Bobby Nordlund
Taylor Newman
Captain O'Reilly
EA201–5001
21 April 2010

100% = 200 points
+ 5 $/pay
+ 5 style points
210

Rocket Competitive Success Criteria (CSC) Analysis

Costly components

Component	*Rate*	*Quantity*	*Cost*
Engine Adaptor System	$5000	2.00	$10,000.00
Body Tube	$10000/in	10.50"	$105,000.00
Balsa Wood	$100/in^2	10.03in^2	$1,003.00
B6-0 & A8-3	$1,000,000	1.00	$1,000,000
			$1,116,003.00

Actual payload: **32.4g**

Cost-to-payload ratio: **$34,444.54/g**

Two tools were used to predict the rocket's performance. Firstly, the commercial RockSim software (by Apogee) was and is a highly-accurate rocketry modeling program that does just about anything rocketry. It was used to model each of the four configurations in order to determine which design held a competitive advantage in the competition. Ultimately, our modeling predicted the B-A design would have a cost-to-payload ratio more than **12%** less than any other design. ← Awkward

MATLAB proved a useful, albeit cumbersome, tool for predicting our rocket's performance. Unfortunately, it was hamstrung by our measured thrust data which lacked the accuracy of Estes' published thrust profiles. The **-12%** error in Impulse seen in the Thrust Lab was carried forward and reflected *almost exactly* in the discrepancy between RockSim's predictions and MATLAB's predictions of our rocket's performance: the difference between **305'** and **260'**. – This is coincidental, seriously (Or maybe Estes lies)

The margin we built into our design was swallowed by 5kt winds out of the SE. Our over-stable rocket experienced significant weather-cocking that turned precious vertical distance into horizontal distance, resulting in a flight just beneath the altitude predicted by RockSim: **292'**. excellent

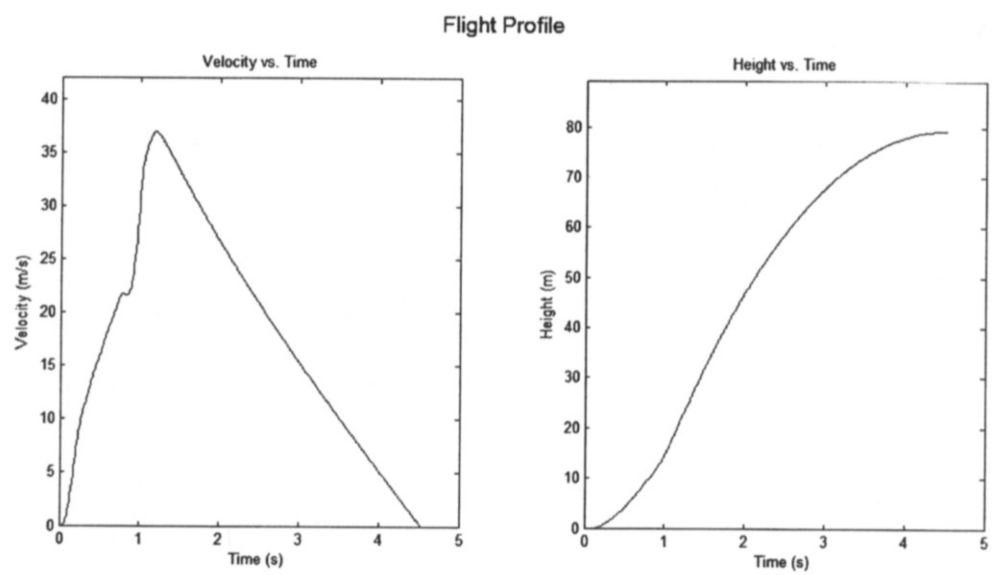
a 1.6% margin is very good though

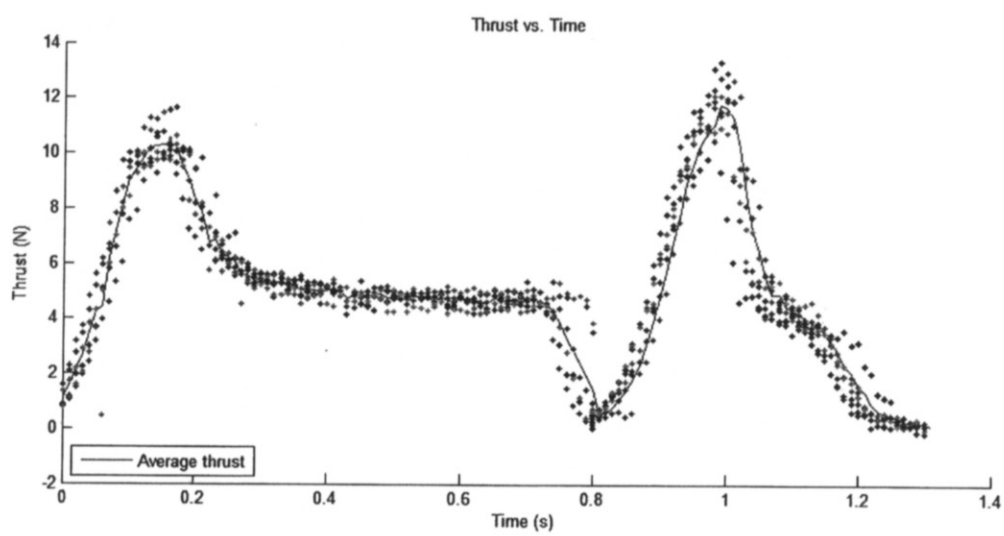
MATLAB Inputs

- Temperature: **293 K**
- Pressure: **101325 Pa**
- Payload-less initial mass: **0.1151 kg**
- Booster mass: **0.0410 kg**
- Payload: **.0324 kg**
- Drag coefficient: **0.80**
- Cross-sectional area: **7.45×10^{-4} m^2**

MATLAB Outputs

- Takeoff mass: **147.5 g**
- At end of boost…
    - Velocity: **21.7603 m/s**
    - Height: **9.6785 m**
- At end of upper stage…
    - Velocity: **36.0384 m/s**
    - Height: **24.8395 m**
- At end of coast…
    - Velocity: **0 m/s (stopped)**
    - Height: **79.2591 m (260.0363 ft)**





Bobby Nordlund
Taylor Newman
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EA201–5001
21 April 2010

Rocket Project: MATLAB Code

EA204 Rocket Project

Contents

Nordlund and Newman 21 March 2010

This script seeks to model the performance of a two-stage rocket fitted with an Estes B6 and A8 serial-stage propulsion system. The values of input parameters are freely adjusted, although the thrust data is the direct result of experimentation and is less-readily modified. Thrust, mass, weight, and drag (all functions of time) are accounted for in the script. Assumptions are limited to the use of published burn-time values.

```
format short, clear all; clc
```

Enter Parameters

```
temperature=293; %Temperature (K)
pressure=101325; %Pressure (Pa)
m_0=.1151; %Payload-less initial mass (kg)
m_b=.0410; %Booster mass (kg)
payload=.0324; %Payload mass (kg)
C_d=.8; %Drag coefficient (approximate)
A=7.45e-4; %Effective cross-sectional area (m^2)
```

