

NRL REPORT 4048

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**MEASUREMENT OF AIR FLOW
THROUGH AN AIRCRAFT GENERATOR
DURING FLIGHT**

PART II

ANALYSIS OF FLIGHT TEST DATA FOR F7F-3 AIRCRAFT

J. M. Marzolf and D. Friedman

Airborne Systems Branch
Electricity Division

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NAVAL RESEARCH LABORATORY

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INTRODUCTION

Although the rating of an electrical generator is a function of its electromagnetic design, the rating can be increased considerably by providing added means of heat dissipation, while still retaining the same size and weight in the generator. In aircraft installations this is usually accomplished by forcing an air blast through the generator, which thus makes its maximum safe rating a function of atmospheric ambient conditions, the particular installation and aircraft speed. Since adequate information was not available for accurately rating aircraft generators, this project was initiated to supply additional data in order that existing theoretical rating charts might be checked and extended. In addition, it was desired to obtain more accurate information on which to base the design of future air duct systems and aircraft generators as higher speeds and altitudes are reached, and to provide a system for checking the adequacy of a particular blast tube installation in new types of aircraft.

In order to accomplish this an instrumentation system was needed which would measure the air flow through the generator during flight under varying conditions of altitude, air speed, inlet air temperature, and blast tube configuration. It had to be small and rugged enough to be installed in an aircraft, should not change appreciably the air flow through the generator, and should be applicable to a large number of installations.

An instrumentation system (1), which met these requirements by measuring the static air pressure drop across a previously calibrated generator, was installed in an F7F-3 aircraft (Bureau of Aeronautics No. 80430) and provided the data for this report.

CALIBRATION

The calibration tests (2) were completed prior to the flight tests. Calibration data for air speed and altitude (3, 4) are shown in Figures 1 and 2. Figures 3 and 4 illustrate the relations existing between the mass rate of air flow, the average air density (obtained by averaging the inlet and outlet values), and the static pressure drop across the generator and was obtained in the York altitude chamber with the generator operating at half load and a speed of 6000 rpm.

In Figure 5 an entirely different approach was tried; here, the static pressure drop across the generator was plotted against the square of the mass rate of air flow divided by the average air density. It was found that a single, approximately linear, curve could be drawn which would represent all the data regardless of altitude. This correlation method is worthy of further study, particularly with different types of generators, since it may make it possible to conduct all calibration tests under sea level conditions and eliminate the need for an altitude chamber for this type of work. The selection of these coordinates

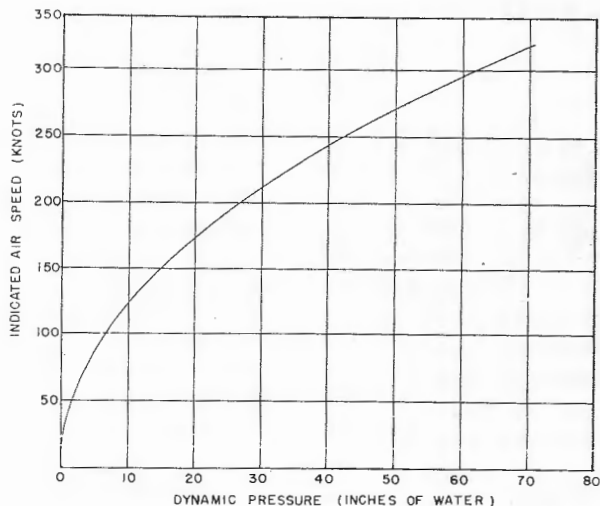


Figure 1 - Indicated air speed calibration curve

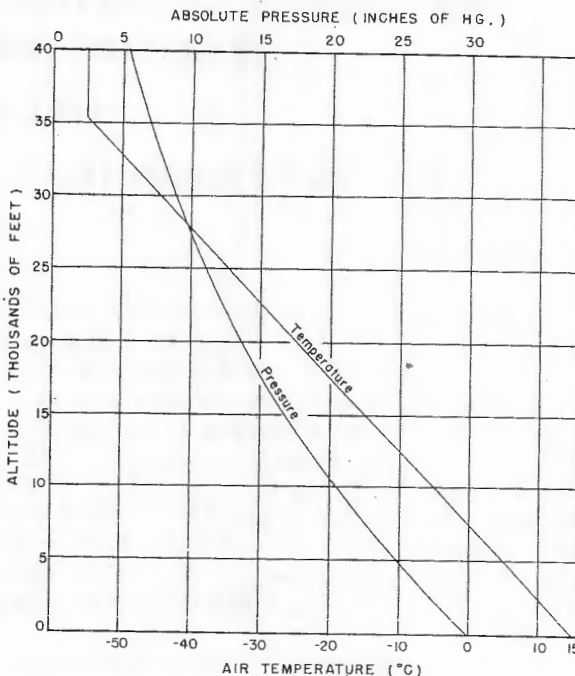


Figure 2 - N.A.C.A. standard atmosphere

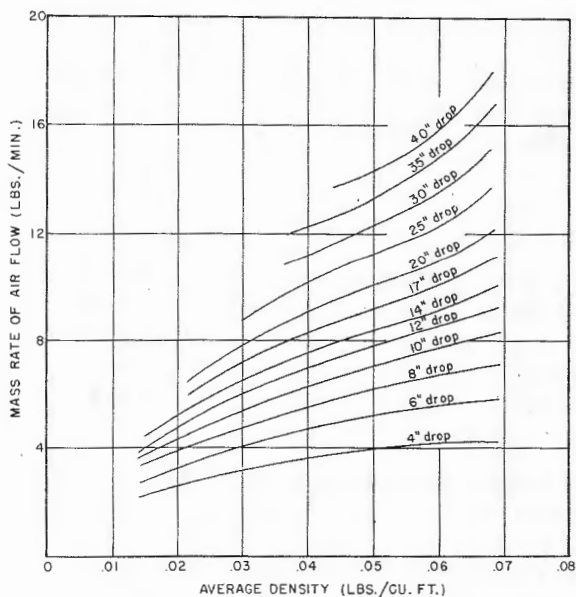


Figure 3 - Generator air flow characteristic showing mass rate of air flow vs. average density for various static pressure drops

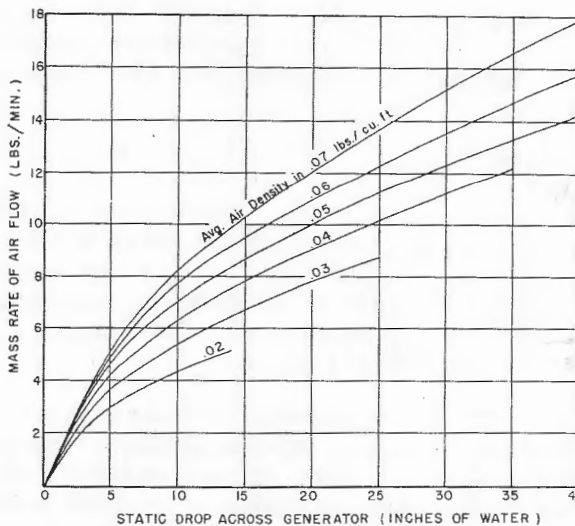


Figure 4 - Generator air flow characteristic showing mass rate of air flow vs. static pressure drop across generator for various average air densities

was based on the following consideration. Since $M = \rho VA$, the quantity M^2/ρ is proportional to the dynamic pressure, $\rho V^2/2$ (as defined in the appendix), where M is the mass rate of air flow, ρ is the average density, V is the velocity, and A is the cross-sectional area of the passage under consideration. Since the pressure drop due to turbulence and friction losses is known to be a function of the dynamic pressure, the use of this parameter assumes that

the pressure drop is largely the result of a similar phenomena. This assumption seems to be justified.

