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Emissions of Nitrogen Oxides
from the Testing of F404-GE-400 Engines
at Naval Air Station, Lemoore, California

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Enclosure (3)

Emissions of Nitrogen Oxides from the Testing of F404-GE-400 Engines
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AESO Report No. 4-85, July 1985

EXECUTIVE SUMMARY

This report determined the weight of nitrogen oxides (NO_x) coming from thirteen different F404-GE-400 engine tests at NAS Lemoore. The weight of nitrogen oxides from each test was determined by adding the weights produced by each power setting used in the test. At each power setting, the amount of fuel used and the emission index for nitrogen oxides, which varies with the power setting, determine the amount of nitrogen oxides produced. The emission index is the pounds of nitrogen oxides produced per 1000 pounds of fuel used. This report used nitrogen oxides emission data furnished by the Naval Air Propulsion Center and F404-GE-400 engine run sheets from NAS Lemoore. The weight of nitrogen oxides produced varied from 50 to 169 pounds per test. The amount of nitrogen oxides for each pound of fuel used varied from 0.01331 to 0.01742 pounds, with an average of 0.01556 pounds. This average can be used as a correlation coefficient to estimate the amount of nitrogen oxides produced during an engine test on the basis of total fuel use only. To estimate the total weight of nitrogen oxides, multiply the weight of fuel used in the test by 0.01556.

Based on the thirteen engine test analyzed, the percentage difference between the amount of nitrogen oxides calculated from the emission indexes and fuel use at the various power settings, and from the total fuel use using the correlation coefficient, varied from -11 to +17. The total amount of nitrogen oxides calculated using this coefficient agreed within 1% of the total amount calculated from the emission indexes.

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Emissions of Nitrogen Oxides
from the Testing of F404-GE-400 Engines
at Naval Air Station, Lemoore, California

1. INTRODUCTION

Nitrogen oxides, a combination of nitrogen oxide and nitrogen dioxide, are an air pollutant from the testing of aircraft engines. The amount of nitrogen oxides formed during an engine test is part of the information which must be included on applications to various regulating agencies for authority to construct and permission to operate test facilities. The emission indexes of nitrogen oxides at various engine power settings and the times at these settings determine the amount of nitrogen oxides coming from an engine test.

This report first develops emission indexes for nitrogen oxides at any power setting of the F404-GE-400 engine. It then applies these indexes to specific engine power settings and run times to give an estimate of the amounts of nitrogen oxides produced by thirteen different engine tests, in Test Cell 3, at NAS Lemoore. The dates of testing were from 8 March to 26 April, 1985. The amounts of nitrogen oxides from these tests varied from 50 to 169 pounds. The testing times were from 22 to 116 minutes. The pounds of nitrogen oxides formed, for each pound of fuel consumed during the test, varied from 0.01331 to 0.01742. The average from the 13 tests was 0.01556 pounds. This means that multiplying the pounds of fuel used in the test by 0.01556 would give a reasonable estimate of the pounds of nitrogen oxides formed during any engine test.

Finally, this report shows how to use a small programmable calculator to establish emission indexes and to estimate the amounts of nitrogen oxides produced during engine testing.

2. EMISSION INDEXES AND ENGINE OPERATIONAL DATA

2.1 Emission Indexes of Nitrogen Oxides at Various Power Settings

An emission index relates the amount of a pollutant in the engine exhaust to the amount of fuel used. Emission indexes are calculated from measured concentrations of carbon monoxide, carbon dioxide, nitrogen oxides and hydrocarbons in the engine exhaust.

This report considers only one pollutant, i.e., nitrogen oxides. The Naval Air Propulsion Center reported nitrogen oxide emission indexes for the F404-GE-400 engine at 14 different power settings (Reference 1). Appendix A includes Tables IV and V of Reference 1. The emission index for nitrogen oxides is different at each engine power setting, being smallest at idle and largest at full power (without afterburner). For use of these data, the Aircraft Environmental Support Office fitted the values of emission index and

thrust, from 15% thrust to IRP (intermediate rated power), to a curve using the exponential curve fitting program of the Hewlett-Packard HP-41C Statistics Pac. This program generated the constants a and b ($a = 2.9747$, and $b = 2.0127 \times 10^{-4}$) for use in the equation

$$y = ae^{bx}, \quad (1)$$

where y = emission index and x = thrust in pounds.

Using the data from Reference 1, the coefficient of determination was found to be 1.00.

This report calculates an emission index for each thrust value recorded on the engine run sheets furnished by NAS Lemoore. Specific power settings may have different emission indexes. For example, for IRP, the thrust varied from 10000 to 10900 pounds. The emission indexes, calculated by equation (1), were 22.35 to 26.79. The thrust and emission index reported in Reference 1 for IRP were 10548 pounds and 25.16.

Reference 1 gave only one emission index for maximum afterburner. All afterburner power settings use this emission index, which is 9.22.

2.2 Engine Operational Data

Naval Air Station, Lemoore furnished engine run sheets for 13 tests. Appendix A includes reproductions of these run sheets. The engine run sheets contain 22 columns of data. Tables 2 - 14, of this report, use four of the data columns from these sheets, e.g., data identification, time, thrust and cell fuel flow.

2.2.1 Data Identification

The tables of this report use the same data identification notation as the engine run sheets. Data are identified as FI (flight idle), various rpm or percent rpm, IRP, and AB (afterburner). Note that 80% is about 13000 rpm and 89% 16500 rpm.

2.2.2 Time at Power Setting

For any row of data, the number in column 1 gives a start time for the data identified in column 22. The number in column 1 of the second row is the finish time for the data identified in column 22 of the first row and the start time for the data identified in column 22 of the second row. On some run sheets, the time at afterburner was not clearly defined. For these times we used 3 minutes and noted that the time was estimated.

2.2.3 Thrust

Several thrust values were missing from the data sheets. They were replaced by average values which were obtained from the other engine run sheets.

2.2.4 Fuel Flow

The fuel flows used for calculations were the test cell fuel flows. These account for the extra fuel used at afterburner. In addition, it is our understanding that the gauge on the test cell is calibrated whereas the gauge on the engine is not.

2.3 Other Test Procedures

In addition to the power settings listed in the data identification column, the engine run sheets record other test procedures which, except for shutdown, consist of more than one power setting. These procedures are: transient break-in, transient, ECU (engine control unit), overspeed and shutdown. For the first three procedures, the engine run sheets usually record a start and finish time. The engine run sheets do not give the duration of the procedures for overspeed and shutdown. After consulting operating manuals and talking with test cell operators, we assigned the following power settings and operating times as representative values.

Transient break-in - flight idle, 12 minutes; 14000 rpm, 3 minutes; 15500 rpm, 5 minutes; and IRP, 9.5 minutes; total time 29.5 minutes.

ECU - flight idle and IRP each 3.5 minutes; total time 7 minutes.

Transient - flight idle, 6 minutes; IRP, 1 minute; afterburner, 10 seconds; total time 7.17 minutes.

Overspeed - flight idle, 1 minute; IRP, 1 minute; total time 2 minutes.

Shutdown - flight idle, 5 minutes.

2.4 Emissions of Nitrogen Oxides from Other Test Procedures

The other test procedures contribute to the total amount of nitrogen oxides produced depending upon the time of operation at the various power settings used in the procedure. For each of these procedures, using average fuel flows and thrusts, we combined the fuel used and the nitrogen oxides produced at each of the component power settings. From these values we calculated the fuel use in pounds per hour and an emission index in pounds per 1000 pounds of fuel. Thus, just as individual power settings, each test procedure has a specific rate of fuel consumption and an emission index. For the other test procedures, these fuel uses (pounds per hour) and emission indexes (pounds per 1000 pounds of fuel) are as follows: transient break-in, 4517, 19.04; transient, 2729, 14.08; ECU (engine control unit), 4757, 22.34; overspeed, 4757, 22.34; and shutdown, 996, 3.23.

3. DESCRIPTION OF TABLES

Table 1 summarizes the emissions of nitrogen oxides from the testing of thirteen F404-GE-400 engines. Tables 2 - 14 give more details about the calculations of the individual tests.

In Table 1, column 3 gives the amount of nitrogen oxides formed in a specific engine test, column 4 gives the amount of fuel used in the test and column 5 gives the amount of nitrogen oxides formed for each pound of fuel used. Table 1 gives a mean for the data in column 5. This mean is a correlation coefficient which can be used to estimate the amount of nitrogen oxides coming from an engine test based on the fuel used. Column 6 shows the application of the correlation coefficient. The number in column 3 multiplied by the number in column 5 gives the number in column 6. Finally, column 7 shows the percent difference between the amounts of nitrogen oxides calculated from the emission indexes and the amounts calculated using the correlation coefficient.

Tables 2 - 14 show the development of the values used in Table 1. In Tables 2 - 14, the addition of the amounts in column 7 for all of the rows gives the total amount of nitrogen oxides from the test. This number appears in column 3 of Table 1. Similarly the addition of the entries in column 6 of Tables 2 - 14 (fuel use) gives the numbers recorded in column 4 of Table 1. Finally the division of the amount of nitrogen oxides formed by the fuel used gives the amount of nitrogen oxides per pound of fuel (column 5 of Table 1).

