percentage of total observations that fall within any specified error interval. For example, for a commonly used "confidence interval" of 90%, a normal distribution would have 90% of all errors equal to or less than 1.645 standard deviations. Another

statistical term used when discussing accuracy is probable error. It is defined as the value for the sample error population which is greater than 50% of the errors, and less than 50% of the errors. The probable error of any instrument with a normal distribution is equal to 0.6745 of its standard deviation (SD) plus any bias error present.

8. CALIBRATION: Assume, for the moment, that a precision measuring equipment laboratory (PMEL) is calibrating a test cell instrument against a standard with a known actual value of the measurand. The instrument's accuracy is determined by observing the standard measurand over a repeated number of observations at each calibration point. This assumed procedure of repeat observations is different from present PMEL procedure which requires only a single reading at each point. The observed values plotted against the "actual" values would probably give a picture like the set of points marked as dots of Figure 3. Through this set of points, a mean line can be fitted by various procedures. This is called a calibration line. About this calibration line, there is a scatter of points representing the various sources of error in the observation process. In general, the points will have a Gaussian or normal distribution about the mean line. The plot of observations from the PMEL calibration points shows that a certain percentage of the total number of the discrete observations points fall within a given error band, illustrated by the two dashed lines on Figure 3. A wide band would take in almost all the points, and a narrow band might take in only a few. The accuracy of the instrument can now be defined in terms of: (a) any bias error (represented by one minus the tangent of the mean calibration line times the "actual" value), (b) the width of the random error band, and (c) the stated percentage (confidence interval) of a large number of observations that would fall within the given error band.

9. INSTRUMENT CAPABILITY SPECIFICATION: Within the context of this definition, a statement of instrument accuracy is meaningful only if it includes both a measure of the width of the error band and a measure of the percentage of observations that fall within this band. One cannot escape this statistical implication in the concept of accuracy. Herein lies some of the difficulty with a common misuse of the term accuracy: a statement like "accuracy: plus or minus 1 percent" defines the width of an error band but says nothing about the percentage of the observations which would fall within the band. (This method of accuracy definition is used in Mil Specs and technical data.) If the percentage is 100%, the instrument is in principle unrealizable. If the percentage is 1%, the instrument is certainly realizable but not very good.

10. ERROR ANALYSIS - UNCERTAINTY: Let's look at some common sense approaches to analyzing the resulting effect of these errors. An error in an instrument reading causes a corresponding error in the trim of a jet engine. If the maintenance technician knew what the error was, he would correct it and it would no longer be an error. In other words, the real error in jet engine test work are those factors that are always vague and to some extent carry some amount of uncertainty. The words

"common sense" have many connotations and mean different things to different people. As used here, they are used to denote a quick and expedient method for examining test data and results for gross errors and variations.

11. MEAN TOTAL ERROR ANALYSIS: A common sense analysis of trim data can be based on the rule of thumb that the error in the test result can at least equal the variation resulting from the maximum error in any single parameter used to calculate the result. Another analysis combines each individual error in the most detrimental way in order to determine the maximum error in the final result. This analysis is sometimes called the maximum total error (MTE) method. The MTE method is a useful way of inspecting test data to determine the magnitude of errors which could be in the final calculation. The MTE analysis is considered severe and, therefore, is normally used only in rough inspections for blunder errors in test data. If the test results appear in error by more than the amounts indicated by the MTE analysis, then the data should be examined more closely for blunders.

12. ROOT-SUM-SQUARE ERROR ANALYSIS: A highly regarded and more precise analysis of uncorrelated instrumentation random uncertainty has been presented by S. J. Kline and F. A. McClintock: "Describing Uncertainties in Single-sample Experiments"; Mechanical Engineering, Page 3, January 1953. Their method is based on the assumption of normally distributed errors and a careful specification of the magnitude of random uncertainty associated with each primary measurements. The expected uncertainty in the final results is found by combining each individual uncertainty through the root-sum-square (RSS) method.

a. Combination of each individual uncertainty by the root-sum-square method requires consideration of how individual measurements relate to the final results. For example, power equals voltage squared divided by resistance.

$$P = E^2/R$$

When such an exponential (non-linear) relationship exists, the uncertainty contributed by the individual measurements will be multiplied by the constant obtained from taking the first partial derivative of the result with respect to that variable. In the example above, the error in voltage measurement will be multiplied by two in its contribution to the total uncertainty in the computed power value.

b. The uncertainty in an engine trim evaluation results from the individual uncertainties in the primary measurements. If the random uncertainties contributed by n separate primary measurements are E_1, E_2, E_3, . . . , E_n, a root-sum-square estimate of their combined random uncertainty (E_t) is:

$$E_t = [(E_1)^2 + (E_2)^2 + (E_3)^2 + \ldots + (E_n)^2]^{1/2}$$

If those n separate primary measurements are each made many times, and their error contributions to the trim results have normal distributions with standard deviations of E_1, E_2, E_3, . . . E_n then they combine in the same root-sum-square fashion to produce a total random uncertainty interval which brackets the true value of engine performance and has a normal distribution with a standard deviation equal to the combined random uncertainty (E_t) given by the equation.

