Practical APCP motor design for Amateur & High Power rocketry

What we will be covering:

- The basics & definitions
- Some other considerations
- The process to get the data to input into the BurnSim program
- Designing motor profiles in BurnSim

What we won't be covering:

$$\rho_p = \frac{1}{\frac{f_a}{\rho_a} + \frac{f_b}{\rho_b} + \frac{f_c}{\rho_c} + \ldots}$$

$$V_1 = \frac{V_p}{V_a} = \frac{I_t}{I_{sp}\,\rho_p\,V_a}$$

$$\rho_p = \frac{m_{grain}}{\mathcal{V}_{grain}}$$

$$\mathcal{V}_{grain} = \frac{\pi}{4}\left(D^2 - d^2\right)L$$

For a hollow cylindrical grain, where D =outer diameter
d =inner (core) diameter
L = Length of grain

$$\rho_p = \frac{1}{\frac{f_o}{\rho_o} + \frac{f_f}{\rho_f}}$$

$$W_f = \frac{D - d}{D} = \frac{2\,r\,t_b}{D}$$

$$\frac{A_p}{A_t} = \frac{\pi\,D^2\left(1 - V_1\right)}{4\,A_t}$$

$C_{12}H_{22}O_{11}$ + 6.29 KNO_3 -> 3.80 CO_2 + 5.21 CO + 7.79 H_2O + 3.07 H_2 + 3.14 N_2 + 3.00 K_2CO_3 + 0.27 KOH

$2\,H_2 + O_2 \leftrightarrow 2\,H_2O$

$$\nu_A A + \nu_B B \Leftrightarrow \nu_C C + \nu_D D$$

$$K_p = \frac{y_C^{\nu_C}\,y_D^{\nu_D}}{y_A^{\nu_A}\,y_B^{\nu_B}}\left(\frac{P}{P_o}\right)^{\nu_C+\nu_D-\nu_A-\nu_B}$$

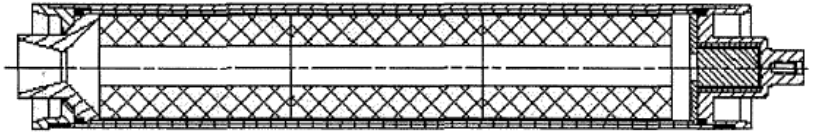
$$\sum_R n_i\left[h_f + \Delta h\right]_i = \sum_P n_e\left[h_f + \Delta h\right]_e$$

$H_2O \leftrightarrow HO + 1/2\,H_2$

$O_2 \leftrightarrow 2\,O$

$H_2 \leftrightarrow 2\,H$

Basic concepts



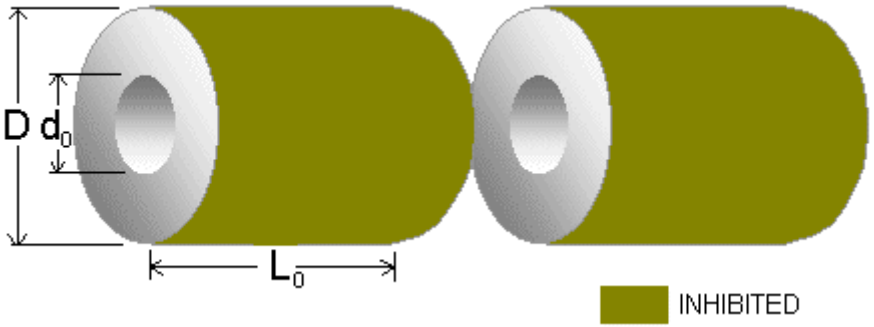
A solid rocket motor usually consists of a casing, nozzle, forward closure, a liner and a fuel grain.

