MAE 4223

Aerospace Engineering Laboratory

Solid Rocket Motor Performance

DATE DUE: 2-15-2001

BY: Charles O'Neill

TABLE OF CONTENTS

ABSTRACT

Two rocket motors in the NAR F and G class are tested to determine their thrust, flow rate, impulse and specific impulse performance. Simple theoretical measurements of rocket motor thrust, flow rate, impulse and specific impulse are discussed and calculated. A simple moment-arm measurement system was used to determine thrust. Uncertainty analysis is used to determine error bounds. Results are discussed.

LIST OF FIGURES

INTRODUCTION

Two small rocket motors are tested to determine their performance characteristics. The motors are National Association of Rocketry (NAR) F and G classified motors manufactured by Aerotech Inc. A moment-arm load cell with a strain gage transducer system connected to an oscilloscope will record the time history of the rocket burns. Motor thrust and propellant properties will be recorded and discussed.

EQUIPMENT

The equipment required for the experiment consisted of rocket motors and the measurement/test equipment.

Two solid propellant rocket motors were tested. Both motors were in the Aerotech RMS 29/40-120 family. Both the F22-7J and the G33-7J used the same reusable casing. The F22 grain was one piece whereas the G33 consisted of two axially connected grains. The rocket nozzle was of a converging-diverging type; however, a quick inspection indicated that the nozzle was probably not shaped to take advantage of the diverging portion. Both motors used the proprietary Aerotech *Black Jack* propellant. Containing less than 4 ounces of propellant, both motors are legal for general use by non-rated civilians.

The rocket test equipment consisted of three systems: measurement, firing and display. A schematic drawing is given in Figure 1. The battery, indicator and oscilloscope were moved away from the rocket firing area.

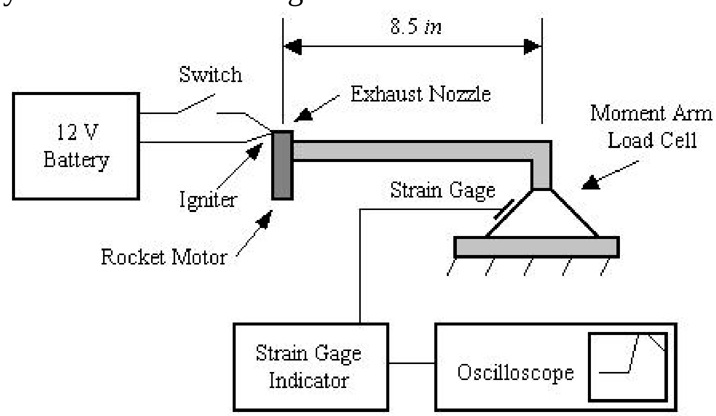


Figure 1. Rocket Test Equipment

The measurement system was a moment-arm load cell. The rocket motor fired upwards at the end of the 8.5 *in* moment arm. The root end of the moment arm was connected to the base through a group of strain gages.

The firing system was electrical. An electrically activated igniter was installed in the motor. Battery power was routed to the igniter with a human activated switch installed for precise control of the firing.

The measurement system consisted of a strain gage, indicator and oscilloscope. The strain gage measured the strain induced into the load cell due to the weight acting at the end of the moment arm. The strain gage indicator consisted of a Wheatstone bridge amplifying the strain gage signal to levels usable by the oscilloscope. The oscilloscope displayed the resulting transducer output.

PROCEDURE

The measurement procedure consisted of calibration, firing and recording. Calibration of the experimental apparatus required three steps. The loaded motor's weight was measured. The load cell was calibrated over the expected experimental range by measuring the transducer output for known test weights. Tests were made above the expected experimental thrust values. Finally, the oscilloscope range was set to capture the transducer output during the rocket firing. Firing the rocket motor consisted of connecting the ignition leads to the battery and connecting the switch. After firing, the empty rocket motor is weighed.

THEORY

Theory was used for three areas of this experiment. First, the load cell calculations were simplified by assuming a linear relationship. Second, rocket motor characteristics are discussed. Finally, a numerical integration method is discussed.

The moment-arm load cell was calibrated to determine a relationship between transducer output and the applied weight. The calibration points are linear due to the particular construction of the load cell. Because of the linearity, the change in applied weight can be described with only a change in output voltage. Thus, the zero point of the calibration setup is useless as long as the load cell remains in a linear transducer output region. Theoretically, this makes the transfer of voltage data to thrust data easier. All zero point load cell calibration will be ignored in this experiment.

Impulse for a rocket motor is defined as the total energy expended during the burn. The impulse's magnitude would give an indication of the change in a satellite's movement.

$$I_b = \int_0^t T dt$$

Specific impulse is defined as the impulse per unit of fuel. Specific impulse of a rocket motor is related to the type of propellant.

$$I_{sp} = \frac{I_b}{W_{eff}}$$

Instantaneous flow rate is simply the amount of propellant exiting the motor. An approximation can be made by assuming the flow rate only depends on the current thrust and the specific impulse of the propellant.

$$\dot{w} = \frac{T}{I_{sp}}$$

Numerical integration was required to determine the impulse of the rocket motor from thrust and time data. From the above definition, impulse is the integral of thrust over time. A 2-point trapezoidal integration scheme was selected. This method has the advantage of being easy to implement with irregularly stepped data and of being first order accurate. Integration was performed by multiplying the time step with the average value of the two nearest data points. This method is mathematically described as,

$$I = \int_0^t y(x) \approx \sum_0^t \left(\left(\frac{y_2 + y_1}{2} \right) \cdot (x_2 - x_1) \right)$$

As seen above, this method is easy to implement with the obtained rocket data. As expected, the total number of regions is one less than the number of points. The accuracy of this method is sufficient with small time steps.