4. CALCULATIONS

The weight in pounds of nitrogen oxides formed during each power setting is determined in the following manner. Using the second entry from Table 2 as an example, first use the thrust of 545 pounds and equation (1) to determine an emission index for the power setting. Thrust values will vary within limits from engine to engine and from test to test. This will change, slightly, the value of the emission index used.

$$y = ae^{bx} \quad (1)$$

$$y = 2.9747 \times e^z,$$

$$\text{where } z = 2.0127 \times 10^{-4} \times 545,$$

$$\text{then } y = 3.32$$

Next, for each power setting, multiply the fuel flow by the time at that setting (hours) to obtain the fuel use for the power setting.

$$955 \text{ pounds per hour} \times 13/60 \text{ hours} = 206.9 \text{ pounds}$$

Finally, divide the fuel used by 1000 (the emission index is for pounds per 1000 pounds of fuel) and multiply by the emission index to obtain the amount of nitrogen oxides produced.

$$206.9 \text{ pounds}/1000 \times 3.32 = 0.69 \text{ pounds}$$

The addition of the amounts of fuel used and nitrogen oxides produced at each power setting, gives the total amounts from the test. Division of the pounds of nitrogen oxides from the test (51.34) by the pounds of fuel used (3858) gives the pounds of nitrogen oxides formed for each pound of fuel used.

$$51.34/3858 = 0.01331$$

In preparing this report, we used an HP-41CV programmable calculator. Appendix B explains how to use this calculator and gives the programs used to make the calculations.

5. CONCLUSIONS

The rate (pounds of nitrogen oxides per pound of fuel) at which the testing of F404-GE-400 engines produces nitrogen oxides can be expressed as an correlation coefficient which then can be used to estimate the amount of nitrogen oxides produced in any test from the amount of fuel used. This coefficient is 0.01556.

Based on the thirteen engine test analyzed, the percentage difference between the amount of nitrogen oxides calculated from the emission indexes and fuel use at the various power settings, and from the total fuel use using the correlation coefficient, varied from -11 to +17. The total amount of nitrogen oxides calculated using this coefficient agreed within 1% of the total amount calculated from the emission indexes.

6. REFERENCES

- (1) A. F. Klarman and J. J. Zidzik, "F404-GE-400 Engine Exhaust Emission Test Results, Interim Report," Naval Air Propulsion Center, NAPC-LR-81-10, 30 November 1981

TABLE 1. Summary of nitrogen oxides emissions from the testing of F404-GE-400 engines at NAS Lemoore

Table	Date 1985 (sequence)	NO _x from test, lbs.	Fuel Used in test, lbs.	lbs. NO _x per lb. of fuel used	NO _x , calcd. from mean, lbs.	% difference (a)
2	8 March (578)	51.34	3858	0.01331	60.03	16.93
3	11 March (579)	104.98	7483	0.01403	116.44	10.91
4	22 March (583)	128.92	7399	0.01742	115.13	-10.70
5	26 March (584)	82.65	5907	0.01399	91.91	11.21
6	27 March (585)	50.10	3443	0.01455	53.57	6.93
7	29 March (586)	168.76	11493	0.01468	178.83	5.97
8	30 March (587)	131.66	7605	0.01731	118.33	-10.12
9	2 April (588)	101.84	6410	0.01589	99.76	-2.05
10	5 April (589)	140.99	9052	0.01558	140.85	-0.10
11	11 April (590)	152.17	9051	0.01681	140.83	-7.45
12	12 April (591)	141.85	8818	0.01609	137.21	-3.27
13	13 April (592)	140.77	8516	0.01653	132.51	-5.87
14	26 April (595)	119.74	7399	0.01618	115.13	-3.85
Total		1515.77			1500.53	-1.01
Mean				0.01556		
Standard deviation				1.34		

(a) % Diff. = $\frac{\text{pounds of NO}_x \text{ calcd. from mean} - \text{pounds of NO}_x \text{ from test}}{\text{pounds of NO}_x \text{ from test}} \times 100$

TABLE 2. Emissions of nitrogen oxides from the testing of an F404-GE-400 Engine at NAS Lemoore (Sequence Number 578, Engine Serial Number 310387, 8 March 1985)

Data ident.	Time in mode, min.	Thrust, pounds	Fuel flow, pounds/hr	EI (a)	Fuel use per mode, pounds	Pounds NO _x per mode
Start/shutdown	5	-	996	3.23	83.0	0.27
Flight idle	13	545	955	3.32	206.9	0.69
80%	7	2540	2253	4.96	262.9	1.30
89%	3	5945	4850	9.86	242.5	2.39
IRP	7	10190	8514	23.22	993.3	23.06
Afterburner	3(b)	15410	29750	9.22	1487.5	13.71
ECU	4	-	4757	22.34	317.1	7.08
Transient	4	-	2729	14.08	181.9	2.56
Shutdown	5	-	996	3.23	83.0	0.27

Pounds of fuel used in test 3858

Pounds of NO_x per test 51.34

Pounds of NO_x per pound of fuel used in test = 0.01331

(a) Emission index for nitrogen oxides expressed as pounds of nitrogen dioxide per 1000 pounds of fuel.

(b) Estimated.

TABLE 3. Emissions of nitrogen oxides from the testing of an F404-GE-400 Engine at NAS Lemoore (Sequence Number 579, Engine Serial Number 310254, 11 March 1985)

Data ident.	Time in mode, min.	Thrust, pounds	Fuel flow, pounds/hr	EI (a)	Fuel use per mode, pounds	Pounds NO _x per mode
Flight Idle	5	360	1050	3.20	87.5	0.28
13000	3	1830	1895	4.30	94.8	0.41
13500	5	2460	2275	4.89	189.6	0.93
14000	4	3550	3000	6.09	200.0	1.22
14500	6	4790	3950	7.82	395.0	3.09
15000	5	6100	4900	10.18	408.3	4.16
15500	6	8205	6700	15.56	670.0	10.43
IRP	2	10075	8400	22.69	280.0	6.35
Trans. brk-in	33	-	4517	19.04	2484.4	47.30
Afterburner	4	15160	30350	9.22	2023.3	18.66
ECU	4	-	4757	22.34	317.1	7.08
Trans.	2	-	2729	14.08	91.0	1.28
Overspeed	2	-	4757	22.34	158.6	3.54
Shutdown	5	-	996	3.23	83.0	0.27

Pounds of fuel used in test 7483

Pounds of NO_x per test 104.98

Pounds of NO_x per pound of fuel used in test = 0.01403

(a) Emission index for nitrogen oxides expressed as pounds of nitrogen dioxide per 1000 pounds of fuel.

TABLE 4. Emissions of nitrogen oxides from the testing of an F404-GE-400 Engine at NAS Lemoore (Sequence Number 583, Engine Serial Number 310097, 22 March 1985)

Data ident.	Time in mode, min.	Thrust, pounds	Fuel flow, pounds/hr	EI (a)	Fuel use per mode, pounds	Pounds NO _x per mode
Flight idle	3	530	1100	3.31	55.0	0.18
13500	3	2810	2500	5.24	125.0	0.66
15000	3	7000	5552	12.20	277.6	3.39
15500	3	8400	6595	16.18	329.8	5.34
16000	3	10750	8700	25.99	435.0	11.31
IRP	8	10850	8740	26.52	1165.3	30.91
15000	4	6290	4745	10.58	316.3	3.35
Trans. brk-in	32	-	4517	19.04	2409.1	45.87
Afterburner	3(b)	16000	30000 (c)	9.22	1500.0	13.83
ECU	4	-	4757	22.34	317.1	7.08
Transient	5	-	2729	14.08	227.4	3.20
Overspeed	2	-	4757	22.34	158.6	3.54
Shutdown	5	-	996	3.23	83.0	0.27

Pounds of fuel used in test 7399

Pounds of NO_x per test 128.92

Pounds of NO_x per pound
fuel used in test = 0.01742

- (a) Emission index for nitrogen oxides expressed as pounds of nitrogen dioxide per 1000 pounds of fuel.
(b) Estimated.

TABLE 5. Emissions of nitrogen oxides from the testing of an F404-GE-400 Engine at NAS Lemoore (Sequence Number 584, Engine Serial Number 310131, 26 March 1985)

Data ident.	Time in mode, min.	Thrust, pounds	Fuel flow, pounds/hr	EI (a)	Fuel use per mode, pounds	Pounds NO _x per mode
Flight idle	6	450	1049	3.26	104.9	0.34
80%	6	2600	2323	5.03	232.3	1.17
89%	15	6620	5189	11.30	1297.3	14.66
IRP	1	10560	8592	25.02	143.2	3.58
ECU	19	-	4757	22.34	1506.4	33.65
Afterburner	3(b)	15600	29590	9.22	1479.5	13.64
Shutdown	5	-	996	3.23	83.0	0.27
Transient	18	-	2729	14.08	818.7	11.53
Overspeed	2	-	4757	22.34	158.6	3.54
Shutdown	5	-	996	3.23	83.0	0.27

Pounds of fuel used in test 5907

Pounds of NO_x per test 82.65

Pounds of NO_x per pound of fuel used in test = 0.01399

(a) Emission index for nitrogen oxides expressed as pounds of nitrogen dioxide per 1000 pounds of fuel.

(b) Estimated.