Aluminum Motor case

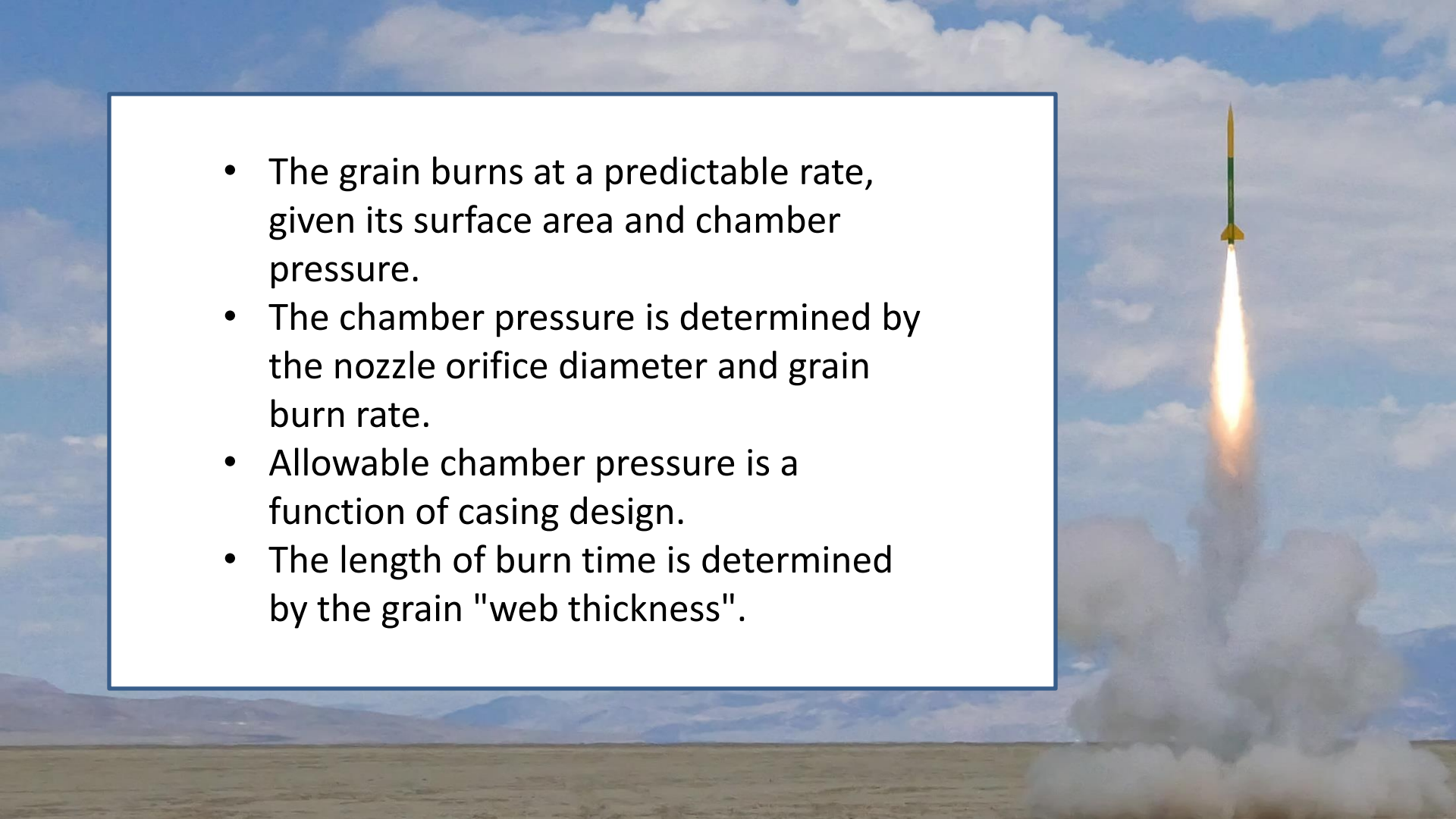
- Aluminum strength rapidly decreases with increased temperature
- Liner material / heat protection
- Case bonding can be used for thermal protection
- The forward closure is a component of the case.

Propellant

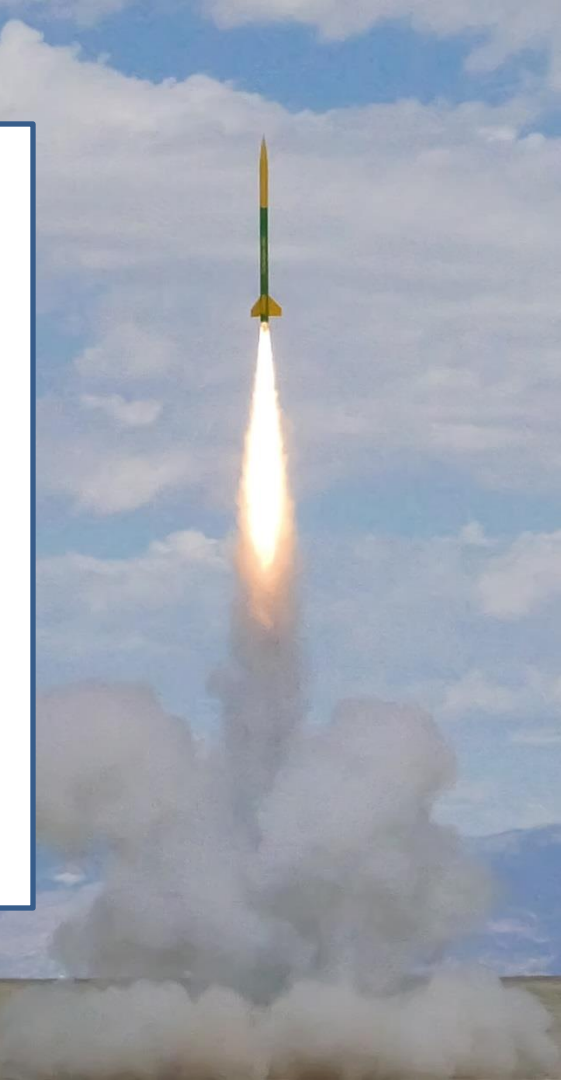
The grain behaves like a solid mass, burning in a predictable fashion and producing exhaust gases. The nozzle dimensions are calculated to maintain a design chamber pressure, while producing thrust from the exhaust gases.