RESULTS

Calibration was performed as described above. For the F22 motor, a linear best-fit line is shown in Figure 2.

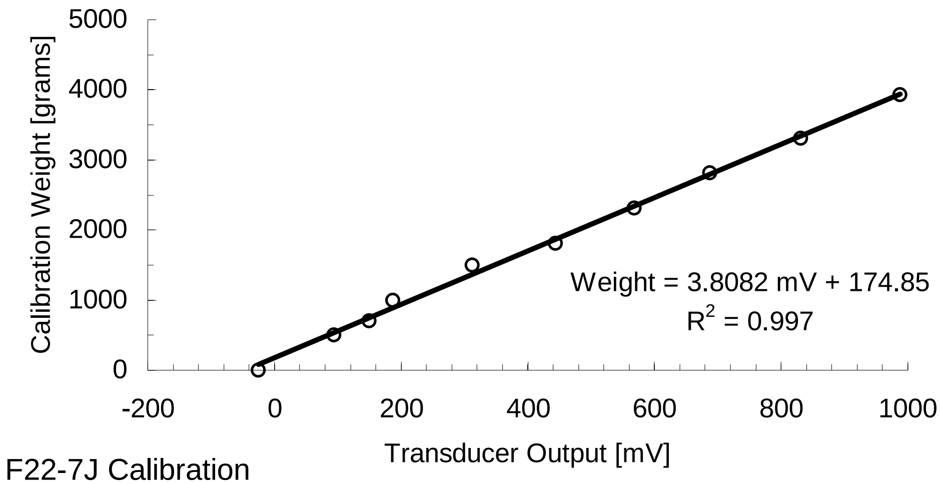


Figure 2. F22-7K Calibration

As discussed in the theory, only the slope of the best-fit line is needed. Thus, the relationship between a change in applied weight and transducer output is determined to be,

$$\Delta W = 3.8082 \cdot \Delta V$$

Similarly for the G33 motor, the best-fit line is shown in Figure 3. The relationship between a change in applied weight and the transducer output is determined to be,

$$\Delta W = 4.2629 \cdot \Delta V$$

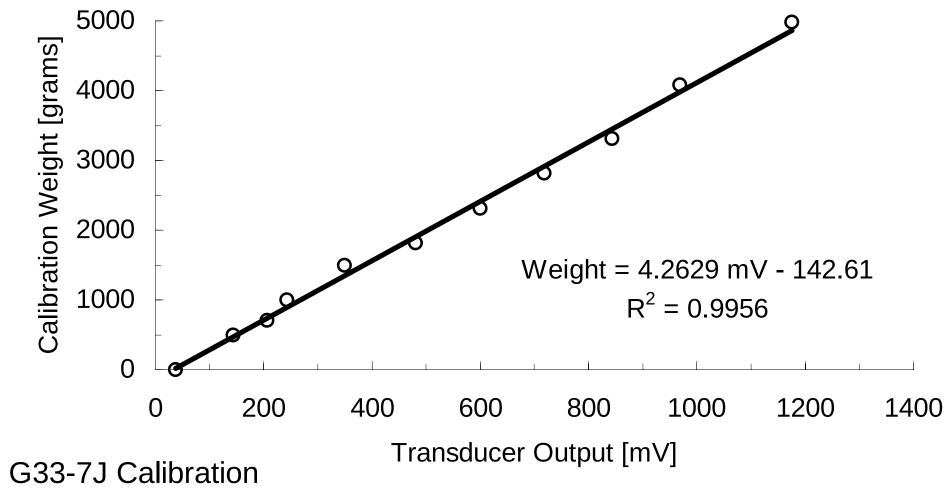


Figure 3. G33-7J Calibration

Experimental uncertainty is estimated by considering the uncertainty in the measurements. For the F22-7J rocket motor, the calibration related thrust and voltage. From above, the thrust is given by,

$$T = 3.808\,mV$$

The transducer output voltage is assumed to be known within ±0.001 Volt and the calibration weights are known to ±1 gram. Thus, the worst-case estimates of the thrust are,

$$T = 3.808\left(V \pm 1mV\right) \pm 1\,gram$$

At 1 second, the F22-7J rocket has a transducer output of 426.868 mV. The minimum thrust estimate as determined by uncertainty analysis is,

$$T = 3.808\left(426.868 - 1\right) - 1\,gram$$

$$T = 1620\,gram$$

$$T = 3.57\,lbf$$

Likewise, the minimum thrust estimate is,

$$T = 3.808\left(426.868 + 1\right) + 1\,gram$$

$$T = 1630\,gram$$

$$T = 3.59\,lbf$$

Thus, the estimated thrust for the F22-7J at 1 second considering the uncertainty of measurement and calibration is,

$$T = 3.58 \pm 0.01\,lbf$$

The uncertainty estimate of less than one quarter of one percent is acceptable for this experiment.