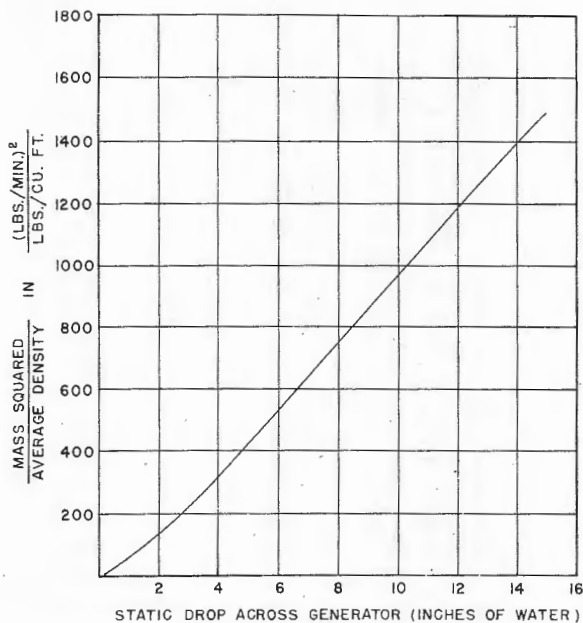


Figure 5 - Generator air flow characteristic showing the square of the mass rate of air flow divided by the average air density vs. the static pressure drop across the generator

FLIGHT TESTS

After installation of the instrumentation system, it was ground checked to verify its satisfactory operation. Several preliminary flights were made to check the equipment and establish the limits of aircraft performance. These flights indicated that the inlet air temperature to the aircraft generator was unstable due to the location of the air scoop behind the engine cylinders and also that the original location of the pressure transducers made them susceptible to vibration. Accordingly an auxiliary air scoop was installed on the lower outboard section of the left engine nacelle and the pressure transducers were relocated (see Figures 13, 14, and 18 of Reference 1).

The record flights were all made in the vicinity of the Naval Air Test Center, Patuxent River, Md. between the dates of 5 November 1951 and 20 November 1951. The weather observations giving the barometric pressure and temperature at the altitude of the flights were obtained from the Naval Air Station, Norfolk, Va. and are included in Table 1. The only data available was for 10:30 am.

Normally, two flights were scheduled each day, weather and aircraft maintenance permitting, one in the morning and one in the afternoon. They were usually of approximately two hours duration at the discretion of the pilot. Before takeoff, the pilot was briefed as to the conditions of air speed, altitude, and generator load that were desired and he was instructed to maintain each condition for approximately 15 minutes. This was found to be the minimum time necessary for the generator temperatures to approximately stabilize.

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TABLE 1
Weather Observations*

Date and Flight Number	Altitude (ft)	Barometric Pressure (in. of mercury)	Temperature ($^{\circ}$ C)
5 Nov. 1951 Nos. 1 and 2	Station	30.40	6.7
	5,000	25.21	-5.0
	10,000	20.08	-6.0
	15,000	17.00	-14.0
7 Nov. 1951 No. 3	Station	29.60	18.9
	5,000	24.81	10.6
	10,000	20.52	3.0
8 Nov. 1951 Nos. 4 and 5	Station	29.68	5.7
	5,000	24.69	-7.5
	10,000	20.41	-8.3
	15,000	16.74	-16.0
	20,000	13.58	-27.2
	25,000	10.93	-35.0
9 Nov. 1951 Nos. 6 and 7	Station	30.03	4.0
	5,000	25.19	1.6
	10,000	20.82	0.0
	15,000	17.19	-7.6
	20,000	14.06	-17.0
	25,000	11.52	-28.0
	30,000	8.09	-41.1
13 Nov. 1951 Nos. 8 and 9	Station	30.11	14.2
	5,000	25.21	7.2
	10,000	21.00	0.0
	15,000	17.03	-7.2
15 Nov. 1951 No. 10	Station	29.93	14.2
	5,000	25.04	7.8
	10,000	20.07	0.0
	15,000	16.09	-5.0
19 Nov. 1951 Nos. 11 and 12	Station	30.11	1.5
	5,000	24.81	-14.2
	10,000	20.38	-23.4
	15,000	16.54	-28.8
	20,000	13.29	-39.4
	25,000	8.86	-44.8
20 Nov. 1951 No. 13	Station	30.29	0.0
	1,000	29.06	-2.4
	5,000	24.81	-12.4
	10,000	20.38	-21.4

* Made at the Naval Air Station, Norfolk, Va., at 10:30 a.m.

The nominal conditions for each flight are listed in Table 2. It should be noted from the data in Tables 2 and 3 that the actual flight conditions showed considerable variation from the nominal values.

TABLE 2
Nominal Flight Conditions

Altitude (feet)	Indicated Air Speed (knots)	Generator Load (% full load)	Flight Number	Altitude (feet)	Indicated Air Speed (knots)	Generator Load (% full load)	Flight Number		
1,000	125	50	1E, 3E, 10D	15,000	125	0	5A		
		75	13A			25	5B		
		50	1C			50	5C		
	200	75	13B			200	75	12A	
		100	1D				25	5D	
		50	13E				50	5E	
	275	75	13C			260	75	5F	
		100	13D				100	12B	
		50					50	12C	
4,400	125	50	3D	20,000	125	0	4E		
		75	3C			25	4F		
	270	50	3A			200	200	50	11A
		75	3B					75	11B
5,000	125	50	8A	30,000	125			0	6A
		75	8C					25	6B
		100	8B			50	6C		
	200	50	1A			200	200	75	7A
		75	9A					0	6D
		100	1B					25	6E
	275	50	9B			245	245	50	7B
		75	9C					75	7C
		100	9D					100	
10,000	125	25	2A	30,000	125	0	6A		
		50	2B			25	6B		
		75	2C			50	6C		
	200	50	2D			200	200	75	7A
		75	2E					0	6D
		100	2F					25	6E
	260	50	10A			200	200	50	7B
		75	10B					75	7C
		100	10C						