Preliminary Calculations

```
R_air=287; %J/(Kg*K)
rho=(pressure)/(R_air*temperature); %kg/m^3
m_0=m_0+payload; %Actual initial mass
% Display Relavent Parameters
disp(cat(2,'Payload mass: ',num2str(payload*1000),' g'))
disp(cat(2,'Booster mass: ',num2str(m_b*1000),' g'))
disp(cat(2,'Takeoff mass: ',num2str(m_0*1000),' g'))
```

```
Payload mass: 32.4 g
Booster mass: 41 g
Takeoff mass: 147.5 g
```

Booster Stage Calculations

Assume three forces: Thrust (T_B6), Weight (W), Drag (D) Note: Worthless data in 1001b6-4a, 2001a8-3a, 2001a8-3b and data from 5001b6-4a (C465:C545) appears to be from a different size engine.

```
T_B6(:,1)=xlsread('thrustdata','2001b6-4a','C225:C305');
T_B6(:,2)=xlsread('thrustdata','3001b6-6a','C685:C765');
T_B6(:,3)=xlsread('thrustdata','3001b6-6b','C315:C395');
T_B6(:,4)=xlsread('thrustdata','5001b6-6a','C553:C633');
T_B6(:,5)=xlsread('thrustdata','6001b6-4a','C605:C685');
T_B6(:,6)=xlsread('thrustdata','6001b6-4b','C463:C543');
% Reference: http://www.commonwealth.net/rocketstore/estes/EngineData.pdf
% 5.0 Ns impulse, .8 s burn time, 6.24 g propellant
```

```
I_B6=trapz(T_B6,1)/100; %Ns
I_B6=mean(I_B6,2); %Average total impulse
Isp_B6=I_B6/(.00624*9.81); %Average specific impulse
m_dot=T_B6/(Isp_B6*9.81); %Mass Flow Rate (Sellers 14-7)
t=.01; %time interval
% Mass Lost (trapezoidal method)
m_lost=t*(-.5*(m_dot(1)+m_dot(length(m_dot)))+cumsum(m_dot(1:length(m_dot))));
m_lost(1)=0; %initial mass lost due to thrust
m_lost(2)=t*(m_dot(1)+m_dot(2))/2; %trapezoidal integration of m_dot from 0 to t
m=m_0-m_lost;
W=m.*9.81; %Weight
v_boost(1)=0; %Initial velocity
a_boost(1)=(T_B6(1)-W(1))./m(1); %acceleration at t=0 (D=0)
a_boost(2)=(T_B6(2)-W(2))./m(2); %acceleration at t=0 (assume D=0)
for k=2:length(T_B6)-1
    v_boost(k)=v_boost(k-1)+t*(a_boost(k-1)+a_boost(k))/2; %trapezoidal integration point by
point
    D(k)=.5*rho*v_boost(k)^2*C_d*A; %Drag
    a_boost(k)=(T_B6(k)-W(k)-D(k))./m(k); %redefine acceleration with Drag
    a_boost(k+1)=(T_B6(k+1)-W(k+1)-D(k))./m(k+1); %temporary D assumption
end
v_b=v_boost(length(v_boost)); %velocity at burnout
h_boost=t*(-.5*(v_boost(1)+v_boost(length(v_boost)))+cumsum(v_boost(1:length(v_boost))));
h_boost(1)=0; %initial height
h_boost(2)=t*(v_boost(1)+v_boost(2))/2; %trapezoidal integration of v from 0 to t
h_b=h_boost(length(h_boost));
disp('At end of boost...')
disp(cat(2,'    Velocity is ',num2str(v_b),' m/s'))
disp(cat(2,'    Height is ',num2str(h_b),' m'))
```

```
At end of boost...
    Velocity is 21.7603 m/s
    Height is 9.6785 m
```

Upper Stage Calculations

Assume three forces: Thrust (T_B6), Weight (W), Drag (D) Reference: Estes A8-3 (2.5 Ns impulse, .5 s burn time, 3.12 g propellant) Note: Worthless data in 1001b6-4a, 2001a8-3a, 2001a8-3b and data from 5001b6-4a (C465:C545) appears to be from a different size engine.

```
T_A8(:,1)=xlsread('thrustdata','1001a8-3a','C305:C355');
T_A8(:,2)=xlsread('thrustdata','2001b6-4b','C1215:C1265');
T_A8(:,3)=xlsread('thrustdata','3001a8-3a','C260:C310');
T_A8(:,4)=xlsread('thrustdata','5001a8-3a','C550:C600');
T_A8(:,5)=xlsread('thrustdata','5001a8-3b','C470:C520');
T_A8(:,6)=xlsread('thrustdata','6001a8-3a','C510:C560');
T_A8(:,7)=xlsread('thrustdata','6001a8-3b','C475:C525');
% Reference: http://www.commonwealth.net/rocketstore/estes/EngineData.pdf
% Estes A8-3 (2.5 Ns impulse, .5 s burn time, 3.12 g propellant)
I_A8=trapz(T_A8,1)/100; %Ns
I_A8=mean(I_A8,2); %Average total impulse
Isp_A8=I_A8/(.00312*9.81); %Average specific impulse
m_dot=T_A8/(Isp_A8*9.81); %Mass Flow Rate (Sellers 14-7)
t=.01; %time interval
% Mass Lost (trapezoidal method)
m_lost=t*(-.5*(m_dot(1)+m_dot(length(m_dot)))+cumsum(m_dot(1:length(m_dot))));
m_lost(1)=0; %initial mass lost due to thrust
m_lost(2)=t*(m_dot(1)+m_dot(2))/2; %trapezoidal integration of m_dot from 0 to t
m=m_0-m_b-m_lost;
W=m.*9.81; %Weight
v_upper(1)=v_b; %Initial velocity
D(1)=.5*rho*v_upper(1)^2*C_d*A; %Initial drag
a_upper(1)=(T_A8(1)-W(1)-D(1))./m(1); %acceleration, D=D(v_b)
a_upper(2)=(T_A8(2)-W(2)-D(1))./m(2); %acceleration, assume D is still D(v_b)
for k=2:length(T_A8)-1
    v_upper(k)=v_upper(k-1)+t*(a_upper(k-1)+a_upper(k))/2; %trapezoidal integration point by
point
    D(k)=.5*rho*v_upper(k)^2*C_d*A; %Drag
    a_upper(k)=(T_A8(k)-W(k)-D(k))./m(k); %redefine acceleration with Drag
    a_upper(k+1)=(T_A8(k+1)-W(k+1)-D(k))./m(k+1); %temporary D assumption
end
v_u=v_upper(length(v_upper)); %velocity at burnout
h_upper=h_b+t*(-.5*(v_upper(1)+v_upper(length(v_upper)))+cumsum(v_upper(1:length(v_upper))));
```

```
h_upper(1)=h_b; %initial height
h_upper(2)=h_b+t*(v_upper(1)+v_upper(2))/2; %trapezoidal integration of v from 0 to t
h_u=h_upper(length(h_upper));
disp('At end of upper stage...')
disp(cat(2,'   Velocity is ',num2str(v_u),' m/s'))
disp(cat(2,'   Height is ',num2str(h_u),' m'))
```

```
At end of upper stage...
   Velocity is 36.0384 m/s
   Height is 24.8395 m
```