- The grain burns at a predictable rate, given its surface area and chamber pressure.
- The chamber pressure is determined by the nozzle orifice diameter and grain burn rate.
- Allowable chamber pressure is a function of casing design.
- The length of burn time is determined by the grain "web thickness".

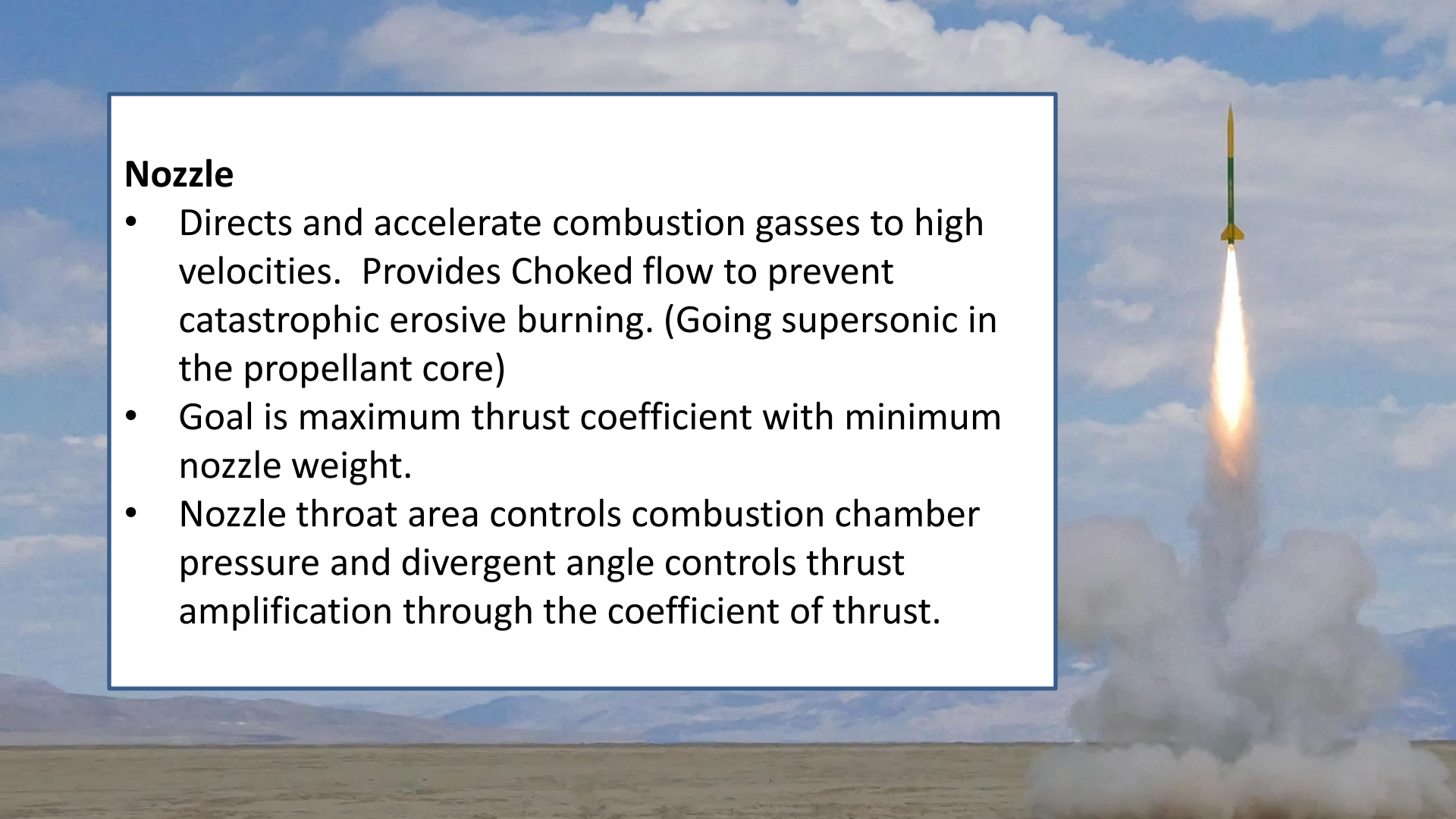


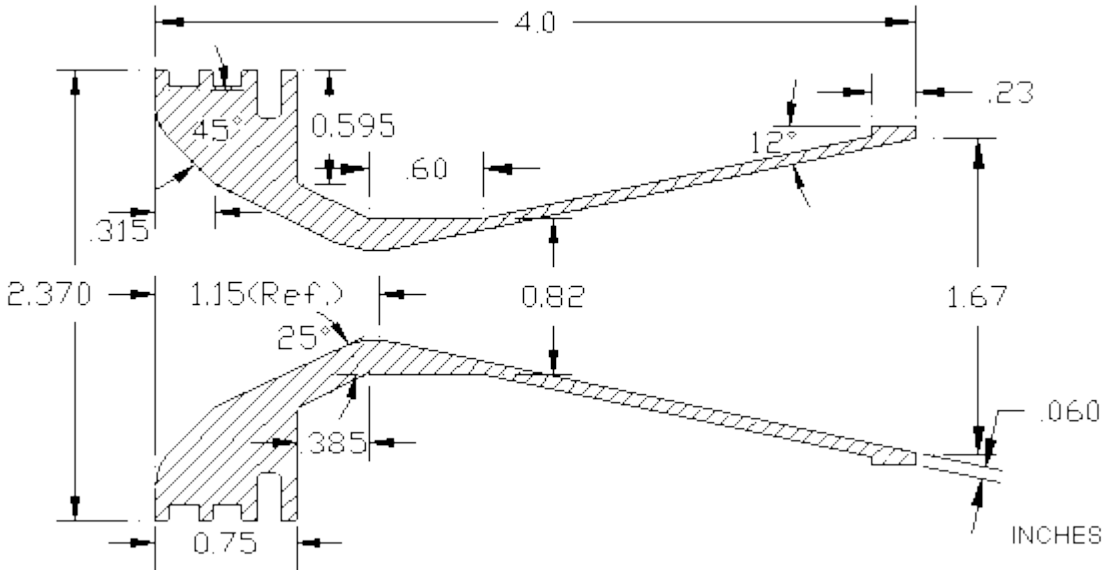
Common modes of failure in solid rocket motors include fracture of the grain, failure of bonding to the casting tube or case bonding, and air pockets in the grain. All of these produce