TABLE 3
Flight Test Observations

Flight Number	Generator Current (Amperes)	Generator Voltage (Volts)	Generator Field Voltage (Volts)	Air Speed (Knots)	Altitude (Feet)	Static Drop Across Gen. (In. Water)	Compartment Pressure (Cm. Mercury)	Generator Speed (rpm)	Generator Field Current (Amperes)	Air Temp. (°C)	
										Inlet	Outlet
1A	95	27.5	7.3	204	4,800	3.7	66.0	5808	3.08	17.7	4
B	183	27.6	9.3	204	4,800	3.7	66.0	5775	3.53	19.1	8
C	93	27.5	7.2	204	500	3.4	75.7	5732	3.00	20.6	4
D	181	27.5	9.6	204	500	3.4	75.7	5687	3.67	23.3	7
E	93	27.7	7.7	126	500	1.1	75.5	5611	2.94	24.4	7
2A	49	27.6	6.1	126	9,900	1.1	55.0	6127	2.52	22.0	5
B	93	27.8	7.1	125	9,900	1.1	55.0	6051	2.72	24.1	7
C	139	28.0	8.7	125	9,900	1.1	55.0	6051	3.00	27.3	10
D	94	27.8	6.5	204	9,900	3.7	55.5	6293	2.57	20.6	5
E	148	27.6	6.8	206	10,000	3.7	55.5	6212	2.72	20.6	7
F	181	27.5	8.1	206	10,000	3.6	55.5	6172	2.99	20.6	9
3A	91	27.5	5.4	271	4,300	5.1	67.7	7182	2.41	42.0	6
B	146	27.6	6.5	273	4,400	5.1	67.5	6855	2.87	44.0	7
C	146	27.7	10.5	126	4,300	1.5	67.0	5004	3.64	38.0	10
D	92	28.0	8.9	128	4,400	1.1	66.6	4883	3.20	36.9	8
E	94	28.2	8.7	123	1,200	1.1	73.8	4801	3.16	39.4	8
4A	0	27.6	5.7	197	19,600	4.8	37.8	5647	2.52	-3.0	7
B	49	27.7	6.0	198	19,700	4.8	38.0	5890	2.77	-3.0	7
C	48	27.6	3.1	242	19,700	5.9	38.4	7018	2.20	1.2	7
D	138	27.6	5.7	242	19,700	6.3	38.0	7018	2.42	2.5	7
E	0	27.7	5.9	126	19,400	1.1	37.1	5926	2.55	-1.8	7
F	48	27.9	5.9	119	19,500	1.2	37.1	6212	2.55	1.2	7
5A	0	27.5	5.9	128	14,800	1.4	45.2	5647	2.52	10.8	7
B	48	27.8	6.6	126	14,800	1.4	45.0	5687	2.74	10.8	7
C	94	28.0	7.4	128	14,800	1.4	45.0	5723	2.96	10.8	7
D	48	27.8	7.0	206	14,900	5.3	45.4	5490	2.96	8.0	7
E	92	27.6	7.4	204	14,900	5.1	45.4	5526	3.20	8.0	7
F	137	27.4	8.1	204	14,900	4.8	45.4	5526	3.32	8.0	7
G	137	27.5	5.2	260	15,200	8.1	46.4	7504	2.36	14.5	7
6A	0	27.8	5.2	126	29,100	2.0	25.7	6096	2.34	-9.4	7
B	48	28.0	5.7	126	29,100	2.0	25.3	6178	2.50	-10.0	7
C	93	28.0	6.8	126	28,900	2.0	25.3	6096	2.65	-10.0	7
D	0	28.0	4.2	200	28,900	4.5	25.8	7461	1.90	-5.9	7
E	48	27.8	4.4	200	29,100	4.5	25.8	7588	2.01	-5.9	7
7A	137	27.7	6.8	125	28,900	1.9	25.5	6066	2.72	-8.2	7
B	92	27.8	4.7	200	28,900	4.5	26.2	7303	2.05	-5.9	7
C	138	27.7	5.2	202	28,900	4.5	25.8	7431	2.16	-4.6	7
8A	90	27.4	7.4	126	4,900	4.8	64.7	5368	3.10	23.3	7
B	177	27.3	9.7	126	4,900	5.1	64.8	5277	3.75	25.0	7
C	134	27.3	8.0	121	4,800	4.7	61.1	5287	3.16	24.4	7
9A	146	27.4	8.8	206	5,000	6.0	65.5	5323	3.67	26.0	7
B	92	27.5	4.9	276	4,900	10.9	66.2	7112	2.36	30.0	7
C	137	27.6	5.5	278	4,900	11.1	66.5	7182	2.63	31.0	7
D	181	27.6	6.2	276	4,900	10.9	66.4	7052	2.77	32.0	7
10A	92	27.7	4.9	258	10,400	9.0	55.5	7218	2.29	27.3	7
B	138	27.8	5.6	258	10,400	9.1	55.2	7218	2.69	28.1	7
C	183	27.7	6.3	158	10,400	8.8	55.0	7188	2.79	28.1	7
D	93	27.7	8.6	128	1,000	1.2	74.4	4731	3.27	32.7	7
11A	92	27.5	5.7	125	19,400	2.7	37.2	6309	2.50	-11.5	7
B	137	27.5	6.6	125	19,300	2.8	37.1	6248	2.69	-11.5	7
C	92	27.4	5.9	208	19,300	6.1	37.3	6339	2.59	-15.3	7
D	136	27.2	6.2	202	19,400	6.2	37.3	6339	2.72	-13.0	7
E	92	27.3	4.3	244	19,700	8.5	37.5	7583	2.01	-5.9	7
F	181	27.3	5.7	244	19,600	8.9	38.0	7558	2.38	-8.9	7
12A	146	27.4	8.1	123	14,700	1.6	45.0	5526	4.38	-4.0	7
B	181	27.4	9.1	200	14,800	5.0	45.2	5893	3.45	-4.0	7
C	92	27.3	4.3	260	15,000	8.1	46.2	7825	2.02	-1.8	7
D	180	27.0	5.7	260	15,100	8.4	46.5	7794	2.38	1.2	7
13A	137	27.4	8.1	128	500	2.0	75.2	5732	3.16	12.8	7
B	137	27.4	7.2	206	600	6.1	75.0	6218	3.06	12.8	7
C	137	27.4	5.3	265	500	11.4	75.5	7430	2.50	16.4	7
D	181	27.4	5.9	261	500	11.6	75.7	7430	2.57	17.7	7
E	92	27.4	4.6	240	700	11.6	75.7	6940	2.13	16.4	7