TABLE 6. Emissions of nitrogen oxides from the testing of an F404-GE-400 Engine at NAS Lemoore (Sequence Number 585, Engine Serial Number 310079, 27 March 1985)

Data ident.	Time in mode, min.	Thrust, pounds	Fuel flow, pounds/hr	EI (a)	Fuel use per mode, pounds	Pounds NO _x per mode
Flight idle	8	380	917	3.21	122.3	0.39
Shutdown	1	404	996	3.23	16.6	0.05
89%	5	6190	4957	10.36	413.1	4.28
IRP	6	10620	8699	25.32	869.9	22.03
Afterburner	3(b)	16000	30840	9.22	1542.0	14.22
ECU	5	-	4757	22.34	396.4	8.86
Shutdown	5	-	996	3.23	83.0	0.27

Pounds of fuel used in test 3443

Pounds of NO_x per test 50.10

Pounds of NO_x per pound
fuel used in test = 0.01455

(a) Emission index for nitrogen oxides expressed as pounds of nitrogen dioxide per 1000 pounds of fuel.

(b) Estimated.

TABLE 7. Emissions of nitrogen oxides from the testing of an F404-GE-400 Engine at NAS Lemoore (Sequence Number 586, Engine Serial Number 310134, 29 March 1985)

Data ident.	Time in mode, min.	Thrust, pounds	Fuel flow, pounds/hr	EI (a)	Fuel use per mode, pounds	Pounds NO _x per mode
Flight idle	7	404(b)	993	3.23	115.4	0.37
13500	5	1090	2265	3.77	188.8	0.70
15000	11	3140	5249	5.60	962.3	5.39
16000	4	9621(b)	7985	20.70	532.3	11.02
16250	7	10136(b)	8755	22.97	1021.4	23.46
IRP	2	10472	8755	24.58	291.8	7.17
Trans. brk-in	38	-	4517	19.04	2860.8	54.47
Afterburner	3	-	32950	9.22	1647.5	15.19
ECU	7	-	4757	22.34	555.0	12.40
Transient	5	-	2729	14.08	227.4	3.20
Shutdown	5	-	996	3.23	83.0	0.27
Afterburner	4	-	30870	9.22	2058.0	18.97
Shutdown	5	-	996	3.23	83.0	0.27
Transient	5	-	2729	14.08	227.4	3.20
ECU	5	-	4757	22.34	396.4	8.86
Overspeed	2	-	4757	22.34	158.6	3.54
Shutdown	5	-	996	3.23	83.0	0.27

Pounds of fuel used in test 11493

Pounds of NO_x per test 168.76

Pounds of NO_x per pound
fuel used in test = 0.01468

(a) Emission index for nitrogen oxides expressed as pounds of nitrogen dioxide per 1000 pounds of fuel. (b) Estimated.

TABLE 8. Emissions of nitrogen oxides from the testing of an F404-GE-400 Engine at NAS Lemoore (Sequence Number 587, Engine Serial Number 310030, 30 March 1985)

Data ident.	Time in mode, min.	Thrust, pounds	Fuel flow, pounds/hr	EI (a)	Fuel use per mode, pounds	Pounds NO _x per mode
Flight idle	4	400	980	3.22	65.3	0.21
13500	3	2580	2276	5.00	113.8	0.57
15000	4	6700	5414	11.49	360.9	4.15
15500	3	8150	6410	15.39	320.5	4.93
16000	2	10070	8050	22.66	268.3	6.08
16250	6	10950	8670	27.06	867.0	23.46
IRP	3	10900	8731	26.79	436.6	11.70
150000	1	6040	4666	10.06	77.8	0.78
Trans. brk-in	28	-	4517	19.04	2107.9	40.14
Shutdown	5	-	996	3.23	83.0	0.27
Afterburner	3(b)	16180	31190	9.22	1559.5	14.38
Shutdown	5	-	996	3.23	83.0	0.27
ECU	10	-	4757	22.34	792.8	17.71
Transient	5	-	2729	14.08	227.4	3.20
Overspeed	2	-	4757	22.34	158.6	3.54
Shutdown	5	-	996	3.23	83.0	0.27

Pounds of fuel used in test 7605

Pounds of NO_x per test 131.66

Pounds of NO_x per pound of fuel used in test = 0.01731

(a) Emission index for nitrogen oxides expressed as pounds of nitrogen dioxide per 1000 pounds of fuel.

(b) Estimated.

TABLE 9. Emissions of nitrogen oxides from the testing of an F404-GE-400 Engine at NAS Lemoore (Sequence Number 588, Engine Serial Number 310357, 2 April 1985)

Data ident.	Time in mode, min.	Thrust, pounds	Fuel flow, pounds/hr	EI (a)	Fuel use per mode, pounds	Pounds NO _x per mode
Flight idle	7	409	1099	3.23	128.2	0.41
13500	3	2115	2361	4.56	118.1	0.54
15000	5	6520	5290	11.08	440.8	4.88
15500	8	8095	6565	15.22	875.3	13.32
IRP	3	10000	8133	22.35	406.7	9.09
15000	7	5755	4574	9.49	533.6	5.07
Trans. brk-in	31	-	4517	19.04	2333.8	44.44
Afterburner	1	14950	29528	9.22	492.1	4.54
ECU	6	-	4757	22.34	475.7	10.63
Transient	8	-	2729	14.08	363.9	5.12
Overspeed	2	-	4757	22.34	158.6	3.54
Shutdown	5	-	996	3.23	83.0	0.27

Pounds of fuel used in test 6410

Pounds of NO_x per test 101.84

Pounds of NO_x per pound of fuel used in test = 0.01589

(a) Emission index for nitrogen oxides expressed as pounds of nitrogen dioxide per 1000 pounds of fuel.

TABLE 10. Emissions of nitrogen oxides from the testing of an F404-GE-400 Engine at NAS Lemoore (Sequence Number 589, Engine Serial Number 310320, 5 April 1985)

Data ident.	Time in mode, min.	Thrust, pounds	Fuel flow, pounds/hr	EI (a)	Fuel use per mode, pounds	Pounds NO _x per mode
Flight idle	5	235	918	3.12	76.5	0.24
13500	3	2110	1925	4.55	96.3	0.44
15000	6	5715	4526	9.42	452.6	4.26
15500	4	7222	5855	12.76	390.3	4.98
16000	6	8735	6993	17.31	699.3	12.11
16250	5	9690	7836	20.99	653.0	13.71
IRP	4	10190	8118	23.22	541.2	12.57
15000	2	5440	4317	8.91	143.9	1.28
Trans. brk-in	26	-	4517	19.04	1957.4	37.27
Afterburner	5	14820	28864	9.22	2405.3	22.18
ECU	13	-	4757	22.34	1030.7	23.03
Transient	8	-	2729	14.08	363.9	5.12
Overspeed	2	-	4757	22.34	158.6	3.54
Shutdown	5	-	996	3.23	83.0	0.27

Pounds of fuel used in test 9052

Pounds of NO_x per test 140.99

Pounds of NO_x per pounds of fuel used in test = 0.01558

(a) Emission index for nitrogen oxides expressed as pounds of nitrogen dioxide per 1000 pounds of fuel.

TABLE 11. Emissions of nitrogen oxides from the testing of an F404-GE-400 Engine at NAS Lemoore (Sequence Number 590, Engine Serial Number 310107, 11 April 1985)

Data ident.	Time in mode, min.	Thrust, pounds	Fuel flow, pounds/hr	EI (a)	Fuel use per mode, pounds	Pounds NO _x per mode
Flight idle	4	470	1017	3.27	67.8	0.22
13500	5	2815	2457	5.25	204.8	1.07
15000	9	6685	5285	11.45	792.8	9.08
15500	6	8509	6772	16.54	677.2	11.20
16000	7	10560	8667	25.02	1011.2	25.30
IRP	4	10640	8636	25.42	575.7	14.64
15000	3	6250	4754	10.49	237.7	2.49
Trans. brk-in	39	-	4517	19.04	2936.1	55.90
Afterburner	3(b)	148550	30004	9.22	1500.2	13.83
ECU	5(b)	-	4757	22.34	396.4	8.86
Transient	9	-	2729	14.08	409.4	5.76
Overspeed	2	-	4757	22.34	158.6	3.54
Shutdown	5	-	996	3.23	83.0	0.27

Pounds of fuel used in test 9051

Pounds of NO_x per test 152.17

Pounds of NO_x per pound of fuel used in test = 0.01681

(a) Emission index for nitrogen oxides expressed as pounds of nitrogen dioxide per 1000 pounds of fuel.

(b) Estimated.