an instantaneous increase in burn surface area and a corresponding increase in exhaust gas production rate and pressure, which may rupture the casing.



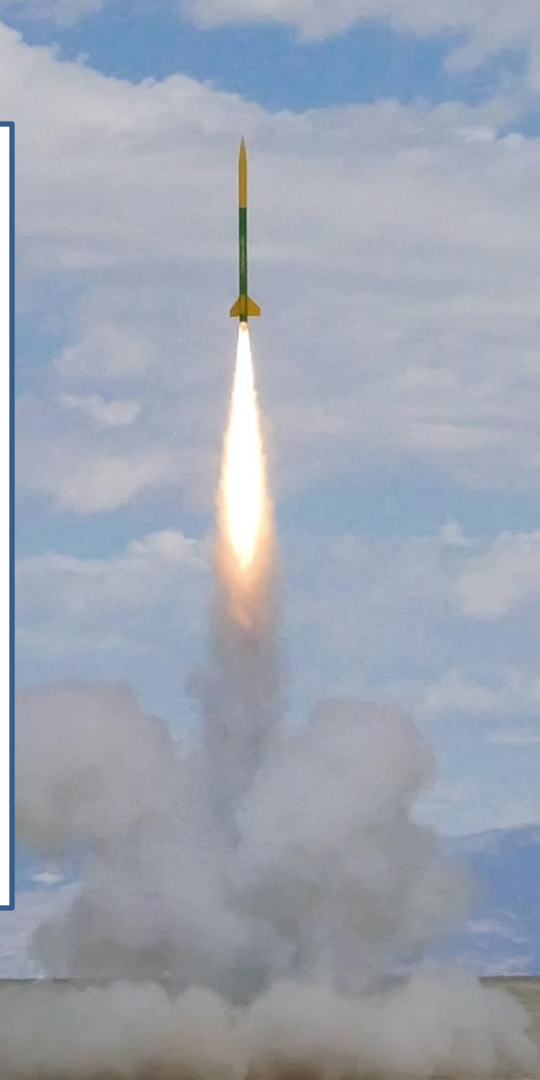
Nozzle

- Directs and accelerate combustion gasses to high velocities. Provides Choked flow to prevent catastrophic erosive burning. (Going supersonic in the propellant core)
- Goal is maximum thrust coefficient with minimum nozzle weight.
- Nozzle throat area controls combustion chamber pressure and divergent angle controls thrust amplification through the coefficient of thrust.