*Based on flight measurements

TABLE 3
Flight Test Observations

(Amperes)	Generator Voltage (Volts)	Generator Field Voltage (Volts)	Air Speed (Knots)	Altitude (Feet)	Static Drop Across Gen. (In. Water)	Compartment Pressure (Cm. Mercury)	Generator Speed (rpm)	Generator Field Current (Amperes)	Air Temp. (°C)		Brush Temp. (°C)		Frame Temp. (°C)		Average Air Density (lb/cu ft)	Mass Rate of Air Flow (lb/min)	Air Temp. Rise (°C)
									Inlet	Outlet	Positive	Negative	Main Pole	Inter Pole			
	27.5	7.3	204	4,800	3.7	66.0	5808	3.08	17.7	47.0	72.0	75.5	53.5	47.0	.0631	4.3	29.3
	27.6	9.3	204	4,800	3.7	66.0	5775	3.53	19.1	81.5	115.5	123.2	105.4	92.0	.0600	4.2	62.4
	27.5	7.2	204	500	3.4	75.7	5732	3.00	20.6	49.2	72.0	76.0	55.9	49.9	.0716	4.3	28.6
	27.5	9.6	204	500	3.4	75.7	5687	3.67	23.3	75.5	109.0	116.4	99.0	86.2	.0678	4.2	52.2
	27.7	7.7	126	500	1.1	75.5	5611	2.94	24.4	72.0	108.0	112.1	89.6	82.9	.0735	2.1	47.6
	27.6	6.1	126	9,900	1.1	55.0	6127	2.52	22.0	51.0	101.0	103.2	68.5	64.2	.0515	1.8	29.0
	27.8	7.1	125	9,900	1.1	55.0	6051	2.72	24.1	79.3	129.0	135.3	96.5	89.6	.0494	1.8	55.2
	28.0	8.7	125	9,900	1.1	55.0	6051	3.00	27.3	106.4	167.0	176.7	143.1	132.0	.0475	1.7	79.1
	27.8	6.5	204	9,900	3.7	55.5	6293	2.57	20.6	58.4	86.5	87.5	67.1	59.9	.0518	3.9	37.8
	27.6	6.8	206	10,000	3.7	55.5	6212	2.72	20.6	70.9	103.0	107.7	85.0	75.8	.0510	3.8	50.3
	27.5	8.1	206	10,000	3.6	55.5	6172	2.99	20.6	93.5	60.0	137.6	122.0	107.7	.0495	3.7	72.9
	27.5	5.4	271	4,300	5.1	67.7	7182	2.41	42.0	68.5	104.0	104.3	72.0	66.0	.0603	5.1	26.5
	27.6	6.5	273	4,400	5.1	67.5	6855	2.87	44.0	79.3	111.0	111.0	95.5	86.5	.0592	5.1	35.3
	27.7	10.5	126	4,300	1.5	67.0	5004	3.64	38.0	100.0	138.0	143.1	126.4	117.8	.0573	2.3	62.0
	28.0	8.9	128	4,400	1.1	66.6	4883	3.20	36.9	86.2	124.0	125.4	104.3	97.9	.0580	1.9	49.3
	28.2	8.7	123	1,200	1.1	73.8	4801	3.16	39.4	86.2	124.0	126.4	103.0	96.0	.0641	2.0	46.8
	27.6	5.7	197	19,600	4.8	37.8	5647	2.52	-3.0	23.3	34.5	36.0	24.4	20.7	.0393	4.0	26.3
	27.7	6.0	198	19,700	4.8	38.0	5890	2.77	-3.0	25.4	44.0	44.5	26.0	22.0	.0394	4.0	28.4
	27.6	3.1	242	19,700	5.9	38.4	7018	2.20	1.2	29.5	66.0	52.1	31.0	27.0	.0391	4.5	28.3
	27.6	5.7	242	19,700	6.3	38.0	7018	2.42	2.5	53.5	85.0	90.0	67.1	56.0	.0375	4.6	51.0
	27.7	5.9	126	19,400	1.1	37.1	5926	2.55	-1.8	46.0	70.0	75.5	48.4	42.5	.0367	1.5	47.8
	27.9	5.9	119	19,500	1.2	37.1	6212	2.55	1.2	53.5	88.5	94.3	54.7	49.9	.0361	1.6	52.3
	27.5	5.9	128	14,800	1.4	45.2	5647	2.52	10.8	47.0	72.0	75.5	46.0	42.5	.0436	1.9	36.2
	27.8	6.6	126	14,800	1.4	45.0	5687	2.74	10.8	54.7	72.0	87.5	57.1	51.4	.0429	1.9	43.9
	28.0	7.4	128	14,800	1.4	45.0	5723	2.96	10.8	68.5	103.0	109.0	78.0	71.8	.0421	1.9	57.7
	27.8	7.0	206	14,900	5.3	45.4	5490	2.96	8.0	34.0	48.0	49.2	36.9	31.9	.0453	4.5	26.0
	27.6	7.4	204	14,900	5.1	45.4	5526	3.20	8.0	39.4	56.0	59.9	46.0	39.4	.0450	4.4	31.4
	27.4	8.1	204	14,900	4.8	45.4	5526	3.32	8.0	52.1	79.0	84.4	66.0	56.0	.0441	4.2	44.1
	27.5	5.2	260	15,200	8.1	46.4	7504	2.36	14.5	56.0	82.0	84.0	70.9	59.9	.0446	5.8	41.5
	27.8	5.2	126	29,100	2.0	25.7	6096	2.34	-9.4	36.8	60.0	62.8	34.0	30.0	.0263	1.9	46.2
	28.0	5.7	126	29,100	2.0	25.3	6178	2.50	-10.0	44.5	71.0	75.5	42.0	37.0	.0258	1.8	54.5
	28.0	6.8	126	28,900	2.0	25.3	6096	2.65	-10.0	57.1	91.0	94.9	63.3	57.0	.0254	1.8	67.1
	28.0	4.2	200	28,900	4.5	25.8	7461	1.90	-5.9	36.9	63.0	67.1	34.0	30.0	.0266	3.1	42.8
	27.8	4.4	200	29,100	4.5	25.8	7588	2.01	-5.9	36.9	67.0	71.7	36.5	31.9	.0266	3.1	42.8
	27.7	6.8	125	28,900	1.9	25.5	6066	2.72	-8.2	79.3	130.9	94.3	85.5	85.5	.0244	1.7	87.5
	27.8	4.7	200	28,900	4.5	26.2	7303	2.05	-5.9	54.7	93.1	62.2	54.6	62.2	.0261	3.1	60.6
	27.7	5.2	202	28,900	4.5	25.8	7431	2.16	-4.6	77.0	120.0	94.3	82.1	82.1	.0251	3.1	81.6
	27.4	7.4	126	4,900	4.8	64.7	5368	3.10	23.3	52.1	77.0	77.0	57.1	52.0	.0609	5.0	28.8
	27.3	9.7	126	4,900	5.1	64.8	5277	3.75	25.0	75.5	106.4	97.0	86.2	86.2	.0588	5.1	50.5
	27.3	8.0	121	4,800	4.7	61.1	5287	3.16	24.4	66.0	97.8	79.3	70.2	70.2	.0599	4.8	41.6
	27.4	8.8	206	5,000	6.0	65.5	5323	3.67	26.0	59.9	82.9	70.0	62.9	62.9	.0607	5.7	33.9
	27.5	4.9	276	4,900	10.9	66.2	7112	2.36	30.0	57.1	73.2	59.9	59.9	59.9	.0617	8.1	27.1
	27.6	5.5	278	4,900	11.1	66.5	7182	2.63	31.0	59.9	88.5	73.2	62.4	62.4	.0615	8.2	28.9
	27.6	6.2	276	4,900	10.9	66.4	7052	2.77	32.0	73.2	95.5	95.5	80.4	80.4	.0601	8.0	41.2
	27.7	4.9	258	10,400	9.0	55.5	7218	2.29	27.3	62.2	80.4	62.2	62.4	62.4	.0514	6.6	34.9
	27.8	5.6	258	10,400	9.1	55.2	7218	2.69	28.1	64.6	86.2	78.0	68.5	68.5	.0509	6.7	36.5
	27.7	6.3	258	10,400	8.8	55.0	7188	2.79	28.1	80.4	107.7	109.0	92.2	92.2	.0496	6.4	51.7
	27.7	8.6	128	1,000	1.3	74.4	4731	3.27	32.7	72.0	107.7	81.5	80.4	80.4	.0665	2.3	39.3
	27.5	5.7	125	19,400	2.7	37.2	6309	2.50	-11.5	42.0	68.5	44.5	38.0	38.0	.0378	2.7	53.5
	27.5	6.6	125	19,300	2.8	37.1	6248	2.69	-11.5	59.9	96.5	75.5	65.1	65.1	.0369	2.7	71.4
	27.4	5.9	208	19,300	6.1	37.3	6339	2.59	-15.3	16.4	36.9	26.0	17.8	17.8	.0403	4.8	31.7
	27.2	6.2	202	19,400	6.2	37.3	6339	2.72	-13.0	32.7	61.0	44.5	35.4	35.4	.0391	4.7	45.7
	27.3	4.3	244	19,700	8.5	37.5	7583	2.01	-5.9	28.7	54.7	32.7	28.8	28.8	.0392	5.6	34.6
	27.3	5.7	244	19,600	8.9	38.0	7558	2.38	-8.9	49.8	81.5	74.5	57.6	57.6	.0389	5.7	58.7
	27.4	8.1	123	14,700	1.6	45.0	5526	4.38	-4.0	69.7	117.8	86.2	77.0	77.0	.0433	2.1	73.7
	27.4	9.1	200	14,800	5.0	45.2	5893	3.45	-4.0	58.4	88.5	84.0	71.0	71.0	.0446	4.4	62.4
	27.3	4.3	260	15,000	8.1	46.2	7825	2.02	-1.8	30.0	56.0	35.3	28.8	28.8	.0475	6.0	31.8
	27.0	5.7	260	15,100	8.4	46.5	7794	2.38	1.2	54.7	88.5	81.5	65.0	65.0	.0458	6.0	53.5
	27.4	8.1	128	500	2.0	75.2	5732	3.16	12.8	66.0	103.2	84.0	75.8	75.8	.0704	3.0	53.2
	27.4	7.2	206	600	6.1	75.0	6218	3.06	12.8	46.0	69.7	58.4	49.9	49.9	.0725	6.3	33.2
	27.4	5.3	265	500	11.4	75.5	7430	2.50	16.4	42.8	62.8	53.2	45.1	45.1	.0733	9.1	26.4
	27.4	5.9	261	500	11.6	75.7	7430	2.57	17.7	52.1	78.0	73.2	59.9	59.9	.0725	9.1	34.4
	27.4	4.6	240	700	11.6	75.7	6940	2.13	16.4	35.3	56.0	40.7	35.4	35.4	.0745	9.2	18.9