Coast Stage Calculations

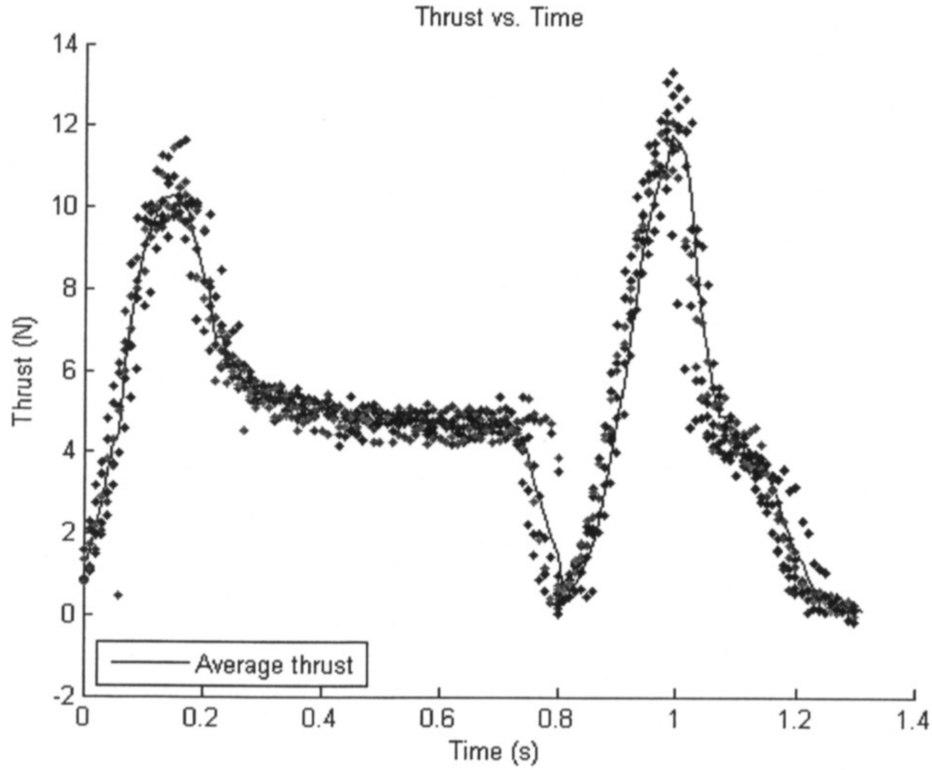
```
m=m(length(m)); %mass at burnout
W=m*9.81; %Weight
v_coast(1)=v_u; %Initial velocity
D(1)=.5*rho*v_coast(1)^2*C_d*A; %Initial drag;
a_coast(1)=(-W-D(1))/m; %acceleration, D=D(v_u)
a_coast(2)=(-W-D(1))/m; %acceleration, assume D is still D(v_u)
k=2; %iterating factor
while v_coast(length(v_coast))>=0
    v_coast(k)=v_coast(k-1)+t*(a_coast(k-1)+a_coast(k))/2; %trapezoidal integration point by
point
    D(k)=.5*rho*v_coast(k)^2*C_d*A; %Drag
    a_coast(k)=(-W-D(k))/m; %redefine acceleration with Drag
    a_coast(k+1)=(-W-D(k))/m; %temporary D assumption
    k=k+1;
end
v_c=v_coast(length(v_coast));
h_coast=h_u+t*(-.5*(v_coast(1)+v_coast(length(v_coast)))+cumsum(v_coast(1:length(v_coast))));
h_coast(1)=h_u; %initial height
h_coast(2)=h_u+t*(v_coast(1)+v_coast(2))/2; %trapezoidal integration of v from 0 to t
h_c=h_coast(length(h_coast));
h_c_feet=h_c*100/(2.54*12); %height in feet
disp('At end of coast...')
disp(cat(2,'   Velocity is ',num2str(v_c),' m/s (stopped)'))
disp(cat(2,'   Height is ',num2str(h_c),' m or ',num2str(h_c_feet),' ft'))
```

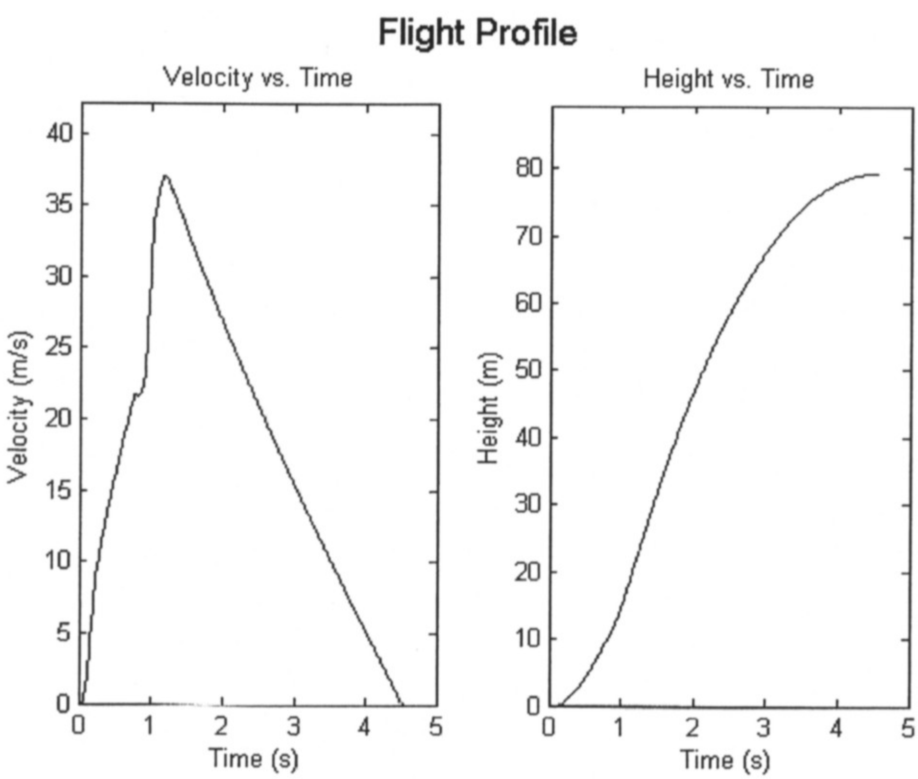
```
At end of coast...
   Velocity is -0.035923 m/s (stopped)
   Height is 79.2591 m or 260.0363 ft
```

Concatenated Profiles

Thrust vs. Time

```
T=cat(1,mean(T_B6,2),mean(T_A8,2))';
figure(1) %Thrust Plot
hold on
plot(0:.01:1.31,T,'-k') %Plot of averages
legend('Average thrust',3)
plot(0:.01:.8,T_B6,'.') %B6-0 Plots
plot(.8:.01:1.3,T_A8,'.') %A8-3 Plots
title('Thrust vs. Time'),ylabel('Thrust (N)'),xlabel('Time (s)')
set(figure(1),'color','white')
% Flight Profile
velocity=cat(2,v_boost,v_upper,v_coast);
height=cat(2,h_boost,h_upper,h_coast);
figure(2)
subplot(1,2,1) %Velocity Profile
plot(0:.01:(length(velocity)-1)/100,velocity,'-k')
axis([0 5 0 max(velocity)+5])
title('Velocity vs. Time'),ylabel('Velocity (m/s)'),xlabel('Time (s)')
subplot(1,2,2) %Height Profile
plot(0:.01:(length(height)-1)/100,height,'-k')
axis([0 5 0 max(height)+10])
title('Height vs. Time'),ylabel('Height (m)'),xlabel('Time (s)')
set(figure(2),'color','white')
suptitle('Flight Profile')
```