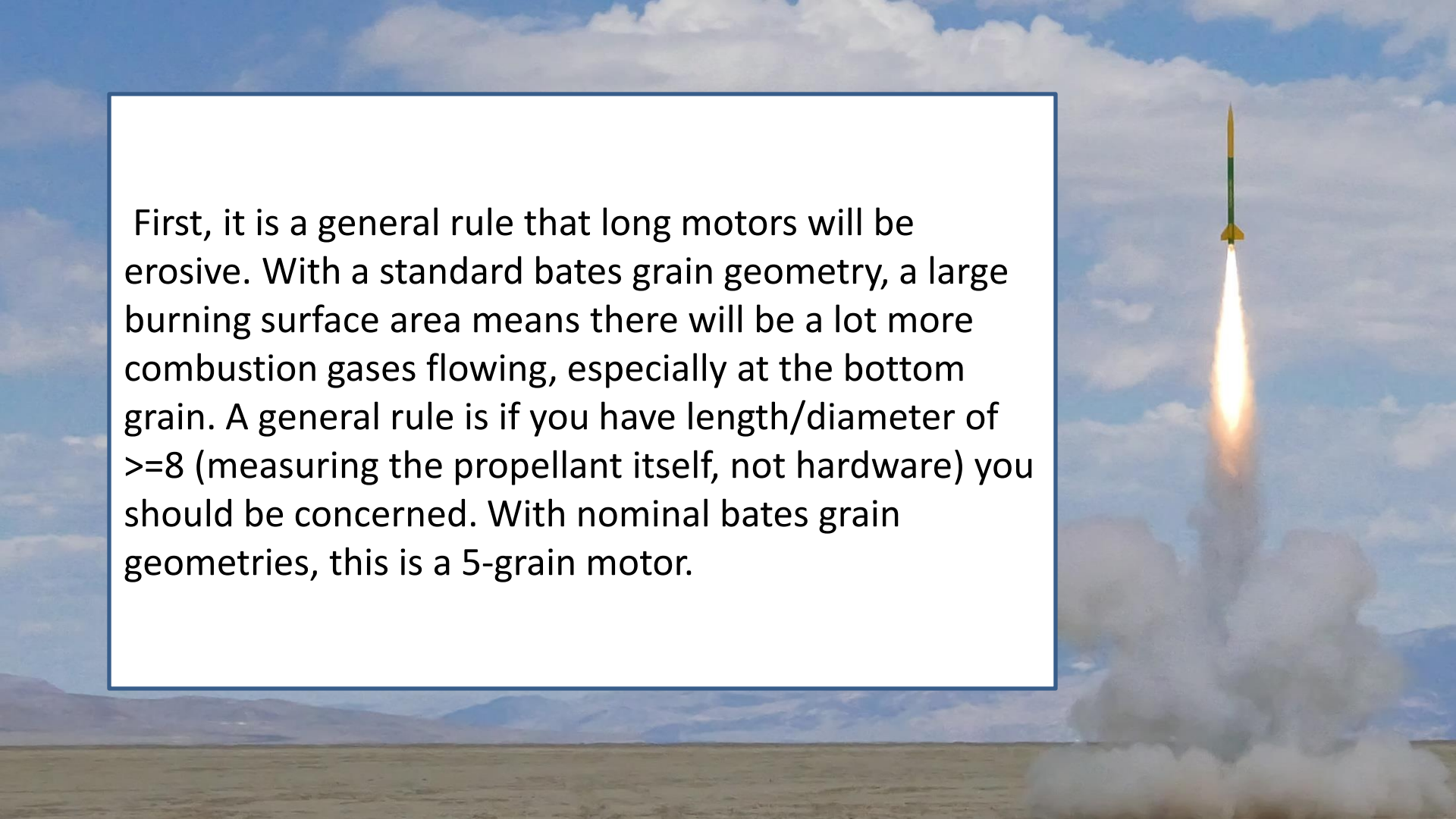



4.0
.23
45°
0.595
.60
12°
.315
2.370
1.15(Ref.)
0.82
1.67
25°
.060
.385
0.75
INCHES

Kn (burning-area to throat-area ratio)



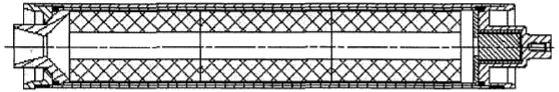
First, it is a general rule that long motors will be erosive. With a standard bates grain geometry, a large burning surface area means there will be a lot more combustion gases flowing, especially at the bottom grain. A general rule is if you have length/diameter of >=8 (measuring the propellant itself, not hardware) you should be concerned. With nominal bates grain geometries, this is a 5-grain motor.