Factory performance characteristics of both the F22 and G33 motors were determined from charts given by Aerotech [1] [2] and included in Data Sheet 3 and 4 in the Appendix. The F22 motor reaches a maximum thrust of just over 6 pounds at ¼ of a second into the burn. The burn is slightly regressive until 2 seconds. After 2 seconds, the motor quickly burns out to zero thrust. A plot of the factory's thrust versus time chart is given in Figure 4. The total impulse delivered by the motor as determined by the factory is 14.55 lb-sec, which compares favorably to 14.6 lb-sec on the data sheet [1]. The propellant specific impulse was 142.7 seconds as determined in Table 2.

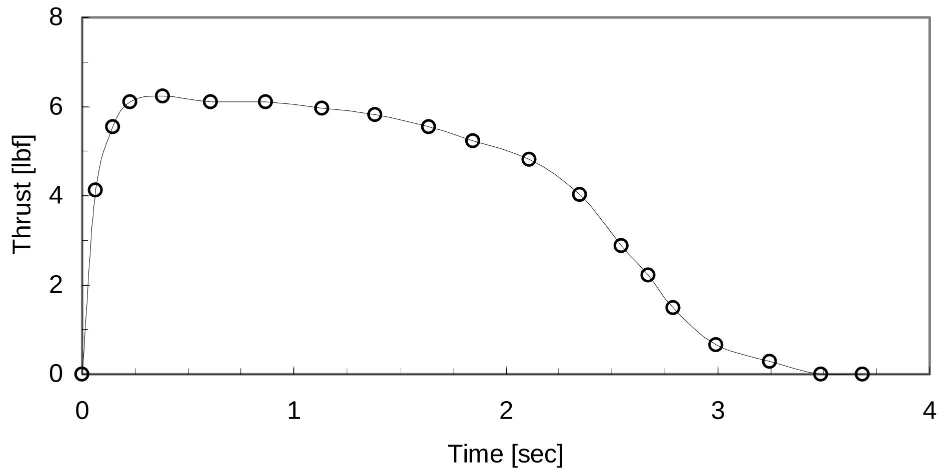


Figure 4. F22-7J Factory Data: Thrust versus Time

The G33 motor reached a peak thrust of just over 8 pounds within 1/10 of second of firing. The burn was neutral until 2 seconds into the burn. After 2 seconds, the motor quickly decreased thrust to zero. A factory plot of thrust versus time is given in Figure 5. From the factory data, the G33 motor has an impulse of 21.5 lb-sec compared to the advertised 22.5 lb-sec. The propellant specific impulse was 135 seconds as determined in Table 3.

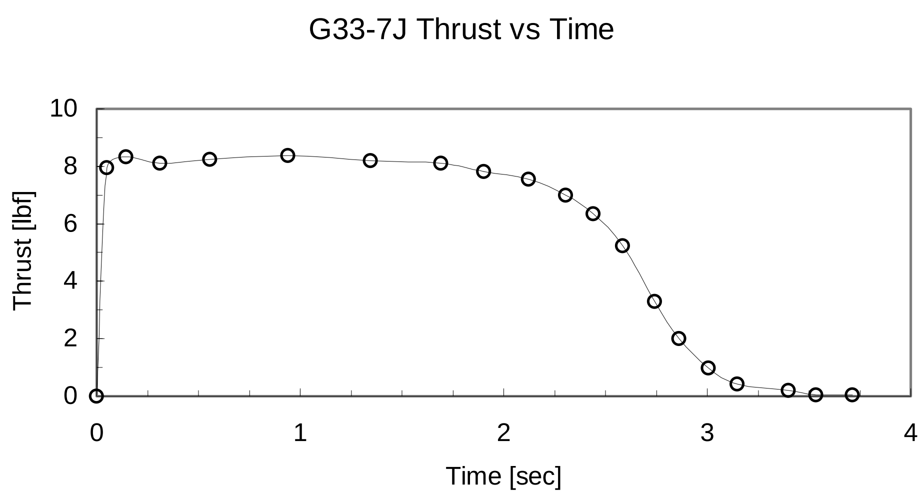


Figure 5. G33-7J Factory Data: Thrust versus Time

Aerotech F22 and G33 motors were experimentally tested as described above. The F22 motor burn history was recorded without errors; however, the G33 motor burn history was not properly captured by the oscilloscope. This improper capture meant that the total propulsive performance is not available for the G33.

The F22-7J motor was tested and the thrust-time history is given in Table 4. The thrust-time history is plotted in Figure 6.