Published with MATLAB® 7.10

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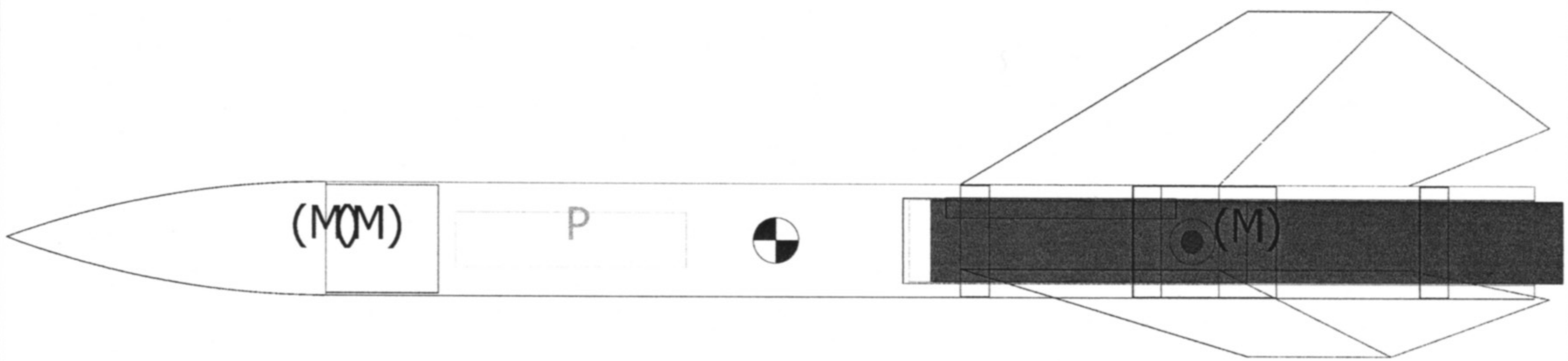
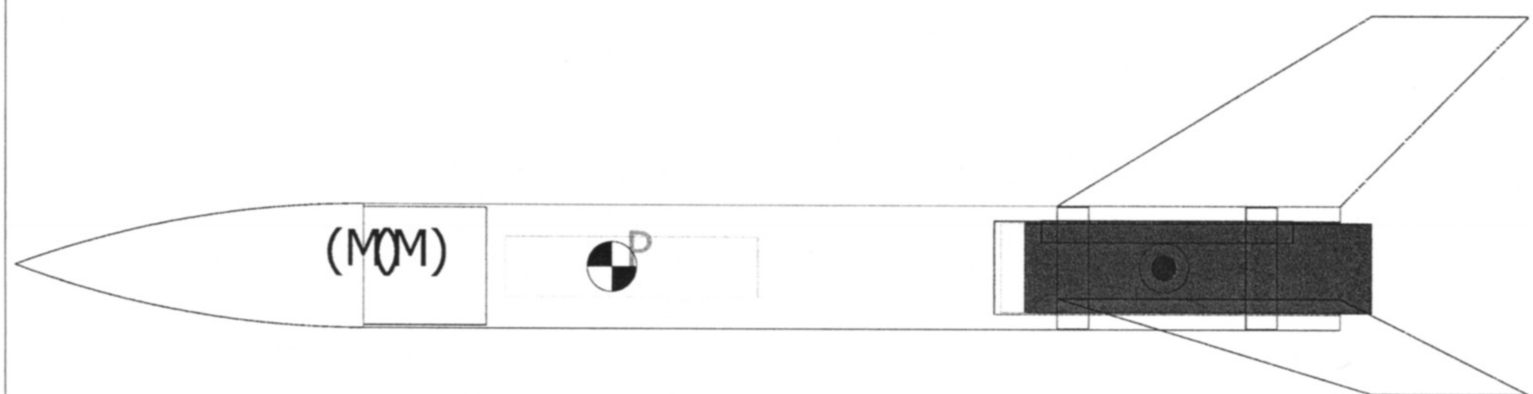
EA201–5001
21 April 2010

Rocket Project: RockSim Model, Predictions, and Parts List

Modified Estes Alpha (Newman/Nordlund)
Length: 13.3800 In. , Diameter: 0.9760 In. , Span diameter: 3.9760 In.
Mass 145.039 g , Selected stage mass 145.039 g
CG: 6.6503 In., CP: 10.2711 In., Margin: 3.71 Overstable
Engines: [A8-3,][B6-0,]



Modified Estes Alpha (Newman/Nordlund)
Length: 13.3800 In. , Diameter: 0.9760 In. , Span diameter: 3.9760 In.
Mass 145.039 g , Selected stage mass 104.016 g
CG: 4.7202 In., CP: 9.0992 In., Margin: 4.49 Overstable
Engines: [A8-3,]



Modified Estes Alpha (Newman/Nordlund) - Simulation summary

Sim.	Res.	Eng.	Alt. Ft.	Vel. ft/s	Acc. Ft./s/s	Time App.	Vel. deploy ft/s	Alt. deploy Ft.	CSimulation index
0		[B6-0] [A8-3]	303.54	119.49	272.43	4.95	18.17	301.28	0
1		[B6-0] [A8-3]	303.76	119.49	272.41	4.95	17.92	301.47	1
2		[B6-0] [A8-3]	305.11	119.50	272.29	4.96	16.31	302.65	2
3		[B6-0] [A8-3]	304.30	119.50	272.36	4.96	17.29	301.94	3
4		[B6-0] [A8-3]	303.92	119.49	272.40	4.95	17.74	301.61	4
5		[B6-0] [A8-3]	306.36	119.51	272.17	4.98	14.69	303.72	5
6		[B6-0] [A8-3]	306.40	119.51	272.17	4.98	14.65	303.75	6
7		[B6-0] [A8-3]	306.34	119.51	272.17	4.98	14.72	303.70	7
8		[B6-0] [A8-3]	305.99	119.51	272.21	4.98	15.18	303.41	8

Sustainer parts

Nose cone - Custom, Material: Balsa

- Nose shape: Solid Ogive, Len: 2.7500 In., Dia: 0.9760 In. Body insert: OD: 0.9300 In., Len: 0.9760 In.
- CG: 2.3917 In. , Mass: 3.717 g Radius of gyration: 0.0344421 (m) , 3.44421 (cm) Moment of inertia: 4.40949e-06 (kgm^2) , 44.0949 (gcm^2) , RockSim XN: 1.2702 In. , CNa: 2

Payload Apogee - 19080 - WNC-13B, Material: Balsa

- CG: 0.0000 In. , Mass: 50.000 g Radius of gyration: 0 (m) , 0 (cm) Moment of inertia: 0 (kgm^2) , 0 (gcm^2)

Altimeter PerfectFlite - Alt15K/WD Rev2 - Altimeter, Material: God

- CG: 0.0000 In. , Mass: 15.700 g Radius of gyration: 0 (m) , 0 (cm) Moment of inertia: 0 (kgm^2) , 0 (gcm^2)

Body tube Estes - EST 3086 - BT-50, Material: Paper

- OD: 0.9760 In. , ID: 0.9500 In. , Len: 7.7500 In.
- CG: 3.8750 In. , Mass: 6.001 g Radius of gyration: 0.0575448 (m) , 5.75448 (cm) Moment of inertia: 1.98708e-05 (kgm^2) , 198.708 (gcm^2) , RockSim XN: 0.0000 In. , CNa: 0