Light measurements

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POST-FLIGHT ALTITUDE CHAMBER TESTS

After the flight tests were completed a correlation of the data indicated that there were apparent discrepancies in the results which required an explanation. Wide variations in air flow under approximately the same flight conditions, generator temperatures which varied considerably from those obtained during the calibration tests, and other deviations from the anticipated results indicated that further study was necessary. In order to analyze the causes of these discrepancies, the generator and instrumentation system were installed in the Guardite altitude chamber. This installation differed from the original calibration setup used previously (2), in that the generator cooling air was not recirculated inside the closed test chamber but was continuously drawn from the atmosphere through a metering orifice, the blowers, air preparation units and generator into the altitude chamber and thence exhausted to the atmosphere by vacuum pumps.

All of the flight tests for which the generator was operating at full load were simulated by duplicating the pertinent recorder readings obtained in flight. Thus, the generator speed, voltage, current, static drop across the generator, chamber pressure, and air inlet temperature were maintained at the values recorded in flight. A scattering of points similar to that obtained during flight was noted, but in practically all cases the generator temperatures were higher in the altitude chamber than they had been during the flight that was being simulated. Since the reason for these apparent temperature variations between flight and chamber conditions were not known, further investigation was necessary.

In the above chamber tests, all known flight conditions had been duplicated. However, since the compartment and mounting flange temperatures had not been recorded during flight, these could not be simulated. During the chamber tests, the compartment temperature had been held arbitrarily at +70°C and the generator was bolted directly to the mounting flange without a gasket. In the aircraft, the flange temperature was unknown, but a gasket was employed. These conditions led to a suspicion that heat was being conducted to or from the generator through the shaft and mounting flange.

To explore this possibility, the generator was bolted to a large block of iron (using an asbestos gasket). This iron block was almost completely immersed in a water bath maintained at 0°C. The generator was surrounded by a three-inch cork jacket to prevent heat loss to the room and was not cooled by an air blast. The generator was heated by applying electrical power to both the field and armature circuits of the generator while the rotor was blocked. All of this power, under steady-state conditions, had to be dissipated primarily through the six mounting bolts and the generator shaft. Thus, while a known amount of power was being dissipated, the temperature difference between the generator and the mounting flange was measured. It was found that a temperature difference between generator and mounting flange of approximately 8°C was sufficient to dissipate 145 watts through the mounting bolts and shaft. This represents approximately seven percent of the generator full load losses, assuming a generator efficiency of 75 percent. Since the pad temperature was not recorded during these flights, it is impossible to evaluate this factor, but it may account for some of the discrepancies noted.

Further tests were conducted in the laboratory to evaluate more accurately the errors which were known to exist in this method of measuring air flow:

- (1) The change in the density of the air as it was heated in passing through the generator,
- (2) The variation in fan action of the generator rotor with a change in generator speed,
- (3) The variation in blast cap orientation with respect to the generator.

The effect of the change in density of the air, due to its change in temperature while passing through the generator, seems to have been automatically taken into consideration by

using the average air density in obtaining the mass rate of air flow. This was done in plotting Figures 3, 4, and 5 and the determination of the mass flow during flight. By using this technique, it appears to be unnecessary to calibrate the generator for load, mounting flange temperature, or other factors affecting the internal generator temperatures. Further study should be made to see if the method of correlation holds for other types of generators.

The error introduced in the determination of mass rate of air flow by the variable effect of the fan action of the generator, while measurable, was not considered to be of sufficient magnitude to warrant its inclusion in this report. The generator was calibrated at 6000 rpm (the mid-point of its speed range) and any deviation from this generator speed in flight would cause an error in determining the mass rate of air flow. For a fixed installation and a given variation in generator speed, the percent error is greatest at sea level and low mass rates of air flow and becomes negligible at high altitudes and high rates of air flow. Of course, for different generators this effect will vary in both magnitude and direction depending upon the construction of the rotor, particularly if a fan is included. The GE type 2CM63C1 generator used in these tests is so constructed that its rotation tends to oppose the flow of air through the generator. While the installation covered by this report and the accuracy of the flight test data warranted the neglect of this factor, a different installation or more precise measurements would require that this effect be considered in the calibration tests. It should be noted that the generator speed could not be specified during flight, because it was geared directly to the aircraft engine, the speed of which had to be variable at the discretion of the pilot for optimum aircraft performance.