TABLE 12. Emissions of nitrogen oxides from the testing of an F404-GE-400 Engine at NAS Lemoore (Sequence Number 591, Engine Serial Number 310249, 12 April 1985)

Data ident.	Time in mode, min.	Thrust, pounds	Fuel flow, pounds/hr	EI (a)	Fuel use per mode, pounds	Pounds NO _x per mode
Flight idle	3	410	875	3.23	43.8	0.14
13500	2	2360	2095	4.79	69.8	0.33
15000	4	5560	4370	9.13	291.3	2.66
15500	5	7475	5725	13.43	477.1	6.41
16000	4	9100	7150	18.64	476.7	8.88
16250	6	10160	7960	23.08	796.0	18.37
IRP	4	10700	8550	25.73	570.0	14.67
15000	7	5250	4000	8.57	466.7	4.00
Trans. brk-in	32	-	4517	19.04	2409.1	45.87
Afterburner	4	15850	30170	9.22	2011.3	18.54
ECU	7	-	4757	22.34	555.0	12.40
Transient	9	-	2729	14.08	409.4	5.76
Overspeed	2	-	4757	22.34	158.6	3.54
Shutdown	5	-	996	3.23	83.0	0.27

Pounds of fuel used in test 8818

Pounds of NO_x per test 141.85

Pounds of NO_x per pound of fuel used in test = 0.01609

(a) Emission index for nitrogen oxides expressed as pounds of nitrogen dioxide per 1000 pounds of fuel.

TABLE 13. Emissions of nitrogen oxides from the testing of an F404-GE-400 Engine at NAS Lemoore (Sequence Number 592, Engine Serial Number 310382, 13 April 1985)

Data ident.	Time in mode, min.	Thrust, pounds	Fuel flow, pounds/hr	EI (a)	Fuel use per mode, pounds	Pounds NO _x per mode
Flight idle	2	335	995	3.18	33.2	0.11
13500	2	2200	2095	4.64	69.8	0.32
15000	3	5725	4700	9.44	235.0	2.22
15500	3	7340	5870	13.07	293.5	3.84
16000	5	9065	7260	18.51	605.0	11.20
16250	3	10080	8100	22.71	405.0	9.20
IRP	7	10340	8310	23.93	969.5	23.20
15000	3	5245	4015	8.57	200.8	1.72
Trans. brk-in	30	-	4517	19.04	2258.5	43.00
Afterburner	4	15160	29350	9.22	1956.7	18.04
ECU	10	-	4757	22.34	792.8	17.71
Transient	10	-	2729	14.08	454.8	6.40
Overspeed	2	-	4757	22.34	158.6	3.54
Shutdown	5	-	996	3.23	83.0	0.27

Pounds of fuel used in test 8516

Pounds of NO_x per test 140.77

Pounds of NO_x per pound of fuel used in test = 0.01653

(a) Emission index for nitrogen oxides expressed as pounds of nitrogen dioxide per 1000 pounds of fuel.

TABLE 14. Emissions of nitrogen oxides from the testing of an F404-GE-400 Engine at NAS Lemoore (Sequence Number 595, Engine Serial Number 310049, 26 April 1985)

Data ident.	Time in mode, min.	Thrust, pounds	Fuel flow, pounds/hr	EI (a)	Fuel use per mode, pounds	Pounds NO _x per mode
Flight idle	3	320	905	3.17	45.3	0.14
13500	2	2440	2180	4.87	72.7	0.35
15000	4	6090	4750	10.16	316.7	3.22
15500	4	7310	5670	12.99	378.0	4.91
16000	3	9175	7280	18.92	364.0	6.89
16250	7	9800	7750	21.46	904.2	19.41
IRP	2	10600	8517	25.22	283.9	7.16
15000	2	5350	4091	8.75	136.4	1.19
Trans. brk-in	26	-	4517	19.04	1957.4	37.27
ECU	10	-	4757	22.34	792.8	17.71
Transient	5	-	2729	14.08	227.4	3.20
Shutdown	5	-	996	3.23	83.0	0.27
Afterburner	3(b)	15800	30250	9.22	1512.5	13.95
Shutdown	5	-	996	3.23	83.0	0.27
Overspeed	2	-	4757	22.34	158.6	3.54
Shutdown	5	-	996	3.23	83.0	0.27

Pounds of fuel used in test 7399

Pounds of NO_x per test 119.74

Pounds of NO_x per pound of fuel used in test = 0.01618

(a) Emission index for nitrogen oxides expressed as pounds of nitrogen dioxide per 1000 pounds of fuel.

(b) Estimated.

Emissions of Nitrogen Oxides
from the Testing of F404-GE-400 Engines
at Naval Air Station, Lemoore, California

APPENDIX A

Tables IV and V, NAPC-LR-81-10

F404-GE-400 Run Sheets 8 March to 26 April 1985

TABLE IV

F404 EMISSIONS

EMISSION CONCENTRATION (PPM)

Power Condition	CO ₂ , ppm	CO, ppm	HC, ppm	NO _x , ppm	Wf, lb/hr	FN, lb	EPR	%H	%A
IRP	45790	24.0	<15.0	349.2	8586.9	10548	3.532	13.85	17.59
94%	44230	26.8	<15.0	286.7	8082.6	9957	3.342		
M/C	43040	25.0	<15.0	244.1	7495.1	9201	3.167		
76%	39880	21.7	<15.0	178.9	6541.3	8031	2.902		
63%	36770	21.2	<15.0	131.3	5586.6	6662	2.609		
46%	32090	28.5	<15.0	81.5	4005.2	4883	2.178		
37%	28990	62.3	15.0	56.5	3108.4	3845	1.937		
26%	25380	73.1	18.0	39.7	2422.5	2728	1.710		
20%	22970	139.1	30.0	32.0	1989.2	2069	1.525		
15%	21180	261.9	58.5	25.7	1666.4	1597	1.409		
F/I	15180	1046.7	811.3	-	814.8	234	1.037		
G/I	17210	1352.1	1232.4	6.9	623.9	78	1.016		
MIN	43000	1678.7	354.0	281.4	10250.0	10996	3.513		
MID	75500	1704.4	311.0	296.6	19071.0	14110	3.500		
MAX	106100	1234.3	15.0	299.9	28396.5	15254	3.486		

TABLE V

F404 EMISSIONS

EMISSION WEIGHT RATIOS (G/KG FUEL)

Power Condition	CO ₂ , g/kg	CO, g/kg	HC, g/kg	NO _x , g/kg	W _f , lb/hr	FN, lb	EPR	%H	%A
IRP	3156	1.05	<0.31	25.16	8586.9	10548	3.532	13.85	17.59
94%	3156	1.22	<0.32	21.38	8082.6	9957	3.342		
M/C	3156	1.17	<0.33	18.71	7495.1	9201	3.167		
76%	3156	1.09	<0.35	14.80	6541.3	8031	2.902		
63%	3156	1.16	<0.38	11.78	5586.6	6662	2.609		
46%	3155	1.78	<0.44	8.37	4005.2	4883	2.178		
37%	3151	4.31	0.48	6.42	3108.4	3845	1.937		
26%	3148	5.77	0.66	5.15	2422.5	2782	1.710		
20%	3136	12.09	1.21	4.56	1989.2	2069	1.525		
15%	3112	24.49	2.54	3.95	1666.4	1597	1.409		
F/I	2815	123.52	44.50	-	814.8	234	1.037		
G/I	2747	137.34	58.18	1.16	623.9	78	1.016		
MIN	2017	74.95	7.35	20.64	10250.0	10996	3.513		
MID	2077	44.21	3.75	12.64	19071.0	14110	3.500		
MAX	3122	23.12	0.13	9.22	28396.5	15254	3.486		

TAT 1112.44min PPMB 29.86
 JMT 15 min
 RDT 13 min ENGIN SIN 310097
 SHIRTS 2
 F-104 RUN SHEET
 ORIGINATOR ML Bossi
 INSPECTOR AER BOCALONE
 ALI ICE CHECK 4
 NCDP 0 PPMFE 4500 102
 TOTAL SERVICE 66.41 (65.80 min)
 SEQUENCE # 583
 TEST DATE 22 MARCH
 TYPE TEST REG. KTN
 RUT N1206
 N2 156

IF FORMULA				NID U.J.T'S				EQU CHECKS				TRANSPARENT TEST				ROLL-OVER				VIG DATA			
TIME	RA	N2	THURST	P3	W36	TSC	N36	TSC	W36	W36	W36	W36	W36	W36	W36	W36	W36	W36	W36	W36	W36	W36	W36
1448	7.5	12115	530	69	15	103	72	22	22	50	341	93	77	31	59	154	247	63	668	1015	2354	2500	13500
1452	7060	12115	530	69	15	103	72	22	22	50	341	93	77	31	59	154	247	63	668	1015	2354	2500	13500
1455	9470	12115	530	69	15	103	72	22	22	50	341	93	77	31	59	154	247	63	668	1015	2354	2500	13500
1458	12050	12115	530	69	15	103	72	22	22	50	341	93	77	31	59	154	247	63	668	1015	2354	2500	13500
1501	12565	12115	530	69	15	103	72	22	22	50	341	93	77	31	59	154	247	63	668	1015	2354	2500	13500
1504	13185	12115	530	69	15	103	72	22	22	50	341	93	77	31	59	154	247	63	668	1015	2354	2500	13500
1507	13160	12115	530	69	15	103	72	22	22	50	341	93	77	31	59	154	247	63	668	1015	2354	2500	13500
1615	11790	12115	530	69	15	103	72	22	22	50	341	93	77	31	59	154	247	63	668	1015	2354	2500	13500
1519		12115	530	69	15	103	72	22	22	50	341	93	77	31	59	154	247	63	668	1015	2354	2500	13500
1547		12115	530	69	15	103	72	22	22	50	341	93	77	31	59	154	247	63	668	1015	2354	2500	13500
1550	13160	12115	530	69	15	103	72	22	22	50	341	93	77	31	59	154	247	63	668	1015	2354	2500	13500
1600		12115	530	69	15	103	72	22	22	50	341	93	77	31	59	154	247	63	668	1015	2354	2500	13500
1601		12115	530	69	15	103	72	22	22	50	341	93	77	31	59	154	247	63	668	1015	2354	2500	13500
1604		12115	530	69	15	103	72	22	22	50	341	93	77	31	59	154	247	63	668	1015	2354	2500	13500
1614		12115	530	69	15	103	72	22	22	50	341	93	77	31	59	154	247	63	668	1015	2354	2500	13500
1705	776	10.4	776	24.2	49	808	96	18	18	0	805	115	69	182	45	242	0	62	1491	8550	30800	15000	15000
1710	40%																						
1720	Start	DOWN																					