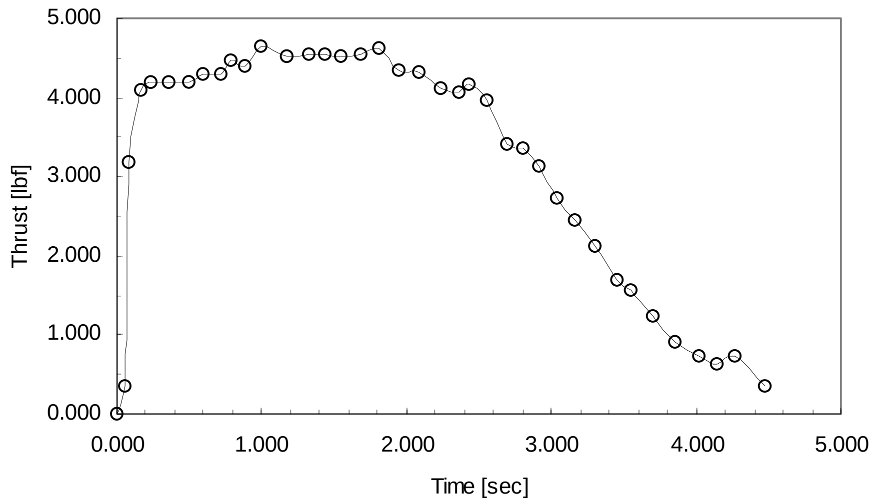


Figure 6. F22-7J Experimental Thrust Time History

The flow rate through the F22 motor is given in Figure 7.

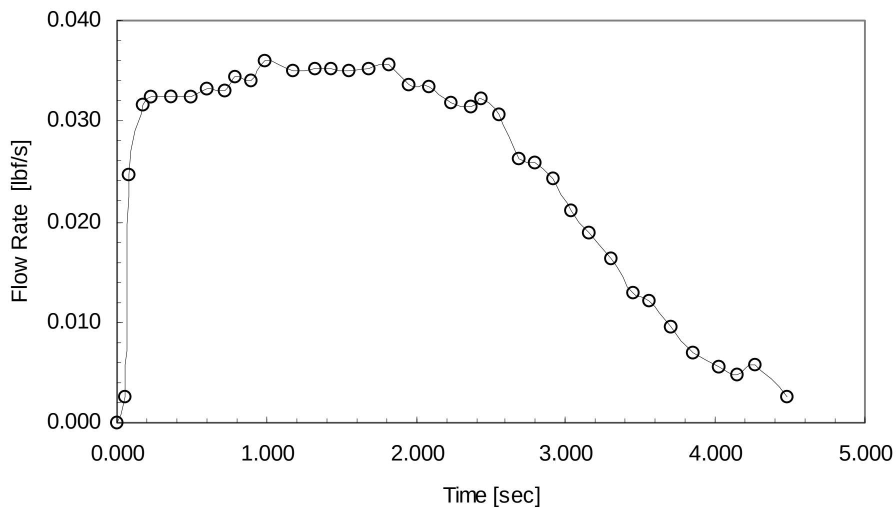


Figure 7. F22-7J Experimental Flow Rate

The total impulse delivered by the F22 motor was 14.2 lb-sec as given in Table 4 and Data Sheet 1 in the Appendix. The propellant specific impulse is 129 seconds.

As compared to the factory data, the experimental data shows significantly less thrust. Where the factory was easily exceeding 6 lbs of thrust, the experiment slowly worked up to 4.5 lbs of thrust. Additionally, the factory data shows a neutral burn rate;

however, the experimental thrust increases up to 2 seconds. The F22 grain has an axial slot. From [3], slots are neutral burning as determined from both the experimental and factory data. The total impulse provided by the motor was slightly over 14 lb-sec for both the factory and experimental data.

The experimental specific impulse was lower than the factory advertised. Aerotech's data was calculated to give a 143 second specific impulse; however, the experiment only achieved a 129 second specific impulse. This may indicate weak or old propellant.

Because the day was cold, the propellant burn rate could have been affected. Also, the moisture content was high, so it may be possible that the motor had absorbed some water between the unpacking time and the firing time. In any case, the F22 motor only provided 75% of the rated and advertised thrust.

The G33-7J motor was tested and the data given in Table 5 and Data Sheet 2 in the Appendix. A thrust-time plot of the G33 motor's burn is given in Figure 8. A plot of flow rate versus time is given in Figure 9.