c. Particular notice should be given to the fact that the uncer-- tainty propagation in the result depends on the squares of the individual uncertainties. This means that if the uncertainty in one measurement is significantly larger than the uncertainty in the other variables, then it will predominate and the others may probably be neglected. Therefore, very little is gained in assurance of a correct trim by trying to reduce the "small" uncertainties. Because of the square propagation, it is the "large" ones that predominate, and any significant improvement in the overall result can be achieved only by improving the instrumentation connected with the relatively large uncertainties. Like with the MTE estimate for uncertainty, if test results appear in error by more than the RSS estimated uncertainty, then the data should be examined more closely for some additional errors in the instrumentation.

13. UNCERTAINTY IN ENGINE TRIMS: The random uncertainty for SAC trim instrument combinations was estimated by both the maximum total error (MTE) and root-sum-square (RSS) methods for a TF30-P-7 engine. The tolerances allowed by satisfactory PMEL calibration are included. The engine was assumed to be operating in a 59°F and 30.00 in Hg day. The resulting uncertainty estimates are given in Table 1. Uncertainty estimates made with the MTE method are the largest value that can occur with calibrated instruments. Estimates made with the RSS method are less than those made with the MTE method and are more likely to occur in normal operations.

14. ACCURACY IMPROVEMENT: When precise measurement of small differences in engine performance is desired, it will be necessary to take multisample data so that the test instrument variation can be isolated from the engine performance variation by statistical methods. Reading one instrument a number of times will not show bias but will show variance. Two or more instruments used simultaneously will allow separation of the measurement variation. The statistical method proposed by F. E. Grubbs: "On Estimating Precision of Measuring Instrument and Product Variability," J. Amer. Statist. Assn., Vol 43, Page 246, 1948, can be used to identify the source of variation if a series of readings are taken with the independent instruments.

15. CURRENT INSTRUMENT CAPABILITY: Engine trim specifications require high accuracy in practice. It is calibration and absence of unsuspected influence (e.g., radiation on a thermometer) which establishes the accuracy that will be obtained from an instrument. An unrealistic measurement-system-accuracy requirement can make a simple job complicated, an inexpensive one expensive. To over-estimate uncertainty or lack of accuracy is equally as unfortunate as to under-estimate it. An under-estimate gives false security, while an over estimate of uncertainty may cause

one to miss an indicator of true engine condition. Table 1 shows that both the test cell and the JetCal are capable of trim with near equal degrees of certainty. Calibrated field trim instruments should, if the trim crew adjusts the operating point to mid-band, produce rechecks within the trim band at the percent rates shown in Table 1.

16. REQUIRED INSTRUMENTATION IMPROVEMENT: The measurement of ambient temperature as currently specified in technical orders represents a prime source of potential error and, therefore, exerts significant influence on the uncertainty in engine trims. Instruments specified in technical orders for use during trims to measure ambient temperature should not depend on free convective heat transfer to overcome radiation effects. The TF30 engine operating in afterburner uses a variable tailpipe nozzle. Field checks cannot use the EPR-thrust relationship as a valid indicator of engine performance since one of the critical parameters is allowed to vary uncontrolled. For this reason, a thrust indicating test cell is the only valid check of engine performance when nozzle area is allowed to vary.

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4. Performance Test Codes Committee No. 6, American Society of Mechanical Engineers (ASME).

   a. "Steam Turbines," PTC 6 - 1964.

   b. "Guidance for Evaluation of Measurement Uncertainty in Performance Test of Steam Turbines," PTC 6 Report - 1969.

INSTRUMENT COMBINATIONS	#1 TEST CELL CAL PMEL		#2 TEST CELL CAL ON-SITE		#3 FLIGHT LINE H-119 JETCAL WX STA OAT		#4 FLIGHT LINE H-119 JETCAL ON-SITE OAT	
COMPUTATION METHOD	MTE	RSS	MTE	RSS	MTE	RSS	MTE	RSS
UNCERTAINTY PERCENT	0.81	0.51	0.50	1.24	1.78	0.973	3.20	1.93
UNCERTAINTY - EPR UNITS	0.016	0.010	0.029	0.024	0.034	0.019	0.063	0.038
UNCERTAINTY - P_{t7} in Hg	0.46	0.29	0.85	0.70	1.00	0.55	1.81	1.09
STANDARD DEVIATION - P_{t7}		0.10		0.23		0.184		0.37
PROBABLE ERROR - P_{t7}		0.07		0.16		0.12		0.25
MID-BAND TRIMMED ENGINES PROBABLE RECHECK IN TRIM IF DISTRIBUTION NORMAL		99%		71%		82%		51%

NOTE: INSTRUMENT COMBINATION #1 - Test Cell using a 0-100 in Hg Precision Aneriod Manometer calibrated per TO 33K6-4-1-5 in a PMEL laboratory.