REMARKS:

1484

W/F

EOP

65

66%

1014

MAINT

DOWN

TRT 52 min PMS F-104 RUN SHEET ORIGINATOR SEQUENCE # 585
 TRPT 5 min INSPECTOR TEST DATE 3/27/85
 ADT 5 min ANTI ICE CHECK 5 TYPE TEST
 STARTS 2 NCOP 0 PPMte RUT #1 171 #2 161
 TOTAL SERVICE 14 USED

I/P FORMULA
 RPM X .91 = FPR
 F56 ÷
 FPR
 MIN EPR
 MIN MIN

NO UNITS
 TOTAL CELL WF
 ENGINE WF
 CORRECTION
 22084 ÷ 8338 =
 AIR UNITS

ECU CHECKS
 PLC FI 28 TRP 85
 RGT HPMS
 FAN SP. TRX OK 2 OK
 N2 LUKV OK
 PO TEST 132213 818
 FAN OVERSPEED 8338

TRANSIENT TEST
 FI to TRP
 TRP to AB
 CRP to TRP
 FI to NO
 PLC TEST OK

KELL-OVER
 N2 24
 ECP 42
 SAF 19
 LEAKS

VIA DATA
 FI 17 #1 17 #2 19 #3 19 #4 17
 80%
 89%
 IRP
 AB

TIME	N2	THROT	P3	N256	TS	N256	TS	TIC	LOVG	TSWA	EDF	AB	PIA	CHL	TEMP	HPVG	TO	T5 °F	ENG. WF	CELL WF	DATA
0824	TTL	7.7	27.7	MAX TS	968	MAX TS	968	64	60P	104	WF	630									
0956	6067	11802	64	14	334	71	17	50	340	77	75	31	51.4	167		33.4	54	652	841	917	FI
0956	Engine	Shutdown																			
1015	TTL	7.1	22.7	MAX TS	1035	MAX TS	1035	64	60P	75	WF	634									
1028	11660	14880	6190	228	638	90	15	17	639	110	15	68	58	214	9.8	55	1191	4903	4957	898	
1031	13100	16125	10620	341	797	97	14	0	798	120	14	87	57	237	3.7	55	1468	8492	8697	IRP	
1037	13100	16180	16000	338	796	97	13	0	797	119	70	132	46	231	4.0	55	1474	8356	30840	AB	
1040	Begin	ECU																			
1045	End	ECU																			
1052	Engine	Shutdown																			

REMARKS:

1



TRT 1HR 50MIN PUMP 29.84

START 16MIN 30SEC

END 11MIN 310.357

STARTS 01

F-404 RUN SHEET

NO. 4

PPM 2

4500

AD1ABECCO

AD2 GALLEGO

AD1 ICE LICK - 4

AD1 ICE LICK - 4

SEQUENCE # 588

TEST DATE 3 APR 1985

TYPE TEST BREAKER

ENGINE SN 310.357

STARTS 01

NO. 4

PPM 2

4500

AD1ABECCO

AD2 GALLEGO

AD1 ICE LICK - 4

AD1 ICE LICK - 4

SEQUENCE # 588

TEST DATE 3 APR 1985

TYPE TEST BREAKER

TIME	N1	N2	THRUST	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14	N15	N16	N17	N18	N19	N20	N21	N22	N23	N24	N25	N26	N27	N28	N29	N30	N31	N32	N33	N34	N35	N36	N37	N38	N39	N40	N41	N42	N43	N44	N45	N46	N47	N48	N49	N50	N51	N52	N53	N54	N55	N56	N57	N58	N59	N60	N61	N62	N63	N64	N65	N66	N67	N68	N69	N70	N71	N72	N73	N74	N75	N76	N77	N78	N79	N80	N81	N82	N83	N84	N85	N86	N87	N88	N89	N90	N91	N92	N93	N94	N95	N96	N97	N98	N99	N100	N101	N102	N103	N104	N105	N106	N107	N108	N109	N110	N111	N112	N113	N114	N115	N116	N117	N118	N119	N120	N121	N122	N123	N124	N125	N126	N127	N128	N129	N130	N131	N132	N133	N134	N135	N136	N137	N138	N139	N140	N141	N142	N143	N144	N145	N146	N147	N148	N149	N150	N151	N152	N153	N154	N155	N156	N157	N158	N159	N160	N161	N162	N163	N164	N165	N166	N167	N168	N169	N170	N171	N172	N173	N174	N175	N176	N177	N178	N179	N180	N181	N182	N183	N184	N185	N186	N187	N188	N189	N190	N191	N192	N193	N194	N195	N196	N197	N198	N199	N200	N201	N202	N203	N204	N205	N206	N207	N208	N209	N210	N211	N212	N213	N214	N215	N216	N217	N218	N219	N220	N221	N222	N223	N224	N225	N226	N227	N228	N229	N230	N231	N232	N233	N234	N235	N236	N237	N238	N239	N240	N241	N242	N243	N244	N245	N246	N247	N248	N249	N250	N251	N252	N253	N254	N255	N256	N257	N258	N259	N260	N261	N262	N263	N264	N265	N266	N267	N268	N269	N270	N271	N272	N273	N274	N275	N276	N277	N278	N279	N280	N281	N282	N283	N284	N285	N286	N287	N288	N289	N290	N291	N292	N293	N294	N295	N296	N297	N298	N299	N300	N301	N302	N303	N304	N305	N306	N307	N308	N309	N310	N311	N312	N313	N314	N315	N316	N317	N318	N319	N320	N321	N322	N323	N324	N325	N326	N327	N328	N329	N330	N331	N332	N333	N334	N335	N336	N337	N338	N339	N340	N341	N342	N343	N344	N345	N346	N347	N348	N349	N350	N351	N352	N353	N354	N355	N356	N357	N358	N359	N360	N361	N362	N363	N364	N365	N366	N367	N368	N369	N370	N371	N372	N373	N374	N375	N376	N377	N378	N379	N380	N381	N382	N383	N384	N385	N386	N387	N388	N389	N390	N391	N392	N393	N394	N395	N396	N397	N398	N399	N400	N401	N402	N403	N404	N405	N406	N407	N408	N409	N410	N411	N412	N413	N414	N415	N416	N417	N418	N419	N420	N421	N422	N423	N424	N425	N426	N427	N428	N429	N430	N431	N432	N433	N434	N435	N436	N437	N438	N439	N440	N441	N442	N443	N444	N445	N446	N447	N448	N449	N450	N451	N452	N453	N454	N455	N456	N457	N458	N459	N460	N461	N462	N463	N464	N465	N466	N467	N468	N469	N470	N471	N472	N473	N474	N475	N476	N477	N478	N479	N480	N481	N482	N483	N484	N485	N486	N487	N488	N489	N490	N491	N492	N493	N494	N495	N496	N497	N498	N499	N500	N501	N502	N503	N504	N505	N506	N507	N508	N509	N510	N511	N512	N513	N514	N515	N516	N517	N518	N519	N520	N521	N522	N523	N524	N525	N526	N527	N528	N529	N530	N531	N532	N533	N534	N535	N536	N537	N538	N539	N540	N541	N542	N543	N544	N545	N546	N547	N548	N549	N550	N551	N552	N553	N554	N555	N556	N557	N558	N559	N560	N561	N562	N563	N564	N565	N566	N567	N568	N569	N570	N571	N572	N573	N574	N575	N576	N577	N578	N579	N580	N581	N582	N583	N584	N585	N586	N587	N588	N589	N590	N591	N592	N593	N594	N595	N596	N597	N598	N599	N600	N601	N602	N603	N604	N605	N606	N607	N608	N609	N610	N611	N612	N613	N614	N615	N616	N617	N618	N619	N620	N621	N622	N623	N624	N625	N626	N627	N628	N629	N630	N631	N632	N633	N634	N635	N636	N637	N638	N639	N640	N641	N642	N643	N644	N645	N646	N647	N648	N649	N650	N651	N652	N653	N654	N655	N656	N657	N658	N659	N660	N661	N662	N663	N664	N665	N666	N667	N668	N669	N670	N671	N672	N673	N674	N675	N676	N677	N678	N679	N680	N681	N682	N683	N684	N685	N686	N687	N688	N689	N690	N691	N692	N693	N694	N695	N696	N697	N698	N699	N700	N701	N702	N703	N704	N705	N706	N707	N708	N709	N710	N711	N712	N713	N714	N715	N716	N717	N718	N719	N720	N721	N722	N723	N724	N725	N726	N727	N728	N729	N730	N731	N732	N733	N734	N735	N736	N737	N738	N739	N740	N741	N742	N743	N744	N745	N746	N747	N748	N749	N750	N751	N752	N753	N754	N755	N756	N757	N758	N759	N760	N761	N762	N763	N764	N765	N766	N767	N768	N769	N770	N771	N772	N773	N774	N775	N776	N777	N778	N779	N780	N781	N782	N783	N784	N785	N786	N787	N788	N789	N790	N791	N792	N793	N794	N795	N796	N797	N798	N799	N800	N801	N802	N803	N804	N805	N806	N807	N808	N809	N810	N811	N812	N813	N814	N815	N816	N817	N818	N819	N820	N821	N822	N823	N824	N825	N826	N827	N828	N829	N830	N831	N832	N833	N834	N835	N836	N837	N838	N839	N840	N841	N842	N843	N844	N845	N846	N847	N848	N849	N850	N851	N852	N853	N854	N855	N856	N857	N858	N859	N860	N861	N862	N863	N864	N865	N866	N867	N868	N869	N870	N871	N872	N873	N874	N875	N876	N877	N878	N879	N880	N881	N882	N883	N884	N885	N886	N887	N888	N889	N890	N891	N892	N893	N894	N895	N896	N897	N898	N899	N900	N901	N902	N903	N904	N905	N906	N907	N908	N909	N910	N911	N912	N913	N914	N915	N916	N917	N918	N919	N920
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TRT 2 HOURS 7 MIN PIMB 29,49 F-404 RUN SHEET
 INPT 4 MIN AD1 SEQUENCE # 589
 ADT 3 MIN AD2 GALLEOS TEST DATE 5 APRIL 85
 STARTS ONE ENGIN VIN 3A0320 NOAP 0 PIMB 4 TYPE TEST BREAK IN
 TOTAL SERVICE FULL USED 450 RUT N1 180 N2 164