Motor Mount Estes - EST 3085 - BT-20, Material: Paper

- OD: 0.7360 In. , ID: 0.7100 In. , Len: 2.7500 In. Location: 0.0000 In. From the base of Body tube
- CG: 1.3750 In. , Mass: 1.599 g Radius of gyration: 0.0212077 (m) , 2.12077 (cm) Moment of inertia: 7.19004e-07 (kgm^2) , 7.19004 (gcm^2) , RockSim XN: 0.0000 In. , CNa: 0

Engine Block Estes - 30162-2 - Eng. block BT-20, Material: Paper

- Engine blockOD: 0.7100 In., Hole #1: : 16.5354 In. Len: 0.1970 In. Location: 2.5000 In. From the base of Motor Mount
- CG: 0.0985 In. , Mass: 0.245 g Radius of gyration: 0.00629212 (m) , 0.629212 (cm) Moment of inertia: 9.6837e-09 (kgm^2) , 0.096837 (gcm^2)

Centering ring Estes - 30125 - CR-20-55, Material: Paper

- Centering ringOD: 0.9600 In., ID: 0.7362 In., Len: 0.2500 In. Location: 0.5000 In. From the front of Motor Mount
- CG: 0.1250 In. , Mass: 3.325 g Radius of gyration: 0.00790673 (m) , 0.790673 (cm) Moment of inertia: 2.07867e-07 (kgm^2) , 2.07867 (gcm^2)

Centering ring Estes - 30125 - CR-20-55, Material: Paper

- Centering ringOD: 0.9600 In., ID: 0.7362 In., Len: 0.2500 In. Location: 0.5000 In. From the base of Motor Mount
- CG: 0.1250 In. , Mass: 3.325 g Radius of gyration: 0.00790673 (m) , 0.790673 (cm) Moment of inertia: 2.07867e-07 (kgm^2) , 2.07867 (gcm^2)

Parachute Estes - 12 in - 12 in. plastic, Material: Polyethylene LDPE

- 1 parachute, Shape: 6 sided Dia: 12.0000 In., Spill hole: 0.0000 In.
- CG: 0.0000 In. , Mass: 2.041 g Radius of gyration: 0.0154558 (m) , 1.54558 (cm) Moment of inertia: 4.87555e-07 (kgm^2) , 4.87555 (gcm^2)

Launch lug Estes - "1/8""" - , Material: Paper

- OD: 0.1720 In., ID: 0.1560 In., Len: 2.0000 In., Loc: 0.3750 In.
- CG: 1.0000 In. , Mass: 0.162 g Radius of gyration: 0.0147552 (m) , 1.47552 (cm) Moment of inertia: 3.53335e-08 (kgm^2) , 0.353335 (gcm^2)

Fin set - Custom, Material: Balsa

- CG: 2.0298 In. , Mass: 1.551 g Radius of gyration: 0.0252479 (m) , 2.52479 (cm) Moment of inertia: 9.8882e-07 (kgm^2) , 9.8882 (gcm^2) , RockSim XN: 9.9263 In. , CNa: 18.9332

Booster parts

Body tube Estes - EST 3086 - BT-50, Material: Paper

- OD: 0.9760 In. , ID: 0.9500 In. , Len: 2.7500 In.
- CG: 1.3750 In. , Mass: 1.987 g Radius of gyration: 0.0219652 (m) , 2.19652 (cm) Moment of inertia: 9.58831e-07 (kgm^2) , 9.58831 (gcm^2) , RockSim XN: 0.0000 In. , CNa: 0

Motor Mount Estes - EST 3085 - BT-20, Material: Paper

- OD: 0.7360 In. , ID: 0.7100 In. , Len: 2.7500 In. Location: 0.0000 In. From the front of Body tube
- CG: 1.3750 In. , Mass: 1.492 g Radius of gyration: 0.0212077 (m) , 2.12077 (cm) Moment of inertia: 6.71072e-07 (kgm^2) , 6.71072 (gcm^2) , RockSim XN: 0.0000 In. , CNa: 0

Engine hook Estes - Engine hook - Standard size, Material:

- CG: 0.0000 In. , Mass: 1.400 g Radius of gyration: 0 (m) , 0 (cm) Moment of inertia: 0 (kgm^2) , 0 (gcm^2)

Centering ring Estes - 30125 - CR-20-55, Material: Paper

- Centering ringOD: 0.9600 In., ID: 0.7362 In., Len: 0.2500 In. Location: 0.7500 In. From the base of Motor Mount
- CG: 0.1250 In. , Mass: 3.325 g Radius of gyration: 0.00790673 (m) , 0.790673 (cm) Moment of inertia: 2.07867e-07 (kgm^2) , 2.07867 (gcm^2)

Tube Coupler Estes - 30125 - CR-20-55, Material: Paper

- Centering ringOD: 0.9600 In., ID: 0.7362 In., Len: 1.0000 In. Location: -0.5000 In. From the front of Motor Mount
- CG: 0.5000 In. , Mass: 13.300 g Radius of gyration: 0.0106317 (m) , 1.06317 (cm) Moment of inertia: 1.50334e-06 (kgm^2) , 15.0334 (gcm^2)

Fin set - Custom, Material: Balsa

- CG: 1.4694 In. , Mass: 1.299 g Radius of gyration: 0.0173447 (m) , 1.73447 (cm) Moment of inertia: 3.90662e-07 (kgm^2) , 3.90662 (gcm^2) , RockSim XN: 11.6108 In. , CNa: 18.3099

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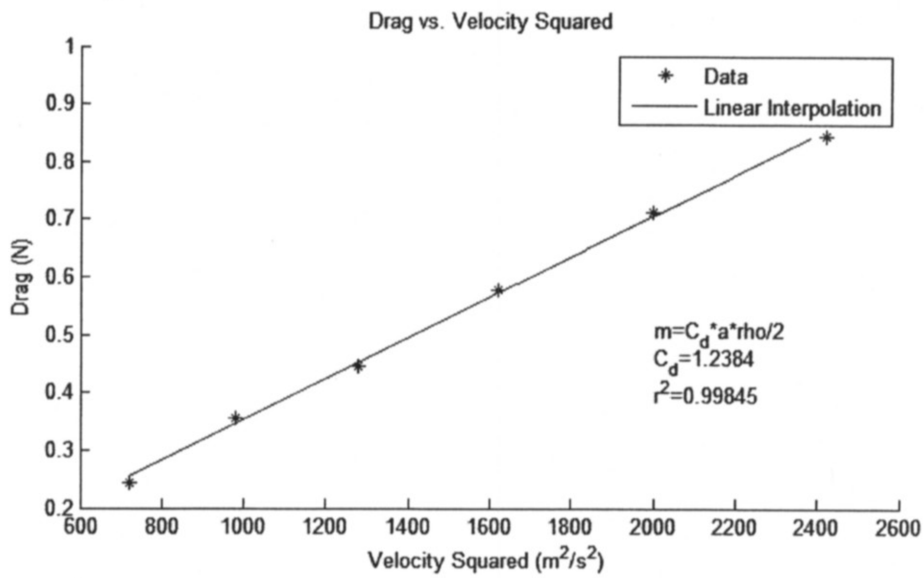
EA201–5001
21 April 2010

Rocket Wind Tunnel Lab Data Reduction

a. Calculated air density: **1.1804 kg/m^3**
b. Rocket's cross-sectional area: **4.827×10^{-4} m^2**
c. [see MATLAB script]
d. Calculated drag coefficient: **1.2384**



e. Calculated r^2 value: **0.99845**
f. [see MATLAB script]

Notes: The obviously incorrect value calculated for the drag coefficient demands a reassessment of the Rocket's actual cross-sectional area. With a cross-sectional area of **7.45×10^{-4} m^2**, the rocket yields a drag coefficient equal to **0.80237**—a much more realistic result.