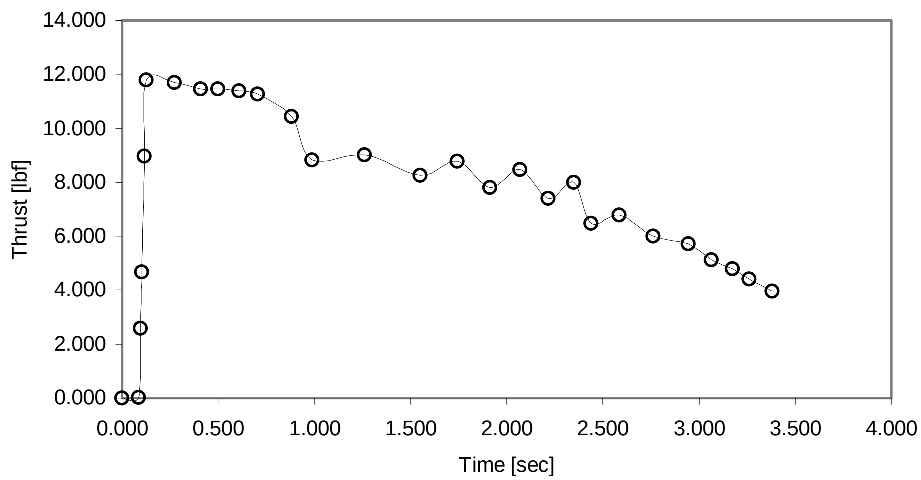


Figure 8. G33-7J Experimental Thrust Time History

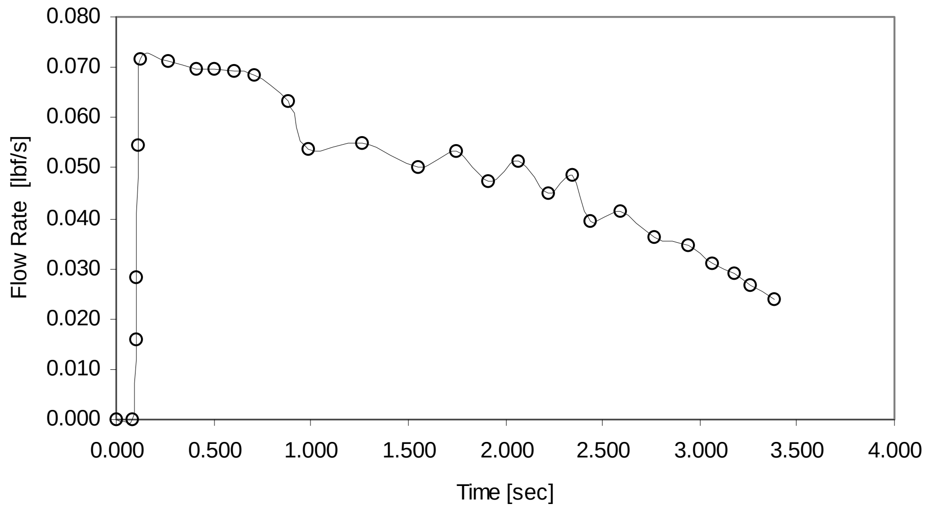


Figure 9. G33-7J Experimental Flow Rate

Total Impulse and specific impulse were not calculated for the G33 motor due to data limitations.

The G33 burn history captured does allow for comparison between the experimental and factory thrust data. Surprisingly, the G33 motor provided almost 12 lbs of thrust whereas the factory only suggests 8 lbs. The thrust does decrease to the expected 8 lbs after 0.75 seconds and reference to Data Sheet 2 shows that the noise level in the measurement system is unusually high during the extra thrust period. Also worthy of notice is the failed start 0.5 second before the high thrust level. Perhaps a chunk of propellant stopped up the nozzle and created an overpressure, which caused the high thrust. This initial spike was neglected during the thrust-time plotting but after analysis, it may need to be included. Overall, the G33 burn was erratic. After the over-thrust, the burn profile looks neutral, which is similar to the factory data. As with the F22, the G33 has an axial slot through the grains, which should produce a neutral burn profile [3].

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations regarding the testing of small rocket motors are suggested.

1. Aerotech's factory performance data did not accurately predict the field performance of their motors. Overall, the factory data did show the general burn trend.
2. The neutral burn profile is consistent with the slotted grain geometry.
3. A possible overpressure may have occurred in the G33 motor.
4. Measurement equipment needs to be tested before experimentation to prevent data acquisition problems. Also, reducing noise in the measurement system would eliminate possible errors.

REFERENCES

1. Aerotech Inc, http://www.aerotech-rocketry.com/customersite/products/motors/RMSreloads/hobbyreloads/E23F22F52graph.GIF, 2001.

2. Aerotech Inc, http://www.aerotech-rocketry.com/customersite/products/motors/RMSreloads/hobbyreloads/G33graph.GIF, 2001.

3. C.D. Brown, *Spacecraft Propulsion*, AIAA, 1996.

APPENDICES

SAMPLE CALCULATIONS

1. Conversion from Transducer Output to Weight

$$T = Constant \cdot Voltage$$

$$T = 3.8082(1000\,mV)$$

$$T = 2808.2\,gram$$

$$T = \frac{2808.2\,gram}{454\,gram/lb}$$

$$T = 6.185\,lb$$

2. Numerical Integration

Thrust [lb]	sec
-1.874	0.059
0.733	0.097

$$I = \int_0^t y(x) \approx \sum_0^t \left(\left(\frac{y_2 + y_1}{2} \right) \cdot (x_2 - x_1) \right)$$

$$I = \left(\frac{-1.874 + 0.733}{2} \right)(0.097 - 0.059)$$

$$I = -0.021$$

SPREADSHEET TABLES

TABLE 1: F22-7J AND G33-7J CALIBRATION TABLES:

F22-7J		J33	
grams	mV	grams	mV
		0	37.5
0	-25	500	143.8
500	93.75	707	206.2
707	150	1000	243.8
1000	187.5	1500	350
1500	312.5	1813	481.3
1813	443.8	2313	600
2313	568.8	2813	718.8
2813	687.5	3313	843.8
3313	831.2	4079	968.8
3927	987.5	4986	1175