IF FORMULA				EVAL CHECKS				TRANSIENT TEST				VIA DATA			
PIMB X .91 = 14.48				FI 33 TRP 100				FI 2 TRP 1.4				N1 24			
P56 ÷ 3.11 = 3.11 EPR				AGE 100				TRP TO AD 1.5				EOP 1.4			
EPR 3.11				FAN SP. TRX 100				FI TO AD 4.5				SAF 1.5			
MIN EPR 3.03				N2 LOSSUP 0.1				PLC TEST OK				LEAKS			
MAX MIN 1.8				PO TEST N13363 15.821											
				FAN OVERSPEED N1 89.84											
TIME	N1	N2	THROTTLE	P3	TS	TS	TS	TS	TS	TS	TS	TS	TS	TS	TS
1447	1447	1447	1447	1447	1447	1447	1447	1447	1447	1447	1447	1447	1447	1447	1447
1450	5982	11893	235	46	13	367	72	37	50	367	74	75	32	57	166
1455	8895	13525	2110	98	18	458	81	35	50	499	76	0	55	57	192
1458	11705	15064	5715	195	31	667	90	34	22	663	98	15	79	56	224
1501	15230	15300	7222	234	36	718	93	33	17	719	101	15	87	56	235
1508	12808	13970	8735	269	41	773	95	33	91	773	104	15	91	56	242
1514	13129	16231	9640	297	44	810	97	33	5	809	106	14	93	56	248
1515	13372	16342	10150	306	45	813	98	31	0	812	106	20	100	55	250
1523	11569	15050	5440	184	29	634	89	34	32	635	96	15	79	56	224
1529	GI	START	SMIN	TRANSIENT	TRANSIENT	TRANSIENT	TRANSIENT	TRANSIENT	TRANSIENT	TRANSIENT	TRANSIENT	TRANSIENT	TRANSIENT	TRANSIENT	TRANSIENT
1530	START	START	START	START	START	START	START	START	START	START	START	START	START	START	START
1601	END TRANSIENT	END TRANSIENT	END TRANSIENT	END TRANSIENT	END TRANSIENT	END TRANSIENT	END TRANSIENT	END TRANSIENT	END TRANSIENT	END TRANSIENT	END TRANSIENT	END TRANSIENT	END TRANSIENT	END TRANSIENT	END TRANSIENT
1607	1371	16284	14820	299	43	811	98	32	50	810	107	71	131	45	247
1612	START	START	START	START	START	START	START	START	START	START	START	START	START	START	START
1625	END	END	END	END	END	END	END	END	END	END	END	END	END	END	END
1630	END	END	END	END	END	END	END	END	END	END	END	END	END	END	END
1636	SHUT DOWN	SHUT DOWN	SHUT DOWN	SHUT DOWN	SHUT DOWN	SHUT DOWN	SHUT DOWN	SHUT DOWN	SHUT DOWN	SHUT DOWN	SHUT DOWN	SHUT DOWN	SHUT DOWN	SHUT DOWN	SHUT DOWN

REMARKS:
 TO V T1600N
 A9 V PL1600D
 EOP 6000

TRT 2 Hours 12 min 2987 F-104 RUN SHEET OPERATOR ABELLO SEQUENCE # 590
 JMT 15 min 20 sec TEST DATE APA 11 85
 ART 7 min 310107 INSPECTOR GALLAGHER TYPE TEST BREAK IN
 STARTS DATE 2003 NR 155
 NOAP PPM 4500
 TOTAL SERVICE 4500

TRANSIENT TEST				ROLL-OVER				VIA DATA			
FUEL IRP 2.1				(N2) 26				#1 #2 #3 #4			
IRP to AB 1.4				EOP 18				.17 .12 .25 .33			
CICP to IRP 1.9				50% 18				.12 .12 .12 .12			
FI to AD 9.1				LEANS				.10 .10 .10 .10			
PLC TEST OKAY											
TIME	IN	N2	TEMP	HPVC	TO	TS °F	ENG. W/F	CELL W/F	DATA IDENT		
947											
957	6600	11928	470	58	77	31	59	170	29.7	6.3	6.96
1001	9410	13509	2815	119	0	55	58	190	15.7	6.3	10.04
1006	11841	15009	6685	222	16	78	58	218	8.3	6.4	12.84
1015	12507	15515	8505	268	16	86	57	228	5.8	6.3	13.96
1021	13170	16020	10580	321	16	92	57	236	3.2	6.4	15.30
1028	13190	16051	10690	323	17	100	57	238	3.3	6.4	15.30
1032	11727	14968	6250	213	15	77	58	228	8.5	6.5	12.02
1035	BEGIN TRANSIENT										
1114	END TRANS										
1121	13216	16029	14885	318	48	820	45	233	3.3	6.7	15.32
1191	END ECA CHECK										
END TRANSIENT											
1259	ENGINE SHUT DOWN										

REMARKS:
 OIL VS 42% GOOD
 DIA VS AB 6000
 DIA VS TIC GOOD

TRT 1.1 min Pumps 29.62 F-404 RUN SHEET OPERATOR ADL ABella SEQUENCE # 591
 INPT 12 min TEST DATE 12 APR 1975
 ADT 5 min ENGINE S/N 510249 INSPECTOR A03 Collier TYPE TEST Block In
 STARTS 1 NOOP 0 PMTC 5 AMI ICE CHECK 5 (AUT N) 185 SEC 136 SEC

199 FORMULA				ECU CHECKS				TRANSIENT TEST				ROLL-OVER				VIA DATA					
TIME	N1	N2	INJECT	P3	USL6	TSC	N1K	TIC	LPV6	TSUA	EOF	AB	PIA	FUEL PSI	OIL TEMP	HPV6	IO	TS °F	ENG. W/F	CELL W/F	DATA IDENT.
TT L	12.2		TTI	30.2	T5	1089	WF	675	50	369	76	64									
1302	5728	11720	410	47	15	367	70	31	50	369	76	76	31	55	163	330	77	699	812	975	F.I.
1303	9075	13535	2360	105	22	494	70	31	50	494	92	0	55	55	190	150	77	932	2040	2095	13500
1305	11580	14940	5560	191	31	627	90	28	28	625	103	17	67	54	216	70	75	1152	4330	4380	15000
1309	12323	15515	7475	238	38	690	93	29	17	690	105	17	72	54	230	30	76	1272	5720	5725	15500
1314	12825	15995	9100	278	44	755	96	27	11	757	108	16	77	54	240	0	76	1343	7190	7150	16000
1319	13074	16250	10160	305	48	795	97	26	5	793	110	12	79	54	245	0	78	1463	7975	7960	16250
1324	13285	16435	10700	322	50	814	99	26	0	815	110	12	87	53	249	0	77	1500	8500	8550	16250
1328	11480	14990	5250	189	31	575	90	30	28	578	97	16	66	54	232	5.5	76	1086	4000	4000	15000
1331	Over/To		G.I.																		
1340	END	START	ADV	STATE	Block IN			Begin		Trans. test											
1412	END	TRANSIENT	Check IN	316	49	811	98	28	0	813	113	71	130	42	242	0	79	1500	8580	50170	A18
1415	13310	16385	15850	316	49	811	98	28	0	813	113	71	130	42	242	0	79	1500	8580	50170	A18
1419			START	DEAMPL	TO																
1425			END	EOU	CHECK																
1432			END	EOU	CHECK																
1441			End	Transient	Test																
1446	NL		Over speed	Engine	shut down																