Excellent! but how did you come up with this?

EA204 Drag Lab

Contents

Nordlund and Newman 21 March 2010

This script seeks to determine drag coefficient from collected drag data.

```
format short, clear all; clc
```

Lab Data

```
v=[60,70,80,90,100,110]; %Wind Tunnel Velocity (mph)
v=v.*5280/3600*12*2.54/100; %(m/s)
drag(1,:)=[.05,.08,.1,.13,.16,.19]; %Axial force while streamlined (lb)
drag(2,:)=[.06,.08,.10,.13,.16,.19]; %Axial force w/ misaligned fins (lb)
```

Data Reduction

Air Density Calculations (rho)

```
P_ambient=29.8; %inHg
P_ambient=P_ambient/29.92*1.0132e5; %Pa
T_ambient=536.8; %R
T_ambient=T_ambient*288/519; %K
R_air=287; %J/(Kg*K)
rho=(P_ambient)/(R_air*T_ambient); %kg/m^3
disp(cat(2,'Air Density: ',num2str(rho),' kg/m^3'))
```

```
Air Density: 1.1804 kg/m^3
```

Drag Calculations

Cross-sectional area d=.976" or 2.48cm

```
r=.0123952; %radius (m)
a=pi*r^2; %cross-sectional area (m^2)
disp(cat(2,'Cross-sectional area: ',num2str(a),' m^2'))
% Calculate r2
drag=mean(drag,1).*4.448; %average drag (to account for slop) (N)
coeff=polyfit(v.^2,drag,1); %coefficients of polynomial
J=sum((polyval(coeff,v.^2)-drag).^2);
mu=mean(drag);
S=sum((drag-mu).^2);
r2=1-J/S;
disp(cat(2,'r^2 value (for D vs. V^2 curve fit): ',num2str(r2)))
% Calculate Drag Coefficient
C_d=coeff(1)/(a*rho/2);
disp(cat(2,'Coefficient of drag: ',num2str(C_d), ...
    ' (this clearly denotes troubled data)'))
```

```
Cross-sectional area: 0.00048268 m^2
r^2 value (for D vs. V^2 curve fit): 0.99845
Coefficient of drag: 1.2384 (this clearly denotes troubled data)
```

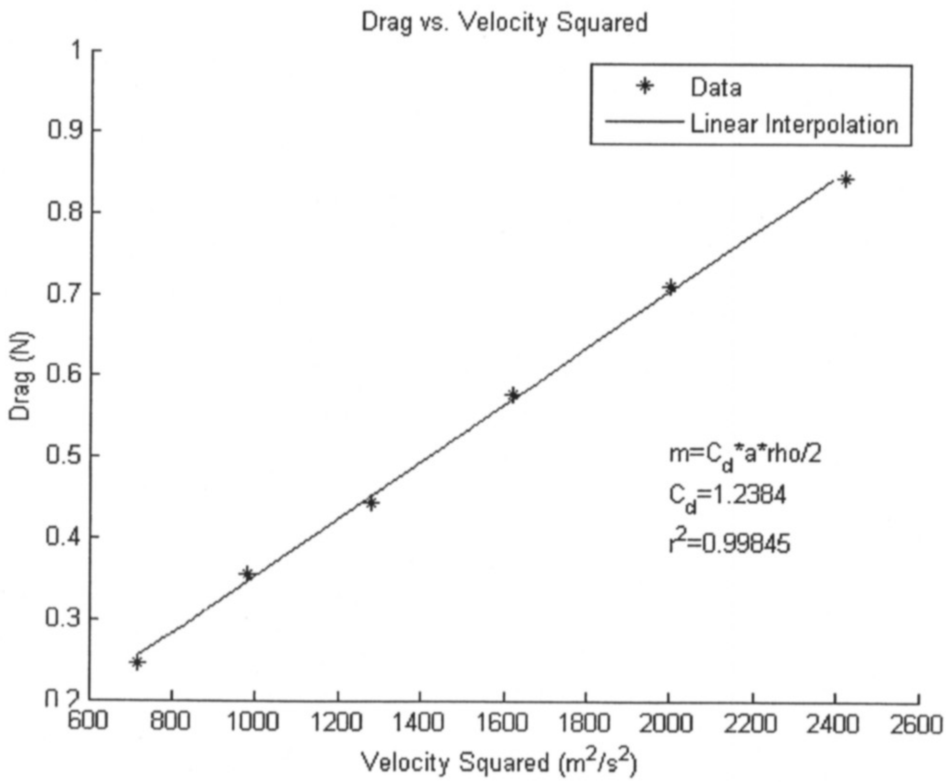
Assume effective area nearer 7.45e-4 m^2

```
a_better=7.45e-4; %more likely cross-sectional area (m^2)
C_d_better=coeff(1)/(a_better*rho/2);
disp(cat(2,'Likely coefficient of drag: ',num2str(C_d_better),...
    ' (assumes a=',num2str(a_better),' m^2 with fins)'))
```

```
Likely coefficient of drag: 0.80237 (assumes a=0.000745 m^2 with fins)
```

Plot (for drag coefficient)

```
figure(1)
hold on
plot(v.^2,drag,'*k',(min(v):max(v)).^2,polyval(coeff,(min(v):max(v)).^2,'-k'))
title('Drag vs. Velocity Squared')
ylabel('Drag (N)')
xlabel('Velocity Squared (m^2/s^2)')
legend('Data','Linear Interpolation',1)
text(2000,.50,'m=C_d*a*rho/2')
text(2000,.45,cat(2,'C_d=',num2str(C_d)))
text(2000,.40,cat(2,'r^2=',num2str(r2)))
set(figure(1),'color','white')
```



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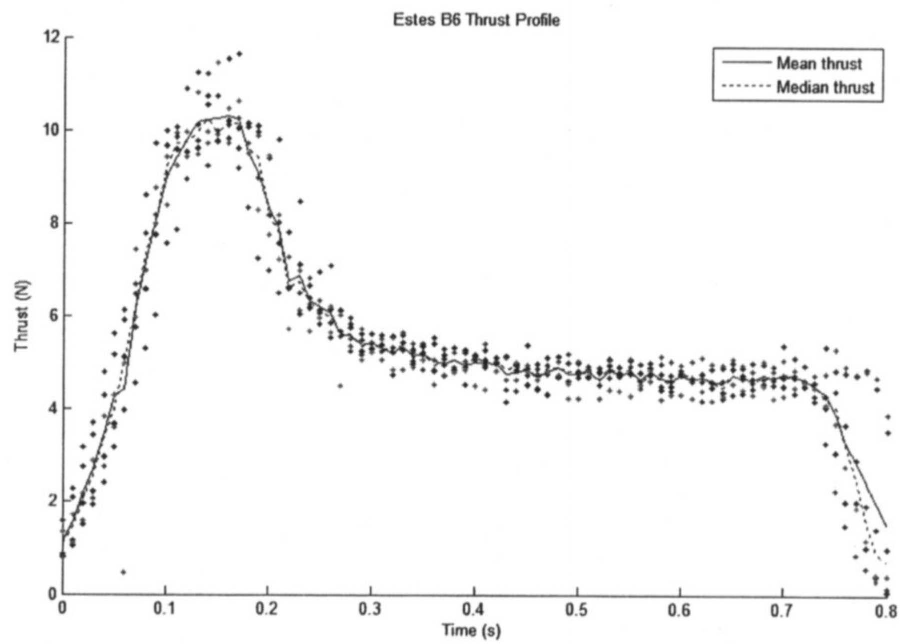
Rocket Thrust Lab Data Reduction

a. Calculated air density: **1.1804 kg/m³**
b. Thrust data taken every 0.01s for the published duration of burn. [see MATLAB script]
c. Integration done in MATLAB. [see MATLAB script]