TABLE 2: F22-7J FACTORY DATA

F22-7J

	quantity	pixel units	rate
thrust cal	8	0.801	9.9875156
time	4	2.2	1.8181818

Propellent Weight 0.1019824 lbf

x	y	Thrust lbs	Time sec	Impulse lb-sec	Flow rate lb/sec
3.76	2.038	0	0		0
3.795	1.625	4.124844	0.0636364	0.131245	0.028911
3.84	1.483	5.543071	0.1454545	0.395506	0.038851
3.885	1.427	6.102372	0.2272727	0.476404	0.042771
3.969	1.413	6.242197	0.38	0.942676	0.043751
4.094	1.427	6.102372	0.6072727	1.402792	0.042771
4.236	1.427	6.102372	0.8654545	1.575522	0.042771
4.382	1.441	5.962547	1.1309091	1.601344	0.041791
4.521	1.455	5.822722	1.3836364	1.489229	0.040811
4.66	1.483	5.543071	1.6363636	1.436223	0.038851
4.774	1.514	5.233458	1.8436364	1.11684	0.036681
4.92	1.556	4.813983	2.1090909	1.333569	0.033741
5.052	1.635	4.024969	2.3490909	1.060674	0.028211
5.16	1.75	2.876404	2.5454545	0.677589	0.020161
5.229	1.816	2.217228	2.6709091	0.31951	0.01554
5.295	1.889	1.48814	2.7909091	0.222322	0.01043
5.406	1.972	0.659176	2.9927273	0.216684	0.00462
5.545	2.01	0.27965	3.2454545	0.118634	0.00196
5.677	2.038	0	3.4854545	0.033558	0
5.785	2.038	0	3.6818182	0	0

Impulse 14.55032

Sp Impulse 142.6749

TABLE 3: G33-7J FACTORY DATA

G33-7J

	quantity	pixel units	rate	
thrust cal	8	0.801	9.987516	lbs/unit
time	4	2.2	1.818182	sec/unit

Propellent Weight 0.159031 lbf

x	y	Thrust lbs	Time sec	Impulse lb-sec	Flow rate lb/sec
3.75	2.042	0	0		0
3.778	1.245	7.96005	0.050909	0.202619	0.058786
3.829	1.208	8.329588	0.143636	0.755247	0.061515
3.921	1.231	8.099875	0.310909	1.374101	0.059818
4.056	1.217	8.2397	0.556364	2.005312	0.060851
4.268	1.204	8.369538	0.941818	3.201053	0.06181
4.49	1.222	8.189763	1.345455	3.341968	0.060482
4.681	1.231	8.099875	1.692727	2.828473	0.059818
4.796	1.259	7.820225	1.901818	1.664374	0.057753
4.917	1.287	7.540574	2.121818	1.689688	0.055688
5.018	1.342	6.991261	2.305455	1.334287	0.051631
5.092	1.407	6.342072	2.44	0.89697	0.046837
5.171	1.518	5.233458	2.583636	0.831334	0.038649
5.259	1.713	3.285893	2.743636	0.681548	0.024267
5.324	1.842	1.997503	2.861818	0.312201	0.014752
5.403	1.944	0.978777	3.005455	0.213751	0.007228
5.481	2	0.419476	3.147273	0.099149	0.003098
5.62	2.023	0.189763	3.4	0.076986	0.001401
5.694	2.037	0.049938	3.534545	0.016125	0.000369
5.792	2.037	0.049938	3.712727	0.008898	0.000369

Impulse 21.53408

Sp Impulse 135.4082

TABLE 4: F22-7J EXPERIMENTAL DATA

F22-J7

	scale	change			Weight		
y	1000.000	1.258	794.913	mv/unit	before	134.000	g
x	2.000	1.550	1.290	sec/unit	after	84.000	g
					Weff	50.000	g

Thrust = 3.808 mV + 174.850 Weff 0.110

	x	y	mV	Thrust [g]	Thrust [lb]	sec	Impulse	Flow Rate
Reference	0.750	1.900	0.000	0.000	0.000	0.000		0.000
	0.796	1.848	41.335	157.414	0.347	0.059	0.010	0.003
	0.817	1.423	379.173	1443.968	3.181	0.086	0.048	0.025
	0.881	1.288	486.486	1852.638	4.081	0.169	0.300	0.032
	0.931	1.273	498.410	1898.046	4.181	0.234	0.266	0.032
	1.027	1.273	498.410	1898.046	4.181	0.357	0.518	0.032
	1.138	1.273	498.410	1898.046	4.181	0.501	0.599	0.032
	1.213	1.256	511.924	1949.508	4.294	0.597	0.410	0.033
	1.310	1.258	510.334	1943.453	4.281	0.723	0.537	0.033
	1.358	1.231	531.797	2025.187	4.461	0.785	0.271	0.035
	1.440	1.240	524.642	1997.943	4.401	0.890	0.469	0.034
	1.519	1.202	554.849	2112.976	4.654	0.992	0.462	0.036
	1.658	1.221	539.746	2055.459	4.527	1.172	0.823	0.035
	1.777	1.219	541.335	2061.514	4.541	1.325	0.696	0.035
	1.860	1.217	542.925	2067.568	4.554	1.432	0.487	0.035
	1.952	1.223	538.156	2049.405	4.514	1.551	0.538	0.035
	2.054	1.219	541.335	2061.514	4.541	1.683	0.596	0.035
	2.154	1.208	550.079	2094.813	4.614	1.812	0.591	0.036
	2.260	1.248	518.283	1973.725	4.347	1.948	0.613	0.034
	2.371	1.252	515.103	1961.617	4.321	2.092	0.621	0.033
	2.479	1.283	490.461	1867.774	4.114	2.231	0.588	0.032
	2.579	1.290	484.897	1846.583	4.067	2.360	0.528	0.031
	2.633	1.277	495.231	1885.937	4.154	2.430	0.286	0.032
	2.731	1.306	472.178	1798.148	3.961	2.556	0.513	0.031
	2.835	1.390	405.405	1543.865	3.401	2.690	0.494	0.026
	2.919	1.398	399.046	1519.647	3.347	2.799	0.366	0.026
	3.008	1.431	372.814	1419.750	3.127	2.914	0.372	0.024
	3.102	1.490	325.914	1241.146	2.734	3.035	0.355	0.021
	3.196	1.533	291.733	1110.977	2.447	3.156	0.314	0.019
	3.308	1.583	251.987	959.618	2.114	3.301	0.330	0.016
	3.423	1.648	200.318	762.851	1.680	3.449	0.281	0.013
	3.502	1.665	186.804	711.389	1.567	3.551	0.166	0.012
	3.615	1.715	147.059	560.029	1.234	3.697	0.204	0.010
	3.738	1.765	107.313	408.670	0.900	3.855	0.169	0.007
	3.867	1.792	85.851	326.936	0.720	4.022	0.135	0.006
	3.965	1.806	74.722	284.555	0.627	4.148	0.085	0.005
	4.058	1.790	87.440	332.990	0.733	4.268	0.082	0.006
	4.219	1.848	41.335	157.414	0.347	4.476	0.112	0.003
						Ib	14.234	
						Ieff	129.241	
							sec	