199 FORMULA

PAPRS X .491 = 14.64

P56 ÷ 50 = 3.10 EPR

FPR 3.40

M/W EPR 3.23

MINIMUM 1.7

ECU CHECKS

NLC FI 29 TRIP 85

HPV6 119

FAN SP. TAX 1 OK 2 OK

N2 LOCKUP

PO TEST N1 134125 812 279

FAN OVERSPEED N1 8006

TRANSIENT TEST

FI TO IRP 119

IRP TO AB 119

CHOP TO IRP 3.5

FI TO AD 3.5

PLC TEST OK

ROLL-OVER

N2 22

ECR 23

SAP 16

LEAKS

VIA DATA

#1 1.2

#2 1.1

#3 1.1

F2 80%

89%

IRP 1.7

AD 1.6

7

7

7

7

7

7

7

7

REMARKS:

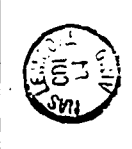
TEST

TEST

END

START

REMARKS:



TRT 1st 4 min 29.51 PPMB F-404 RUN SHEET OPERATOR Norton CPL SEQUENCE # 595
 JMT 1st 4 min 3100.49 PPMF INSPECTOR Barclay TEST DATE 26/11/18
 ADT 3 STARTS 3100.49 NCOP TOTAL SERVIC Full 4520 602 ADH ICE CHECK -4 TYPE TEST Backcheck
 KUT NO. 197 NR 152

VIA DATA				TRANSIENT TEST				CELL OVER				DATA			
#1	#2	#3	#4	FI	IRP	IRP to IRP	IRP to AD	PLC TEST	HPVC	TO	TS °F	ENG. W/F	CELL W/F	IDENT	
17	12	12	13	80%	81%	IRP	IRP	AD							
13	13	13	13												
17	17	17	17												
17	17	17	17												

TIME	NR	THROST	IR	IR	IR	IR	IR	IR	IR	IR	IR	IR	IR	IR	IR
1638	N28	65	MAXTS	1091	100	W/F	694	TTL	8.9	TRP	85	324			
647	5978	11755	320	51	14	355	78	28	49	355	80	77	31	55	168
650	9245	13570	2440	110	21	492	81	27	48	492	96	5	53	55	184
652	11695	15120	6090	205	33	650	90	25	21	649	111	17	68	55	215
656	12200	15500	7310	235	37	670	93	25	14	693	112	17	72	54	222
700	12825	16000	9175	282	44	761	96	24	6	761	116	17	76	54	233
703	12975	16172	9800	297	46	787	96	23	4	786	116	15	78	53	238
710	13252	16400	10600	319	49	816	98	23	0	815	117	16	87	53	242
712	11367	14910	5350	188	31	599	90	25	26	600	104	17	65	55	228
714	End	Steady	Stable	break in	begin	begin	begin	begin	begin	begin	begin	begin	begin	begin	begin
719	End	transient	break in	begin	begin	begin	begin	begin	begin	begin	begin	begin	begin	begin	begin
730	End	ECU	begin	begin	begin	begin	begin	begin	begin	begin	begin	begin	begin	begin	begin
759	Shutdown														
1348	13235	16276	15800	312	48	811	97	22	0	812	118	75	131	42	233
1900		shut down													
2011	START	TTL	6.9	TLE	20.2	TS	1020	N2	64	FOR	100	WF	675		
2015	shut down														

REMARKS:
 T1 vs TO good
 EOP good
 AB vs PLA

BT 118 18250

Emissions of Nitrogen Oxides
from the Testing of F404-GE-400 Engines
at Naval Air Station, Lemoore, California

APPENDIX B

The Use of a Small Programmable Calculator
for Estimation of the Amounts of Nitrogen Oxides
Produced during the Testing of F404-GE-400 Engines

The Use of a Small Programmable Calculator
for Estimation of the Amounts of Nitrogen Oxides
Produced during the Testing of F404-GE-400 Engines

B1. USE OF THE HP-41C/CV CALCULATOR

A programmable calculator, preferably with a printer, will aid in making estimations of the emissions of nitrogen oxides. The following paragraphs show how to use a Hewlett Packard HP-41C/41CV calculator to make these estimates. The instructions assume that the user knows how to load and run a program. Program NOP requires an HP 82162A Thermal Printer with an HP-IL Module. Program NO does not require a printer. Both programs make the same calculations. The Aircraft Environmental Support Office prefers using program NOP because it provides a permanent record of the data entered and values calculated. Program NO is provided for the convenience of users who do not have a printer. Programs NOP and NO use nine of the keys in the top two rows of the calculator as "local labels" A through J (label G is not used). This means that to use these programs, the calculator must be in "user" mode and must not have user assignments on these keys.

For additional information about these programs or for help in modifying them to meet specific needs, contact:

Aircraft Environmental Support Office, Code 643
Naval Air Rework Facility
Naval Air Station, North Island
San Diego, CA 92135
(Autovon 951 5032, Commercial (619) 437 5032)

B2. DESCRIPTION OF PROGRAMS NOP AND NO

The programs make the calculations described in this report. The programs use two storage registers. The functions of the labels are as follows:

Label	Use
I	Initiates the program and sets both registers 00 and 01 to zero. After asking for a sequence number, to identify the test, label I requires the input of data for each power setting used in the test. These data are: time (as minutes), thrust (as pounds), and fuel flow (as pounds per hour). The program first calculates an emission index for nitrogen oxides for the power setting using equation (1). The constants needed for this calculation are in the program. The program next calculates the amount of fuel used for the time at the power setting and adds this amount of fuel to whatever number is in register 00

Label

Use

(always zero at the start of the data entry). The program next calculates the amount of nitrogen oxides produced by the time of operation at that power setting, using the emission index already calculated, and adds this number to whatever number is in register 01 (again zero at the start of data entry). Thus registers 00 and 01 accumulate the amounts of fuel used and nitrogen oxides produced by the various power settings in the test run. As label I always sets registers 00 and 01 to zero, it must be used only to initiate the determination of fuel and nitrogen oxides from a test.

A to F

Labels A to F are alternate methods for entering data. They are used with test procedures or power settings for which some of the data does not vary. These keys allow faster entry of data.

A

This label calculates fuel use and nitrogen oxides produced for the transient break-in test procedure (see Paragraph 2.3). This test procedure uses an emission index and fuel flow which already has been determined. Thus, the only entry needed is the time of operation for the test procedure.

B and C

These labels make calculations for transient and ECU similar to those made by label A.

D and E

These labels make calculations for overspeed and shutdown similar to those made by label A . In this report, the times at these test procedures usually do not change. Overspeed always is 2 minutes and shutdown usually is 5 minutes. Thus, keys D and E need no data entries.

F

This label is used for afterburner. The emission index for afterburner is not calculated from thrust. Instead a constant value is used. Thus, the only data entries are time and fuel flow.

H

Label H changes a bad entry. It deletes the row of data just entered.

J

Label J determines the total amount of fuel used and nitrogen oxides produced. Label J also calculates the amount of nitrogen oxides produced per pound of fuel used in the test.

B3. INSTRUCTIONS FOR USING PROGRAMS NOP AND NO

The instructions for programs NOP and NO use data from Table 5 of the report. With the calculator at the desired program, start the calculation by the keystroke, I, or by XEQ NOP (or NO).

B3.1 Program NOP

KEYSTROKES	DISPLAY	REMARKS
I	SEQUENCE?	Key in an identifying sequence number. if no number is assigned, a blank space will appear on the printer tape.
584	584	Key in R/S to continue.
R/S	MINUTES?	Key in data from Table 5 starting with the first data row. Key in time.
6	6	Key in R/S to continue.
R/S	THRUST?	Key in thrust.
450	450	Key in R/S to continue.
R/S	FUEL?	Key in fuel.
1049	1049	Key in R/S to continue.
R/S	MINUTES?	The first line of the print-out (6 450 1049) shows the data entered in the order entered. The second line of the print-out (3.26 104.9 0.34) shows the emission index for nitrogen oxides at the power setting used, the pounds of fuel used for the time at that power setting and the amount of nitrogen oxides produced. In a similar manner, key in the next three rows of data.
R/S	MINUTES?	Key in the time at ECU.
19	19	ECU is a special test procedure. It is a combination of more than one power settings. Key in C to continue.
C	MINUTES?	The first line of the print-out identifies the test procedure. The second line of the print-out shows the time and the fuel flow. The third line shows the emission index, the fuel used and the amount of nitrogen oxides produced. Key in R/S to continue.