#2 - Test Cell using a 0-100 in Hg Precision Aneroid Manometer calibrated per TO 00-25-238 with portable test stand calibrator (PMEL trailer).

#3 - Flight line trim using an H-119 JetCal calibrated per TO 33D-4-6-262-1 and OAT-DP from weather station.

#4 - Flight line trim using an H-119 JetCal calibrated per TO 33D-4-6-262-1 and on-site OAT with weather station dew point.

NOTE: The RSS computation method used the given allowable error for each instrument as a three standard deviation value of a normal error distribution.

TABLE 1 - Measurement Uncertainty in a TF30-P-7 engine trim introduced by allowable instrumentation accuracy tolerances and calibration procedures. Data computed from TO 1F-111(B)A-2-6-1-1 trim charts using the maximum total error (MTE) and root-sum-square (RSS) methods with an assumed 29.90 in Hg barometer, 59°F OAT, and 8°F dew point depression.

COMPUTATION OF UNCERTAINTY
(OAT - WX STATION - JETCAL)

Assume that ambient conditions for the TF30-P-7 engine trim are OAT=59°F, dew point depression=8°F, and uncorrected field barometric pressure=29.00 in Hg. For these conditions, TO 1F-111(B)A-2-6-1-1, page 2-50, gives a dry trim EPR of 1.954 units.

Conputation of uncertainty using the Root-Sum-Square (RSS) method after Kline and McClintock requires that each instrument's uncertainty be expressed as a percent of the reading under trim conditions. Expressing the uncertainty as a percent of the parameter value provides the normalization required for combination under the RSS method.

The evaluation effort in an engine trim consists of computing a target turbine discharge pressure (P_{t7}) from engine performance curves and then operating the engine to obtain an actual P_{t7} which is compared to the target value. Fuel flow, turbine inlet temperature, N_1 and N_2 RPM, and interstage compressor pressures are measured and compared to limits as go-no-go values. Adjustment of the fuel control, normally, does not depend on any parameter other than the comparison of the meausred P_{t7} value and the computed target P_{t7} value.

The uncertainty in the trim comes from both the instruments used to measure engine performance $E(M-P_{t7})$ and those used to measure ambient conditions as the basis for extracting a target P_{t7} from the performance curves, $E(C-P_{t7})$.

$$\text{Total Uncertainty} = [E(M-P_{t7})^2 + E(C-P_{t7})^2]^{1/2}$$

For flight line trim using a JetCal calibrated per TO 33D4-6-262-1.

$$\%\ E(M-P_{t7}) = 0.3 \text{ in Hg}/56.67 \text{ in Hg} = 0.53\%$$

Trim target depends on OAT, dew point depression, and barometric pressure.

$$\%\ E(C-P_{t7})^2 = E(OAT)^2 + E(Dew\ Pt)^2 + E(Baro)^2 = 0.82$$

Where % E(OAT) = 0.012 EPR units/1.954 EPR units based on a 3°F maximum weather station temperature error and an EPR temperature sensitivity of 1°F equal to 0.004 EPR units.

$$\%\ E(Dew\ Pt) = 0.010 \text{ EPR units}/1.954 \text{ EPR units} = 0.51\%$$

Based on 5°F error in dew point depression and sensitivity of 0.002 EPR units per degree F of dew point depression.

$$\%\ E(Baro) = 0.0325 \text{ in Hg}/29.00 \text{ in Hg} = 0.11\%$$

Based on expected barometer error of 0.0325 in Hg per AGMC/MLT letter, 9 October 1973.

$$\% \ E(C-P_{t7})^2 = (0.63)^2 + (0.51)^2 + (.11)^2$$

$$\% \ E(C-P_{t7}) = .818$$

$$\% \ E(\text{Total}) = [E(M-P_{t7})^2 + E(C-P_{t7})^2]^{1/2}$$

$$= [(0.53)^2 + (0.818)^2]^{1/2}$$

Trim Uncertainty = 0.973%
(Percent)

For this trim with a P_{t7} target of 56.67 in Hg, the uncertainty band is plus and minus 0.55 in Hg. The certified AFTO Form 132 showing a mid-band trim at 56.67 in Hg actually means that the engine produced a P_{t7} which was really between 56.12 and 57.23 in Hg. On recheck of this trim, 82% of the time this engine would be expected to operate within the ± 0.5 inch Hg trim band tolerance.

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*S. J. Kline and F. A. McClintock: "Describing Uncertainties in Single-sample Experiments"; Mechanical Engineering, page 3, January 1953.