It was found that, for the generator under consideration, a change in the orientation of the blast cap had a very small effect on the calibration of the generator. However, if this factor were important, the location of the cap on the generator during flight conditions could be determined and the same position used for all calibration tests. It should also be pointed out that unless the generator band is put on correctly, the resultant air leakage will cause an error in the determination of the air flow through the generator.

ANALYSIS OF FLIGHT DATA

The analysis of the flight data was made extremely difficult by the fact that none of the variables involved were capable of very close control. It was found to be practically impossible to vary one factor and keep the others constant. For example, the weather conditions at a given location were continuously changing and obviously could not be controlled; the pilot's skill and care and minor errors in the pilot's instruments, all affected the stability of the generator ambient conditions. In addition, the pilot must be allowed complete freedom to select the combination of engine rpm, propellor pitch, flight attitude, and cowling flap setting, which in his opinion produce the optimum aircraft operating conditions. Unfortunately, these selections will vary with different pilots and even the same pilot on different occasions.

In addition, the load, although nominally fixed, changes with varying flight conditions. Since the generator load consisted of a bank of fixed resistors cooled by the air stream, the electrical load varied slightly with ambient air temperature and aircraft speed. Slight changes in the voltage regulator setting also affected the load.

Furthermore, the generator may never have reached a stabilized condition, due to continuous minor variations in ambient conditions. Flights were maintained at the same nominal conditions for 15 minutes and visual observations of the record indicated approximate stabilization of the generator in this time except for minor variations. These minor variations, however, were probably sufficient to mask the fact that the generator was not completely stabilized, since chamber tests usually required from 45 minutes to an hour for complete stabilization. However, it is doubtful if a longer flight period would have served any practical purpose because of the continuously changing ambient conditions.

Since there were so many uncontrolled variables, it was extremely difficult to find a suitable means of presenting the flight data. After a careful study of the problem, Figures 6 and 7 were plotted from the data in Table 3. Since a constant mass flow could not be maintained during flight, the test points plotted in Figure 6 were obtained by interpolation of the data obtained in the vicinity of the desired air flow rate. For reference purposes, the data obtained in the three laboratory facilities available for generator testing at NRL was also included. The York chamber is the altitude chamber used for preflight tests. The Guardite is the smaller altitude chamber used for the postflight tests. The test stand provided no facilities for air preparation or altitude simulation.

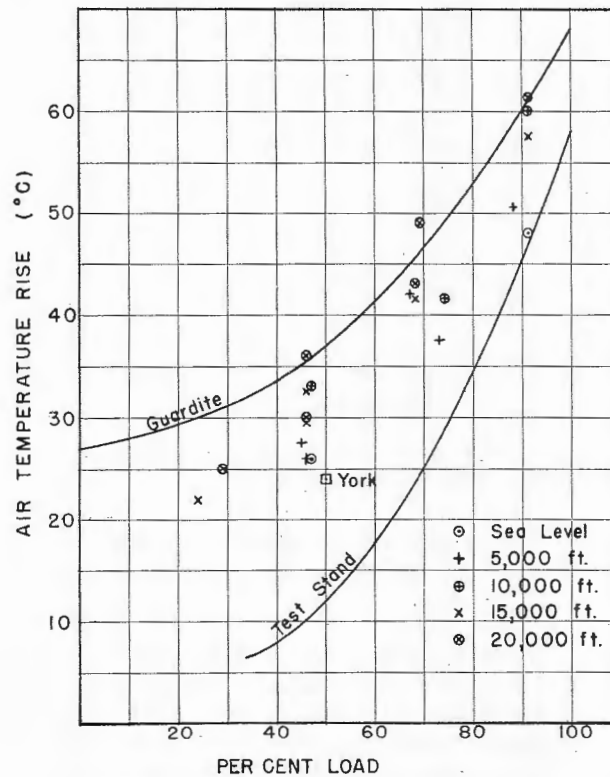


Figure 6 - Effect of load on air temperature rise at a mass rate of air flow of 5 lb/min

Figure 6 shows that for a given generator load, the temperature rise in the generator increased with increasing altitude. This is also shown in Figure 7. However, if the measured temperature rise is multiplied by the square root of the ratio of the air density at the generator inlet to the density at standard conditions, the altitude effect is almost completely removed. From cooling considerations, it is expected that this ratio would help eliminate the altitude effect since the engine temperature probably would vary inversely as the square root of the air density, all other factors remaining constant. Since the generator was bolted to the engine pad, a change in engine temperature would also affect the generator temperature by causing a variation in the heat conduction between them.

The physical construction of these facilities and the relative positions of the curves in Figure 6 seem to confirm the theory that the heat flow through the generator shaft and mounting studs is an important factor in determining the generator temperature. This presents a possible explanation for the higher generator temperatures obtained at high altitudes for the same generator load. Since the mounting flange temperatures were not measured during these flights, this effect cannot be evaluated. It should be noted that

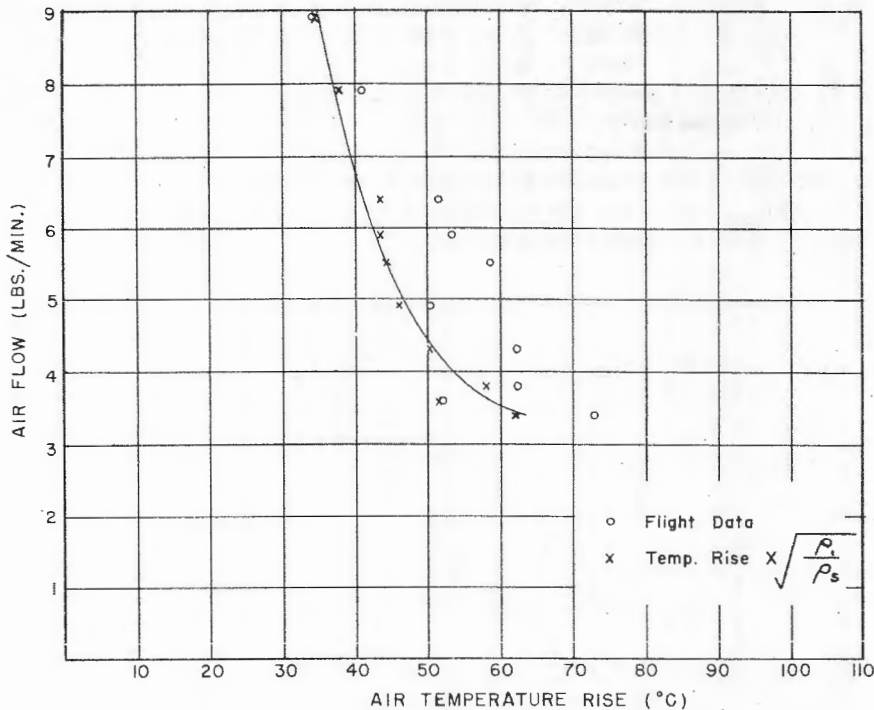


Figure 7 - Effect of mass rate of air flow on air temperature rise with generator operating under full load

generator acceptance tests run on the three NRL test facilities might yield entirely different results because the brush and winding temperatures are a function of the air temperature rise.