Erosive Burning Motor Design Issues - 1

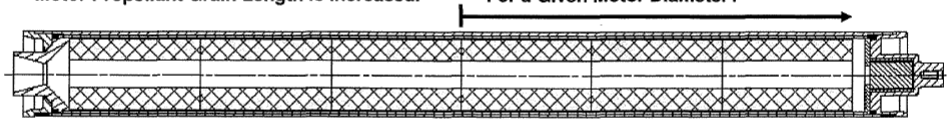
High Length-to-Diameter (L/D) Motors Increase Rocket Flight Performance.

Maximizes Total Impulse within a Given Frontal Area,
Minimizes Aerodynamic Drag in Minimum Diameter Rockets.



Keeping the Core Diameter the Same,
Motor Propellant Grain Length is Increased.

How Much Can Motor Length Be Increased
For a Given Motor Diameter?



For Velocity-Based Erosive Burning:

1) Increased Propellant Grain Length Increases Propellant Surface Area.
2) For Same K_n, Increased Propellant Surface Area Requires Increase in Throat Area (A_{th}).
3) Increased Throat Area Approaches Port Area (A_p, the Core Cross-Sectional Area). Port-to-Throat Area Ratio (A_p/A_{th}) Decreases, Core Mach Number Increases, Increased Velocity-Based Erosive Burning.

For Mass Flux-Based Erosive Burning:

1) Increased Propellant Grain Length Increases Propellant Surface Area.
2) Increased Propellant Surface Area Increases Mass Flow Rate Down Core.
3) With Same Core Diameter, Port Area (Core Cross-Sectional Area) Remains the Same. Increased Core Mass Flow Rate through Same Core Cross-Sectional Area Results in Increased Core Mass Flux, Increased Mass Flux-Based Erosive Burning.

Figure 1. Erosive Burning Motor Design Issues - 1.

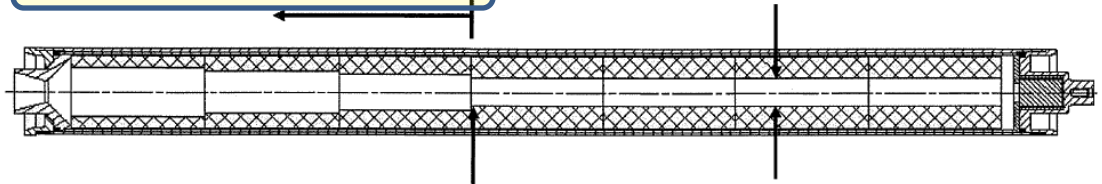
Constant Core Mass Flux Core Design

Core Mach Number and Core Mass Flux Design Point Conditions are at Motor Ignition

Core Mass Flux Values Based on <u>Non-Erosive</u> Propellant Burn Rate

Provides Maximum Motor Length, Minimum Motor Core Diameter, Maximum Propellant Loading for a Given Level (Design Point) of Erosive Burning

Core Diameter Increased Past This Point to Maintain Constant Core Mass Flux



Design Point Core Mass Flux Achieved

Design Point Core Mass Flux (Recommended Values)

Non-Erosive;	p_c = 400-600 psia	Core Mass Flux ≤ 1.0 lb/sec-in^2
	p_c = 800 psia	Core Mass Flux ≤ 1.75 lb/sec-in^2
	p_c = 1400 psia	Core Mass Flux ≤ 2.0 lb/sec-in^2
Max Erosive;	p_c = 400 psia	Core Mass Flux = 2.0 lb/sec-in^2
	p_c = 600 psia	Core Mass Flux = 2.5 lb/sec-in^2
	$p_c \geq$ 800 psia	Core Mass Flux = 3.0 lb/sec-in^2

Initial Core Diameter Based On Design Point Core Mach Number

Non-Erosive; $M_a = 0.50$
$\gamma = 1.2$; $A_p/A_{th} = 1.36$

Max Erosive; $M_a = 0.70$
$\gamma = 1.2$; $A_p/A_{th} = 1.10$

Figure 9. Constant Core Mass Flux Core Design.

My motor design process from the start to finish

Using PROPEL20 spreadsheet workbook, ProPep3, and BurnSim

Select Propellant formula for characteristics desired

- Simple formula to start
- Colored flame
- Smoke or no smoke
- Fast burn / High thrust / High performance
- Slow burn / Long burning / Long length to diameter motors
- Packable or pourable

Select the motor size (Impulse, motor case to be used, etc.)