Estes B6 Results:

- Average total impulse: **4.3665 Ns**
- Average specific impulse: **71.3318 s**
- Average thrust: **5.4582 N**
- Average maximum thrust: **10.8837 N**
- Average standard deviation: **0.5635 N**

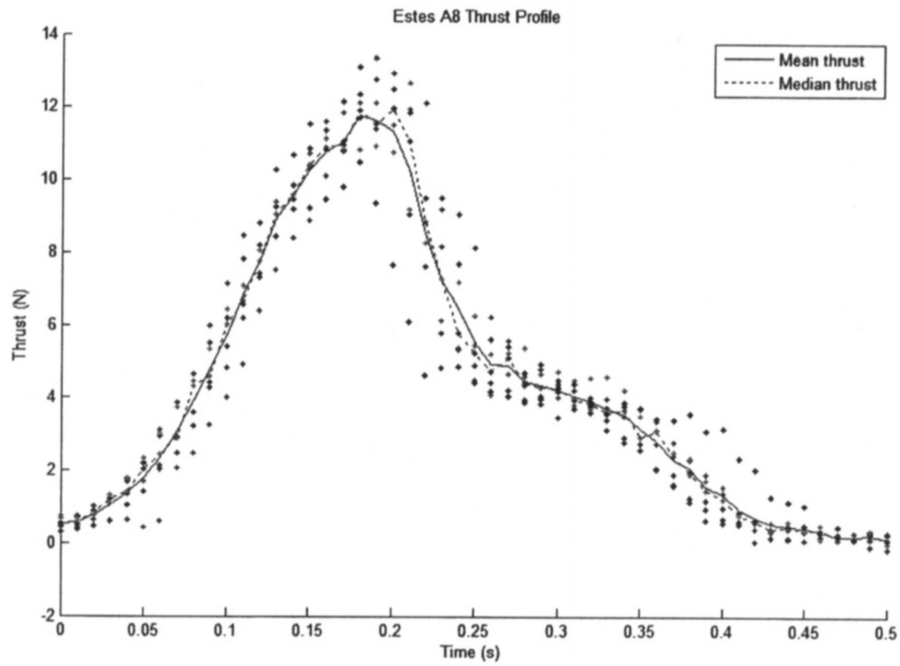


Estes B6 Error Analysis

	Published Value	*Measured Value*	*% Error*
Maximum Thrust (N)	12.10	10.88	-10.05
Average Thrust (N)	6.25	5.46	-12.67
Impulse (Ns)	5.00	4.37	-12.67

Estes A8 Results:

- Average total impulse: **2.1898 Ns**
- Average specific impulse: **35.7734 s**
- Average thrust: **4.3797 N**
- Average maximum thrust: **12.0857 N**
- Average standard deviation: **0.72021 N**



Estes A8 Error Analysis

	Published Value	*Measured Value*	*% Error*
Maximum Thrust (N)	11.80	12.09	2.42
Average Thrust (N)	5.00	4.38	-12.41
Impulse (Ns)	2.50	2.19	-12.41

Conclusion: With motors in the A and B range, even the smallest standard deviation will result in significant variability in motor performance. Adding margin between the performance requirements and predicted performance is the best way to mitigate the demonstrated effects of motor inaccuracy. Yes

Notes: Propellant mass comparison is impossible due to unmeasured ejection charge mass. Published values were used instead. – Excellent

EA204 Thrust Lab

Contents

Nordlund and Newman 21 March 2010

This script seeks to aggregate data from test cell experiments and publish averaged results.
This script will also display error analysis results to compare published and measured values.

```
format short, clear all; clc
```

Thrust Data

Note: Worthless data in 1001b6-4a, 2001a8-3a, 2001a8-3b and data from 5001b6-4a (C465:C545) appears to be from a different size engine. Estes B6

```
T_B6(:,1)=xlsread('thrustdata','2001b6-4a','C225:C305');
T_B6(:,2)=xlsread('thrustdata','3001b6-6a','C685:C765');
T_B6(:,3)=xlsread('thrustdata','3001b6-6b','C315:C395');
T_B6(:,4)=xlsread('thrustdata','5001b6-6a','C553:C633');
T_B6(:,5)=xlsread('thrustdata','6001b6-4a','C605:C685');
T_B6(:,6)=xlsread('thrustdata','6001b6-4b','C463:C543');
% Estes A8
T_A8(:,1)=xlsread('thrustdata','1001a8-3a','C305:C355');
T_A8(:,2)=xlsread('thrustdata','2001b6-4b','C1215:C1265');
T_A8(:,3)=xlsread('thrustdata','3001a8-3a','C260:C310');
T_A8(:,4)=xlsread('thrustdata','5001a8-3a','C550:C600');
T_A8(:,5)=xlsread('thrustdata','5001a8-3b','C470:C520');
T_A8(:,6)=xlsread('thrustdata','6001a8-3a','C510:C560');
T_A8(:,7)=xlsread('thrustdata','6001a8-3b','C475:C525');
```

Preliminary Calculations

```
P_ambient=29.8; %inHg
P_ambient=P_ambient/29.92*1.0132e5; %Pa
T_ambient=536.8; %R
T_ambient=T_ambient*288/519; %K
R_air=287; %J/(Kg*K)
rho=(P_ambient)/(R_air*T_ambient); %kg/m^3
disp(cat(2,'Air Density: ',num2str(rho),' kg/m^3'))
```

```
Air Density: 1.1804 kg/m^3
```