TABLE 5: G33-7J EXPERIMENTAL DATA

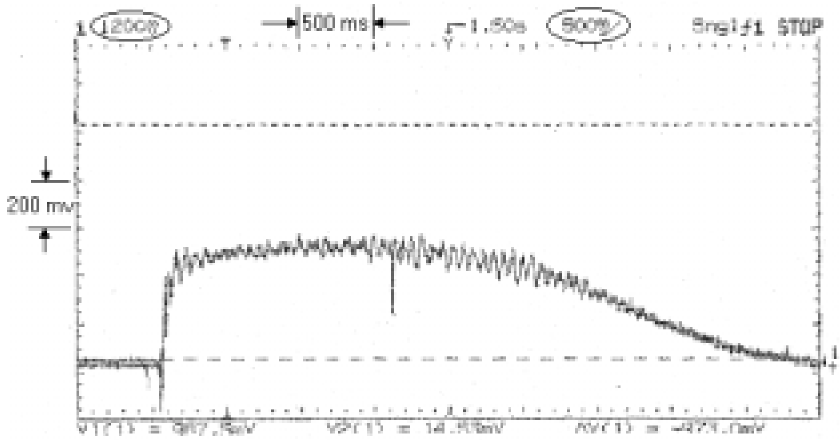
G33-7J

	scale	change				Weight		
y	1000.000	1.267	789.266	mv/unit		before	158.000	g
x	1.500	1.150	1.304	sec/unit		after	83.000	g
						Weff	75.000	g
Thrust	=	4.263	mV	+	142.610	Weff	0.165	

Average Thrust

	x	y	mV	Thrust [g]	Thrust [lb]	sec	Impulse	Flow Rate
reference	1.625	1.842	0.000	0.000	0.000	0.000		0.000
	1.692	1.838	3.157	13.458	0.030	0.087	0.001	0.000
	1.700	1.492	276.243	1177.597	2.594	0.098	0.014	0.016
	1.705	1.211	498.027	2123.039	4.676	0.104	0.024	0.028
	1.714	0.633	954.223	4067.755	8.960	0.116	0.080	0.054
	1.721	0.250	1256.511	5356.383	11.798	0.125	0.095	0.072
	1.833	0.263	1246.251	5312.643	11.702	0.271	1.717	0.071
	1.938	0.296	1220.205	5201.613	11.457	0.408	1.586	0.070
	2.008	0.296	1220.205	5201.613	11.457	0.500	1.046	0.070
	2.092	0.304	1213.891	5174.696	11.398	0.609	1.252	0.069
	2.167	0.321	1200.474	5117.499	11.272	0.707	1.109	0.068
	2.300	0.433	1112.076	4740.668	10.442	0.880	1.883	0.063
	2.383	0.650	940.805	4010.558	8.834	0.989	1.043	0.054
	2.592	0.625	960.537	4094.672	9.019	1.261	2.433	0.055
	2.813	0.729	878.453	3744.757	8.248	1.550	2.489	0.050
	2.963	0.658	934.491	3983.641	8.775	1.745	1.665	0.053
	3.092	0.788	831.886	3546.248	7.811	1.913	1.395	0.047
	3.213	0.700	901.342	3842.330	8.463	2.071	1.284	0.051
	3.325	0.842	789.266	3364.562	7.411	2.217	1.160	0.045
	3.425	0.763	851.618	3630.362	7.996	2.348	1.005	0.049
	3.496	0.967	690.608	2943.992	6.485	2.440	0.671	0.039
	3.608	0.925	723.757	3085.303	6.796	2.587	0.970	0.041
	3.742	1.033	638.516	2721.931	5.995	2.761	1.118	0.036
	3.883	1.071	608.524	2594.077	5.714	2.945	1.077	0.035
	3.975	1.150	546.172	2328.277	5.128	3.065	0.651	0.031
	4.058	1.196	509.866	2173.507	4.787	3.173	0.537	0.029
	4.125	1.246	470.403	2005.279	4.417	3.261	0.402	0.027
	4.217	1.308	421.468	1796.676	3.957	3.381	0.502	0.024