- Test motor grain size x multiple burns for mix batch amount

Click to add header

Propellant designation	Orange Sunset II		Date
Propellant density	0.05565	lb/in^3	Bowl Weight

GRAINS TO BE CAST

	Grain #1	Grain #2	Grain #3
Diameter	1.14	1.775	3.25
Length	11	9	11
Core (mandrel) dia.	0.375	0.624	0.875
Number of grains	2	2	0
Expected waste, %	5		

Ingredient	NEEDED THIS BATCH	Actual Used:	Original batch: Weight	Percent
	0.00			0.0%
Ammonium perchlorate 200 um	1121.77		75.00	71.7%
	0.00			0.0%
Amonium Chloride	29.31		2.00	1.9%
Zinc	29.31		2.00	1.9%
Calcium Carbonate	83.74		6.00	5.7%
	0.00			0.0%
	0.00			0.0%
R45M HTPB	186.96		12.50	11.9%
Dioctyl adipate	74.78		5.00	4.8%
Castor Oil	0.00			0.0%
Silicone Oil (1 drop/500g)	0.00			0.0%
E744 (Add Last)	31.56		2.11	2.0%
	0.00			0.0%
	0.00			0.0%
Total wt.	1564.64		104.61	
Percent solids	81.25%			

PREPARATION STEPS		DATA AND COMMENTS
Mix liquids minus curative	5 min	Got rid of castor oil & upped DOA, much nicer propellant.
Add Metals	10 min/scrape 5 min	Theoretic Density .0597394 Chamber pressure 700 psi / 14.7
Vacuum process	15 min	C* 4222.455 Molecular wt. 23.42465
Add 1/3 200 um AP	5 min	CP/CV 1.246553
Add 1/3 200 um AP	5 min	a & n Values derived from 4 burns using regression
Add 1/3 200 um AP	30 min	on the ballistic page.
		(a) .011836 (n) .481303
Vacuum process		
Add curative		
Vacuum process		

	Kn		Burn time	
	Kn		Burn time	
	Kn		Burn time	

Actual Density:

Click to add footer

Click to add header

This is the propellant "name"

38mm	54mm	76mm	98mm	114mm
1.14	1.775	2.55	3.25	3.78
1.75	2.84	5.25	6.1875	7
0.375	0.625	0.875	1.250	1.375

Enter core size ONLY if a mandrel will be used
to form the core, otherwise, leave it "zero"
(If you are drilling the core, enter 'zero' for mandrel size)

If only solids are placed in the first eight rows
the "% solids" at the bottom will be correct

Print the spreadsheet when it's finished and punch it
to fit a notebook. You can then write in actual
amounts, data, comments, etc.
Total wt. of original batch need not add up to 100

This space is for writing your comments or
descriptions of working steps, temp, mixing, etc.

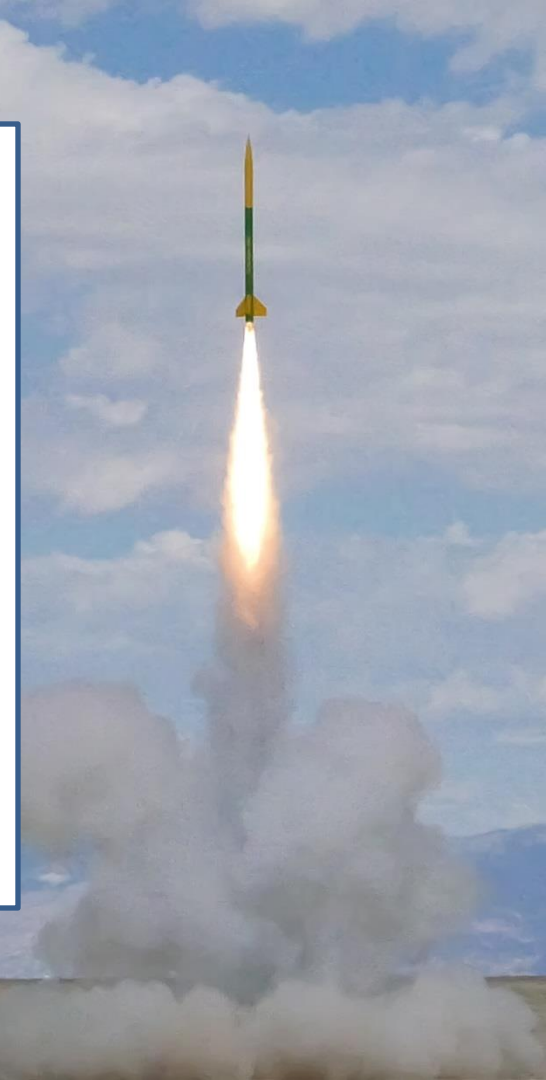
The 'Batch' sheet for mixing your propellant

Click to add footer

Kn | DENSITY | BALLISTIC | BATESBURN | Everclear | Everclear Modified | Pitch Black Sparky | Orange Sunset II+Papi | OSII + E744