KEYSTROKES	DISPLAY	REMARKS
R/S	MINUTES?	The next row is afterburner data. It is a special situation in that the emission index used always is 9.22. Key in the time.
3	3	Key in F to continue.
F	A/B FUEL?	Key in the fuel used at afterburner.
29590	29590	Key in R/S to continue.
R/S	MINUTES?	The first line of the print-out identifies the power setting. The second line shows the data entered. The third line shows the emission index, fuel used and nitrogen oxides produced. The next data row is for shutdown. It is a special situation. Key in E to continue.
E	MINUTES?	This label assigns a time of 5 minutes, an average fuel flow of 996 pounds per hour, and an emission index of 3.23. The first line of the print-out identifies the power sequence. The second line of the print-out shows the time and the fuel flow. The third line shows the emission index, the fuel used and the amount of nitrogen oxides produced. Note that an overspeed operation always is assigned a time of 2 minutes and a shutdown operation usually is assigned a time of 5 minutes. When using a shutdown procedure of other than 5 minutes, enter time, average thrust (404), and fuel flow (996) for flight idle. The next operation is another special situation, transient. Key in time to continue.
19	19	Transient is a special situation. It is a combination of more than one power settings. Key in B to continue.
B	MINUTES?	The first line of the print-out identifies the operating sequence. The second line of the print-out shows the time and the fuel flow. The third line shows the emission index, the fuel used and the amount of nitrogen oxides produced. Key in D to enter overspeed data.
D	MINUTES?	The print-out identifies and shows overspeed data. Key in E for shutdown data.
E	MINUTES?	The print-out identifies and shows shutdown data. All data have been entered. Key in J for accumulated data.

KEYSTROKES	DISPLAY	REMARKS
J	SEQUENCE?	The print-out shows the pounds of nitrogen oxides formed during the test, the pounds of fuel used in the test, and the pounds of nitrogen oxides formed for each pound of fuel used. The calculator is ready to repeat the calculations using another test.
H	ENTRY DELETED	Label H removes a bad entry. It must be used immediately after the printing of the second line showing emission index, fuel used and nitrogen oxides produced.
B3.2 Program <u>NO</u>		
I	MINUTES?	Key in the time for the first data row.
6	6	Key in R/S to continue.
R/S	THRUST?	Key in thrust.
450	450	Key in R/S to continue.
R/S	FUEL?	Key in fuel.
1049	1049	Key in R/S to continue.
R/S	EI=	Key in R/S to continue.
R/S	3.26	The display shows the emission index for nitrogen oxides at this power setting. Key in R/S to continue.
R/S	FUEL=	Key in R/S to continue.
R/S	104.9	The display shows the fuel used for the time at this power setting. Key in R/S to continue.
R/S	LBS/MODE=	Key in R/S to continue.
R/S	0.34	The display shows the pounds of nitrogen oxides formed during the operation of the engine at flight idle for 6 minutes. Key in R/S to continue.
R/S	MINUTES?	Enter the other data rows in a similar manner. when using labels A - F to enter data for transient break-in, transient, ECU, overspeed, shutdown and afterburner, the display shows the fuel used and the amount of nitrogen oxides produced by the test procedures. It does not show emission indexes. After entering all data continue with Label J.

J	NOX/TEST=	Key in R/S to continue.
R/S	82.65	The display shows the total amount of nitrogen oxides produced from all of the power settings used in the test. Key in R/S to continue.
R/S	TOTAL FUEL=	Key in R/S to continue.
R/S	5907	The display shows the amount of fuel used in the test. Key in R/S to continue.
R/S	NOX/LB FUEL=	Key in R/S to continue.
R/S	0.01399	The display shows the pounds of nitrogen oxides produced for each pounds of fuel used. The calculation is complete. Key in R/S to restart the program on a new calculation.
R/S	MINUTES?	
H	DELETED	Label H removes a bad entry. It must be used immediately after the numerical display of pounds per mode. Re-enter correct time, thrust and fuel.

B4. LISTING OF PROGRAMS NOP AND NO

B4.1 Program NOP

01+LBL "NOP"	41 *	81 ACA	121+LBL D
02+LBL I	42 FIX 1	82 FIX 5	122 2
03 FIX 0	43 ACX	83 /	123 "OVERSPEED"
04 .	44 ST+ 00	84 ACX	124 4757
05 STO 00	45 STO 2	85 ADV	125 22.34
06 STO 01	46 FIX 2	86 FIX 1	126 GTO 06
07 "SEQUENCE?"	47 X<>Y	87 ADV	127+LBL E
08 PROMPT	48 FIX 2	88 GTO "NOP"	128 5
09 X=0?	49 1 E3	89+LBL A	129 "SHUTDOWN"
10 GTO 00	50 /	90 "TRANS BREAK-IN"	130 996
11 ACX	51 *	91 4517	131 3.23
12+LBL 00	52 ACX	92 19.04	132 GTO 06
13 PRBUF	53 ADV	93+LBL 06	133+LBL F
14+LBL 01	54 FIX 1	94 ACA	134 "A/B FUEL ?"
15 "MINUTES?"	55 ADV	95 PRBUF	135 PROMPT
16 PROMPT	56 ST+ 01	96 ENTER↑	136 9.22
17 ACX	57 FIX 0	97 RCL T	137 CLA
18 "THRUST ?"	58 GTO 01	98 ACX	138 "AFTERBURNER"
19 PROMPT	59+LBL J	99 " "	139 GTO 06
20 ACX	60+LBL 02	100 ACA	140+LBL "CHG"
21 2.0165	61 "LBS NOX/TEST ="	101 RCL Z	141+LBL H
22 1 E-4	62 ACA	102 ACX	142 FIX 6
23 *	63 RCL 01	103 PRBUF	143 ST- 01
24 *	64 FIX 2	104 RDN	144 RDN
25 E+X	65 ACX	105 X<>Y	145 ST- 00
26 2.974733	66 ADV	106 RCL T	146 94
27 *	67 ADV	107 X<>Y	147 ACCHR
28 "FUEL?"	68 "LBS FUEL/TEST ="	108 FIX 2	148 " "
29 PROMPT	69 ACA	109 ACX	149 ACA
30 ACX	70 FIX 0	110 GTO 03	150 "ENTRY DELETED"
31 PRBUF	71 RCL 00	111+LBL B	151 FIX 0
32 X<>Y	72 ACX	112 "TRANSIENT"	152 ACA
33 FIX 2	73 ADV	113 2729	153 ADV
34 ACX	74 ADV	114 14.08	154 ADV
35+LBL 03	75 "LBS NOX"	115 GTO 06	155 GTO 01
36 RCL Z	76 ACA	116+LBL C	156 RTN
37 60	77 "/LBS OF FUEL"	117 "ECU"	157 END
38 /	78 ACA	118 4757	
39 STO 2	79 PRBUF	119 22.34	
40 RCL T	80 "USED IN TEST ="	120 GTO 06	

B4.2 Program NO

01*LBL "NO"	41 1 E3	81 GTO 01
02*LBL I	42 /	82*LBL B
03 .	43 *	83 "TRAN"
04 STO 00	44 FIX 2	84 2729
05 STO 01	45 "LBS/MODE="	85 14.08
06*LBL 01	46 PROMPT	86 GTO 06
07 "MINUTES?"	47 ST+ 01	87*LBL C
08 PROMPT	48 STOP	88 "ECU"
09 "THRUST ?"	49 RTN	89 4757
10 PROMPT	50*LBL J	90 22.34
11 2.0165	51*LBL 02	91 GTO 06
12 1 E-4	52 "NOX/TEST="	92*LBL D
13 *	53 PROMPT	93 2
14 *	54 RCL 01	94 "OVERSPEED"
15 E+X	55 FIX 2	95 4757
16 2.974733	56 STOP	96 22.34
17 *	57 "TOTAL FUEL="	97 GTO 06
18 "FUEL?"	58 PROMPT	98*LBL E
19 PROMPT	59 FIX 0	99 5
20 X<>Y	60 RCL 00	100 "SHUTDOWN"
21 FIX 2	61 STOP	101 996
22 "EI="	62 "NOX/LB FUEL="	102 3.23
23 PROMPT	63 PROMPT	103 GTO 06
24 STOP	64 FIX 5	104*LBL F
25 XEQ 03	65 /	105 "A/B FUEL ?"
26 GTO 01	66 STOP	106 PROMPT
27*LBL 03	67 GTO "NO"	107 9.22
28 RCL Z	68*LBL A	108 CLA
29 60	69 "TRANS BREAK-IN"	109 "AFTERBURNER"
30 /	70 4517	110 GTO 06
31 STO Z	71 19.04	111*LBL "CHG"
32 RCL T	72*LBL 06	112*LBL H
33 *	73 ENTER↑	113 ST- 01
34 FIX 1	74 RCL T	114 RDN
35 "FUEL="	75 RCL Z	115 ST- 00
36 PROMPT	76 RDN	116 "DELETED"
37 STOP	77 X<>Y'	117 PROMPT
38 ST+ 00	78 RCL T	118 GTO 01
39 STO Z	79 X<>Y	119 RTN
40 X<>Y	80 XEQ 03	120 END

B5. EXAMPLE OF PRINT-OUT FROM PROGRAM NOP

584
6 450 1049
3.26 104.9 0.34

6 2600 2323
5.03 232.3 1.17

15 6620 5189
11.30 1297.3 14.66

1 10560 8592
25.02 143.2 3.58

ECU
19 4757
22.34 1506.4 33.65

AFTERBURNER
3 29590
9.22 1479.5 13.64

SHUTDOWN
5 996
3.23 83.0 0.27

TRANSIENT
18 2729
14.08 818.7 11.53

OVERSPEED
2 4757
22.34 158.6 3.54

SHUTDOWN
5 996
3.23 83.0 0.27

LBS NOX/TEST = 82.65

LBS FUEL/TEST = 5907

LBS NOX/LBS OF FUEL
USED IN TEST = 0.01399