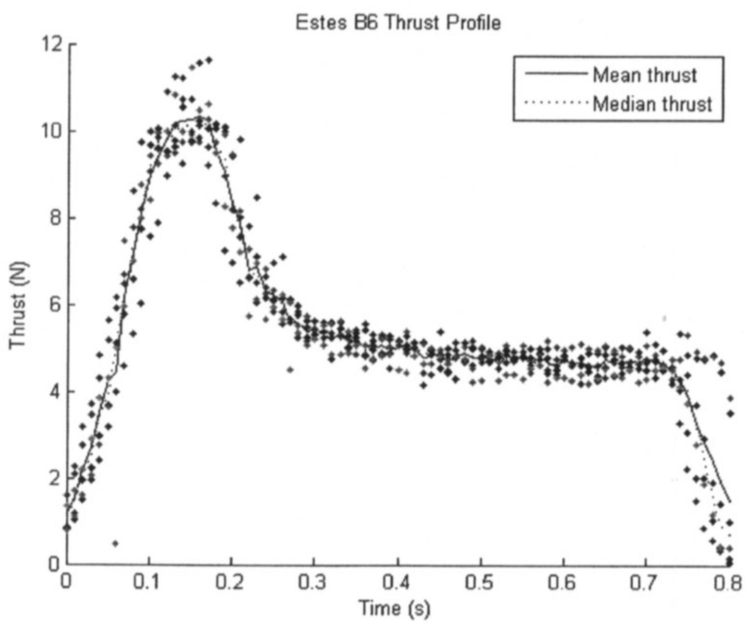
Estes B6 Data Reduction

Reference: 5.0 Ns impulse, .8 s burn time, 6.24 g propellant

```
disp('B6 Results:')
I_B6=trapz(T_B6,1)/100; %Ns
I_B6=mean(I_B6,2); %Average total impulse
disp(cat(2,'   Average total impulse: ',num2str(I_B6),' Ns'))
Isp_B6=I_B6/(.00624*9.81); %Average specific impulse
disp(cat(2,'   Average specific impulse: ',num2str(Isp_B6),' s'))
T_B6_average=I_B6/.8; %Impulse divided by burn time
disp(cat(2,'   Average thrust: ',num2str(T_B6_average),' N'))
T_B6_max=mean(max(T_B6,[],1),2); %Average maximum thrust
disp(cat(2,'   Average maximum thrust: ',num2str(T_B6_max),' N'))
T_B6_std=mean(std(T_B6,0,2));
disp(cat(2,'   Average standard deviation: ',num2str(T_B6_std),' N'))
% Error Array
% Note: propellant mass comparison impossible due to unmeasured ejection
% charge mass.
Error={'Category','Published Value','Measured Value','% Error'};
```

```
Error(2:4,1)={'T max. (N)';'T ave. (N)';'Impulse (Ns)'};
Error(2:4,2)={12.1;6.25;5.0};
Error(2:4,3)={T_B6_max;T_B6_average;I_B6};
percent=100*(([T_B6_max;T_B6_average;I_B6]-[12.1;6.25;5.0])./[12.1;6.25;5.0]);
Error(2:4,4)={percent(1);percent(2);percent(3)};
disp('B6 Error Analysis')
disp(Error)
% Thrust Plot
figure(1)
hold on
plot(0:.01:.8,mean(T_B6,2),'-k',0:.01:.8,median(T_B6,2),':k')
legend('Mean thrust','Median thrust')
plot(0:.01:.8,T_B6,'.')
title('Estes B6 Thrust Profile'),xlabel('Time (s)'),ylabel('Thrust (N)')
set(figure(1),'color','white')
```

```
B6 Results:
   Average total impulse: 4.3665 Ns
   Average specific impulse: 71.3318 s
   Average thrust: 5.4582 N
   Average maximum thrust: 10.8837 N
   Average standard deviation: 0.5635 N
B6 Error Analysis
    'Category'          'Published Value'    'Measured Value'     '% Error'
    'T max. (N)'        [        12.1000]    [       10.8837]     [-10.0522]
    'T ave. (N)'        [         6.2500]    [        5.4582]     [-12.6694]
    'Impulse (Ns)'      [              5]    [        4.3665]     [-12.6694]
```



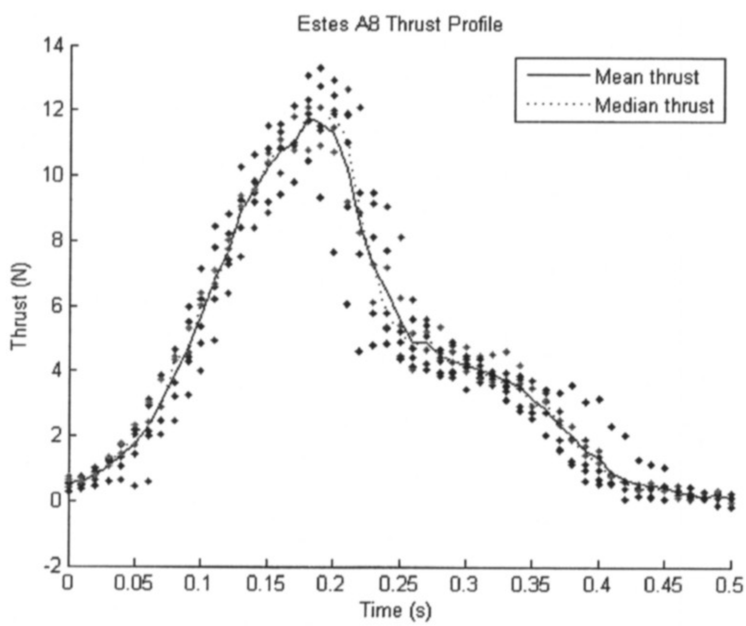
Estes A8 Data Reduction

Reference: 2.5 Ns impulse, .5 s burn time, 3.12 g propellant

```
disp('A8 Results:')
I_A8=trapz(T_A8,1)/100; %Ns
I_A8=mean(I_A8,2); %Average total impulse
disp(cat(2,'   Average total impulse: ',num2str(I_A8),' Ns'))
Isp_A8=I_A8/(.00624*9.81); %Average specific impulse
disp(cat(2,'   Average specific impulse: ',num2str(Isp_A8),' s'))
T_A8_average=I_A8/.5; %Impulse divided by burn time
disp(cat(2,'   Average thrust: ',num2str(T_A8_average),' N'))
T_A8_max=mean(max(T_A8,[],1),2); %Average maximum thrust
disp(cat(2,'   Average maximum thrust: ',num2str(T_A8_max),' N'))
T_A8_std=mean(std(T_A8,0,2));
disp(cat(2,'   Average standard deviation: ',num2str(T_A8_std),' N'))
% Error Array
% Note: propellant mass comparison impossible due to unmeasured ejection
% charge mass.
```

```
Error={'Category','Published Value','Measured Value','% Error'};
Error(2:4,1)={'T max. (N)';'T ave. (N)';'Impulse (Ns)'};
Error(2:4,2)={11.8;5.0;2.5};
Error(2:4,3)={T_A8_max;T_A8_average;I_A8};
percent=100*(([T_A8_max;T_A8_average;I_A8]-[11.8;5.0;2.5])./[11.8;5.0;2.5]);
Error(2:4,4)={percent(1);percent(2);percent(3)};
disp('A8 Error Analysis')
disp(Error)
% Thrust Plot
figure(2)
hold on
plot(0:.01:.5,mean(T_A8,2),'-k',0:.01:.5,median(T_A8,2),':k')
legend('Mean thrust','Median thrust')
plot(0:.01:.5,T_A8,'.')
set(figure(2),'color','white')
title('Estes A8 Thrust Profile'),xlabel('Time (s)'),ylabel('Thrust (N)')
```

```
A8 Results:
   Average total impulse: 2.1898 Ns
   Average specific impulse: 35.7734 s
   Average thrust: 4.3797 N
   Average maximum thrust: 12.0857 N
   Average standard deviation: 0.72021 N
A8 Error Analysis
    'Category'          'Published Value'    'Measured Value'    '% Error'
    'T max. (N)'        [        11.8000]    [       12.0857]    [  2.4216]
    'T ave. (N)'        [              5]    [        4.3797]    [-12.4060]
    'Impulse (Ns)'      [         2.5000]    [        2.1898]    [-12.4060]
```



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