The mass flow values used for the flight data were calculated using the calibration data shown in Figure 5. No independent method could be used to measure the mass flow in flight and therefore no data is available with which to estimate the accuracy of the method used. Valuable information has been obtained by using the calibrated generator to measure the quantity of air flow, and since no better method has been devised as yet, this method certainly warrants further study and application.

The static pressure drop across the generator appears to be only about 20 percent of the dynamic pressure available due to the speed of the aircraft. Although the pressure drop between the compartment and free stream static pressure was not measured very accurately, being the difference between two absolute static pressure readings, the data seems to indicate that this pressure drop accounted for approximately 40 percent of the available dynamic pressure. This drop was considerably higher than was anticipated before flight tests and indicates that much of the available pressure head was being lost by exhausting the generator cooling air into the accessory compartment. This could have been avoided by shrouding the generator and discharging the air into the air stream in a relatively low pressure area.

Another fact that may have been responsible for the lower air flow than was anticipated was the location of the air scoop. As explained above, a separate air scoop was installed on this plane for the test generator to eliminate the effects of engine temperatures on the generator air inlet temperature. Since the pressure drops across the generator recorded during these flights were much lower than anticipated, there is a possibility that this scoop was located in a low pressure area. Incidentally the location of this scoop behind the propeller may have produced pulsating air flow in the generator, the magnitude and frequency of which varied with engine rpm and propeller pitch. The effect of these pulsations on the

accuracy of the flight observations is not known. However, a preliminary laboratory check indicated no observable variation in readings between smooth and pulsating flow under sea level conditions.

In analyzing the flight data, the total theoretical ram temperature rise possible due to the speed of the aircraft was found to be much lower than the actual temperature rise based on the measured air temperature at the inlet to the generator and the weather data for that day at the altitude of the flight. Since the weather data were not taken simultaneously with the other data, an exact analysis cannot be made. However, the fact that the measured air temperature rise was always considerably higher than the theoretically possible ram temperature rise, seems to indicate that the air was receiving heat from another source before entry to the generator. This is to be expected because the tube connecting the air scoop to the generator air inlet was approximately four feet of flexible metal tubing and passed through the hot engine compartment. In view of these findings, consideration should be given to the addition of thermal insulation to the blast tube or the substitution of a duct constructed of some thermally insulating material in place of the present metal duct.

In the tests outlined in this report, a standard production generator was used and the frame temperatures were obtained from thermocouples embedded in the iron yoke. These temperatures may not be indicative of the critical temperature occurring in the generator windings. The embedding of thermocouples in the generator winding after production, without damaging the generator, is very difficult, but such elements would prove extremely useful in evaluating the performance of test generators. The only practical solution would be to place such thermocouples in the winding at the time of manufacture of generators to be used for evaluation testing.

RESULTS AND CONCLUSIONS

In the process of evaluating the use of the static pressure drop across a calibrated generator as a means of determining the quantity of air flowing through it, the following general results and conclusions were formulated:

- (1) Much valuable information was obtained by using this method of flow measurement. Although it does have many inherent limitations, it is the best method available at the present time.
- (2) Correlation methods have been developed which may appreciably reduce the amount of calibration data needed in order to get a desired degree of accuracy. Further study is necessary to evaluate the applicability of these methods properly. For accurate results, the generator should be calibrated to take into account the effect of changing generator speed.
- (3) Considerable heat conduction seems to be taking place through the mounting bolts and generator shaft under both flight and test conditions. When confirmed, this will affect altitude rating charts and generator acceptance tests.

The flight test data also show that for the specific airplane investigated:

- (1) The static pressure drop across the generator varied widely for different flights at the same indicated air speed and altitude. This indicates that the pilot's selection of the aircraft operating conditions such as engine rpm, propeller pitch, cowl flap openings, etc., can have a large effect on the cooling of the generator.
- (2) The generator cooling air temperature increased during its passage through the blast tube due to heat absorbed from the hot engine compartment.

(3) A large portion of the available pressure drop is being wasted by exhausting the generator cooling air into the engine compartment.

RECOMMENDATIONS

Future flight data should include measurements of outside air temperature, mounting flange temperature, and static pressure drop from the accessory compartment to the altitude static pressure.

It is believed that further study should be made by this Laboratory and others of the following factors:

(1) The advisability of shrouding the generator and exhausting the cooling air to the outside, preferably a low pressure area, rather than discharging it into the accessory compartment.

(2) The advisability of providing a thermally insulated inlet air blast tube.

(3) The magnitude and direction of heat transfer between the mounting flange and the generator under various flight conditions and generator loads.

(4) The magnitude of the effect of the pilot's choice of the aircraft operating parameters on generator cooling.

(5) The applicability of the proposed method of using sea level calibration tests at all altitudes for various types of generators.

(6) The practicability of including thermocouples at the time of manufacture in the windings of generators to be used in flight test evaluation.

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APPENDIX
Aerodynamic Concepts and Definitions

Static Pressure: Pressure exerted on a small body immersed in the air stream and moving at the same velocity; usually determined by measuring the pressure at the wall of a duct where the static pressure gradients are negligible or by measuring the static pressure on a stationary body immersed in the air stream at a point where the flow disturbances created by the body cancel. This is the pressure used to calculate the air density.

Total Pressure (also called stagnation pressure): Pressure that would be measured if the air were brought to rest without any losses.

Dynamic Pressure: The difference between the total pressure and static pressure for incompressible flow. The dynamic pressure in lb/sq ft is equal to $\rho V^2/2g$ where ρ is the air density in lb/cu ft, V is the air velocity with respect to the fixed frame of reference in ft/sec, and g is the gravitational constant in ft/sec².

Impact Pressure: The difference between the total and static pressure for compressible flow. It is equal to the dynamic pressure times a compressible flow correction factor. This factor changes from a value of 1.00 at very low speeds to a factor of 1.276 at the speed of sound.

Static Temperature: Temperature that would be indicated by a thermometer immersed in the air stream and moving with the same velocity. This is the temperature used to calculate the air density.

Total Temperature (also called stagnation temperature): Temperature that would be measured if the air were brought to rest adiabatically, that is, without any heat addition or removal. It is a direct measure of the total heat content of the air and is independent of the air velocity at the measuring station.

Ram Temperature Rise: The difference between the total and the static temperature. The ram temperature rise in degrees centigrade is equal to $(V/100)^2$ where V is the air velocity with respect to the fixed frame of reference in miles per hour.