DATA SHEET 1: F22-7J EXPERIMENTAL OSCILLOSCOPE OUTPUT



	State	Volts/Div	Position	Cplg	BW Lim	Inv	Probe
Chan 1	On	200.0mV	550.3mV	DC	Off	On	1:1
Chan 2	Off	1.000 V	-2.906 V	DC	Off	Off	1:1
Chan 3	Off	100.0mV	0.000 V	DC	---	---	1:1
Chan 4	Off	100.0mV	0.000 V	DC	---	---	1:1

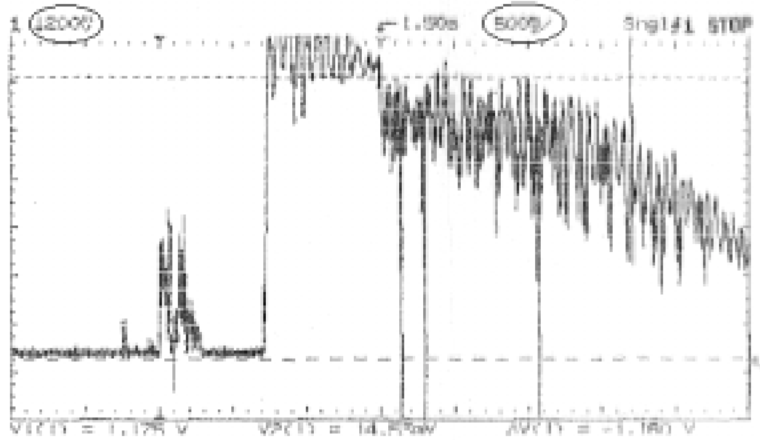
	Mode	Main Time/Div	Main Delay	Time Ref	Delayed Time/Div	Delayed Delay
Horizontal	Normal	500.0ms/	1.500 s	Cntr	---------	-----

Trigger	Mode	Source	Level	Holdoff	Slope	Couplg	Reject	NoiseRej
	Single	Ch 1	-475.0mV	20.00ms	Pos	DC	Off	Off

Display Mode: Normal

Cursors: t1=-1000.0ms t2=1000.0ms V1(1)=987.5mV V2(1)=14.53mV

DATA SHEET 2: G33-7J EXPERIMENTAL OSCILLOSCOPE OUTPUT



	State	Volts/Div	Position	Cplg	BW Lim	Inv	Probe
Chan 1	On	200.0mV	556.3mV	DC	Off	On	1:1
Chan 2	Off	1.000 V	-2.906 V	DC	Off	Off	1:1
Chan 3	Off	100.0mV	0.000 V	DC	---	---	1:1
Chan 4	Off	100.0mV	0.000 V	DC	---	---	1:1

	Mode	Main Time/Div	Main Delay	Time Ref	Delayed Time/Div	Delayed Delay
Horizontal	Normal	500.0ms/	1.500 s	Cntr	---------	------

Trigger	Mode	Source	Level	Holdoff	Slope	Couplg	Reject	NoiseRej
	Single	Ch 1	-475.0mV	20.00ms	Pos	DC	Off	Off

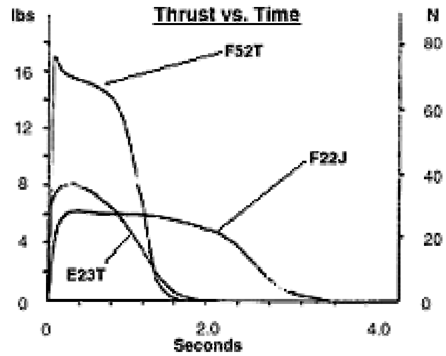
Display Mode: Normal

Cursors: t1=-1000.0ms t2=1000.0ms V1(1)=1.175 V V2(1)=14.53mV

DATA SHEET 3: F22-7J FACTORY PERFORMANCE CURVE

Motor Type	Propellant Weight		Total Impulse		Average Thrust		Loaded Motor Weight	
	oz	gms	lb-sec	N-sec	lbs	N	oz	gms
E23T	0.61	17.4	9.0	40.0	5.2	23.0	3.7	104
F22J	1.63	46.3	14.6	65.0	4.9	22.0	4.7	133
F52T	1.29	36.6	18.0	80.0	11.7	52.0	4.3	123

T= Blue Thunder Propellant
J=Black Jack Propellant



DATA SHEET 4: G33-7J FACTORY PERFORMANCE CURVE

Motor Type	Propellant Weight		Total Impulse		Average Thrust		Loaded Motor Weight	
	oz	gms	lb-sec	N-sec	lbs	N	oz	gms
G33J	2.55	72.2	22.5	100.0	7.4	33.0	5.6	159

J=Black Jack Propellant