* * *

TABLE 3
Flight Test Observations

Flight Number	Generator Current (Amperes)	Generator Voltage (Volts)	Generator Field Voltage (Volts)	Air Speed (Knots)	Altitude (Feet)	Static Drop Across Gen. (In. Water)	Compartment Pressure (Cm. Mercury)	Generator Speed (rpm)	Generator Field Current (Amperes)	Air Temp. (°C)		Brush Temp. (°C)	
										Inlet	Outlet	Positive	Negative
1A	95	27.5	7.3	204	4,800	3.7	66.0	5808	3.08	17.7	47.0	72.0	75.5
B	183	27.6	9.3	204	4,800	3.7	66.0	5775	3.53	19.1	81.5	115.5	123.2
C	93	27.5	7.2	204	500	3.4	75.7	5732	3.00	20.6	49.2	72.0	76.0
D	181	27.5	9.6	204	500	3.4	75.7	5687	3.67	23.3	75.5	109.0	116.4
E	93	27.7	7.7	126	500	1.1	75.5	5611	2.94	24.4	72.0	108.0	112.1
2A	49	27.6	6.1	126	9,900	1.1	55.0	6127	2.52	22.0	51.0	101.0	103.2
B	93	27.8	7.1	125	9,900	1.1	55.0	6051	2.72	24.1	79.3	129.0	135.3
C	139	28.0	8.7	125	9,900	1.1	55.0	6051	3.00	27.3	106.4	167.0	176.7
D	94	27.8	6.5	204	9,900	3.7	55.5	6293	2.57	20.6	58.4	86.5	87.5
E	148	27.6	6.8	206	10,000	3.7	55.5	6212	2.72	20.6	70.9	103.0	107.7
F	181	27.5	8.1	206	10,000	3.6	55.5	6172	2.99	20.6	93.5	60.0	137.6
3A	91	27.5	5.4	271	4,300	5.1	67.7	7182	2.41	42.0	68.5	104.0	104.3
B	146	27.6	6.5	273	4,400	5.1	67.5	6855	2.87	44.0	79.3	111.0	111.0
C	146	27.7	10.5	126	4,300	1.5	67.0	5004	3.64	38.0	100.0	138.0	143.1
D	92	28.0	8.9	128	4,400	1.1	66.6	4883	3.20	36.9	86.2	124.0	125.4
E	94	28.2	8.7	123	1,200	1.1	73.8	4801	3.16	39.4	86.2	124.0	126.4
4A	0	27.6	5.7	197	19,600	4.8	37.8	5647	2.52	-3.0	23.3	34.5	36.0
B	49	27.7	6.0	198	19,700	4.8	38.0	5890	2.77	-3.0	25.4	44.0	44.1
C	48	27.6	3.1	242	19,700	5.9	38.4	7018	2.20	1.2	29.5	66.0	52.1
D	138	27.6	5.7	242	19,700	6.3	38.0	7018	2.42	2.5	53.5	85.0	90.4
E	0	27.7	5.9	126	19,400	1.1	37.1	5926	2.55	-1.8	46.0	70.0	75.1
F	48	27.9	5.9	119	19,500	1.2	37.1	6212	2.55	1.2	53.5	88.5	94.1
5A	0	27.5	5.9	128	14,800	1.4	45.2	5647	2.52	10.8	47.0	72.0	75.1
B	48	27.8	6.6	126	14,800	1.4	45.0	5687	2.74	10.8	54.7	72.0	87.1
C	94	28.0	7.4	128	14,800	1.4	45.0	5723	2.96	10.8	68.5	103.0	109.1
D	48	27.8	7.0	206	14,900	5.3	45.4	5490	2.96	8.0	34.0	48.0	49.1
E	92	27.6	7.4	204	14,900	5.1	45.4	5526	3.20	8.0	39.4	56.0	59.1
F	137	27.4	8.1	204	14,900	4.8	45.4	5526	3.32	8.0	52.1	79.0	84.1
G	137	27.5	5.2	260	15,200	8.1	46.4	7504	2.36	14.5	56.0	82.0	84.1
6A	0	27.8	5.2	126	29,100	2.0	25.7	6096	2.34	-9.4	36.8	60.0	62.1
B	48	28.0	5.7	126	29,100	2.0	25.3	6178	2.50	-10.0	44.5	71.0	75.1
C	93	28.0	6.8	126	28,900	2.0	25.3	6096	2.65	-10.0	57.1	91.0	94.1
D	0	28.0	4.2	200	28,900	4.5	25.8	7461	1.90	-5.9	36.9	63.0	67.1
E	48	27.8	4.4	200	29,100	4.5	25.8	7588	2.01	-5.9	36.9	67.0	71.1
7A	137	27.7	6.8	125	28,900	1.9	25.5	6066	2.72	-8.2	79.3		130
B	92	27.8	4.7	200	28,900	4.5	26.2	7303	2.05	-5.9	54.7		93
C	138	27.7	5.2	202	28,900	4.5	25.8	7431	2.16	-4.6	77.0		120
8A	90	27.4	7.4	126	4,900	4.8	64.7	5368	3.10	23.3	52.1		77
B	177	27.3	9.7	126	4,900	5.1	64.8	5277	3.75	25.0	75.5		106
C	134	27.3	8.0	121	4,800	4.7	61.1	5287	3.16	24.4	66.0		97
9A	146	27.4	8.8	206	5,000	6.0	65.5	5323	3.67	26.0	59.9		82
B	92	27.5	4.9	276	4,900	10.9	66.2	7112	2.36	30.0	57.1		73
C	137	27.6	5.5	278	4,900	11.1	66.5	7182	2.63	31.0	59.9		88
D	181	27.6	6.2	276	4,900	10.9	66.4	7052	2.77	32.0	73.2		95
10A	92	27.7	4.9	258	10,400	9.0	55.5	7218	2.29	27.3	62.2		80
B	138	27.8	5.6	258	10,400	9.1	55.2	7218	2.69	28.1	64.6		80
C	183	27.7	6.3	258	10,400	8.8	55.0	7188	2.79	28.1	80.4		10
D	93	27.7	8.6	128	1,000	1.3	74.4	4731	3.27	32.7	72.0		10
11A	92	27.5	5.7	125	19,400	2.7	37.2	6309	2.50	-11.5	42.0		61
B	137	27.5	6.6	125	19,300	2.8	37.1	6248	2.69	-11.5	59.9		9
C	92	27.4	5.9	208	19,300	6.1	37.3	6339	2.59	-15.3	16.4		3
D	136	27.2	6.2	202	19,400	6.2	37.3	6339	2.72	-13.0	32.7		6
E	92	27.3	4.3	244	19,700	8.5	37.5	7583	2.01	-5.9	28.7		5
F	181	27.3	5.7	244	19,600	8.9	38.0	7558	2.38	-8.9	49.8		8
12A	146	27.4	8.1	123	14,700	1.6	45.0	5526	4.38	-4.0	69.7		11
B	181	27.4	9.1	200	14,800	5.0	45.2	5893	3.45	-4.0	58.4		8
C	92	27.3	4.3	260	15,000	8.1	46.2	7825	2.02	-1.8	30.0		5
D	180	27.0	5.7	260	15,100	8.4	46.5	7794	2.38	1.2	54.7		8
13A	137	27.4	8.1	128	500	2.0	75.2	5732	3.16	12.8	66.0		10
B	137	27.4	7.2	206	600	6.1	75.0	6218	3.06	12.8	46.0		6
C	137	27.4	5.3	265	500	11.4	75.5	7430	2.50	16.4	42.8		6
D	181	27.4	5.9	261	500	11.6	75.7	7430	2.57	17.7	52.1		6
E	92	27.4	4.6	240	700	11.6	75.7	6940	2.13	16.4	35.3		1

*Based on flight measurements