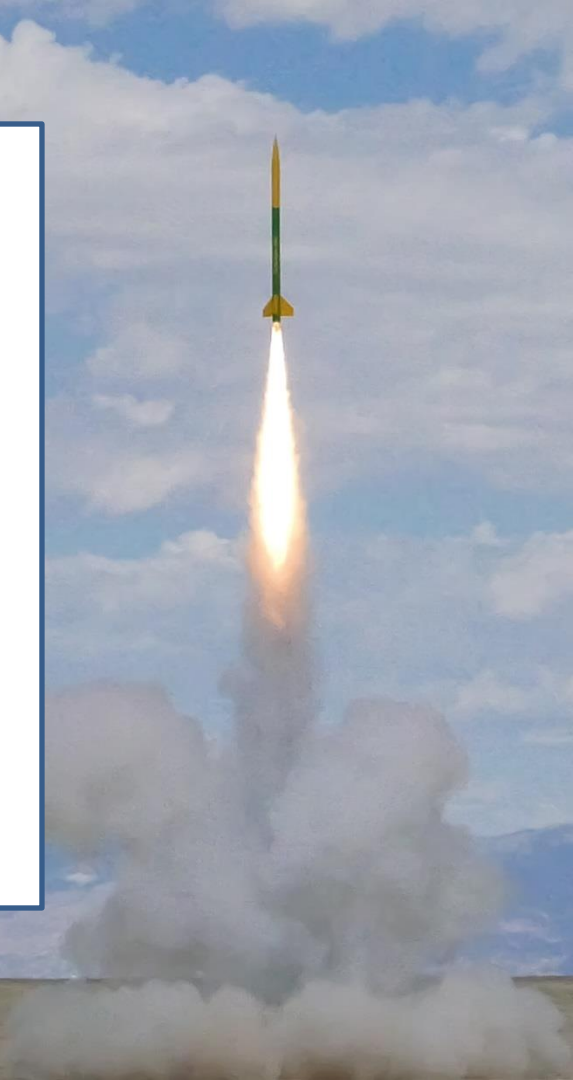
Mixing the propellant

- HTPB / Binder – fuel
- Plasticizer
  - DOA (Dioctyl adipate)
  - IDP (Isodecyl Pelargonate)
- Cross linking agent
  - Castor Oil
- Bonding Agent
  - Tepanol or HX-878
- Surfactant (Surface Acting Agent)
  - Lecithin
  - Silicon Oil



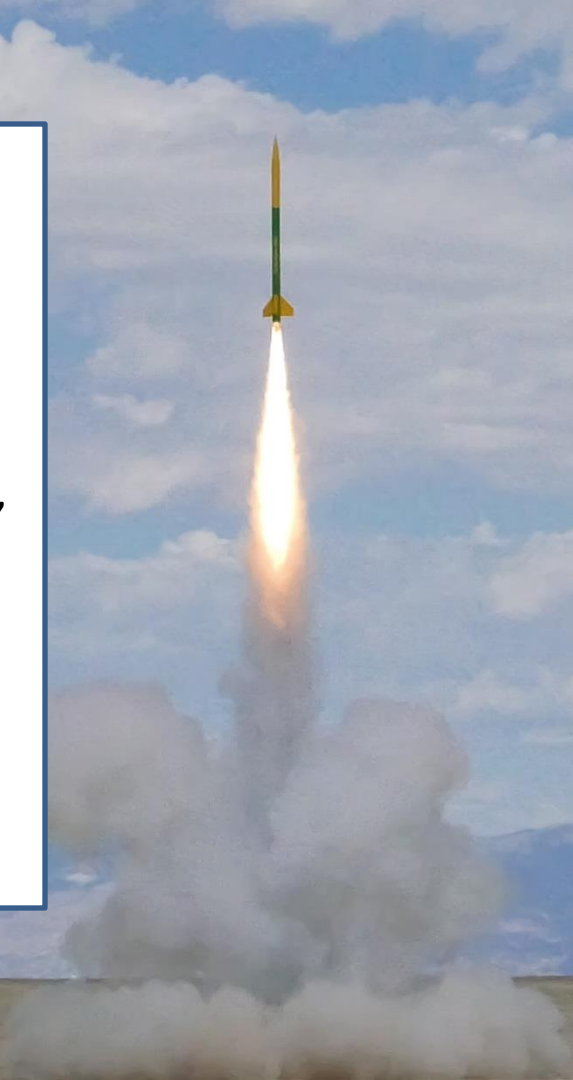
Metals are fuel (Powdered Aluminum, Magnesium, Zinc)

- Increases combustion temperature
- Dampens combustion instability
- Magnesium reported to improve low pressure burning



Burn Rate Modifiers

- Catalyst
  - Transition Metal Oxides 0.05% to 1% such as red Iron Oxide, manganese dioxide, cupric oxide, chromium oxide, etc.
- Burn Rate Suppressant
  - oxamide, ammonium chloride, calcium carbonate, etc.



Opacifier if needed

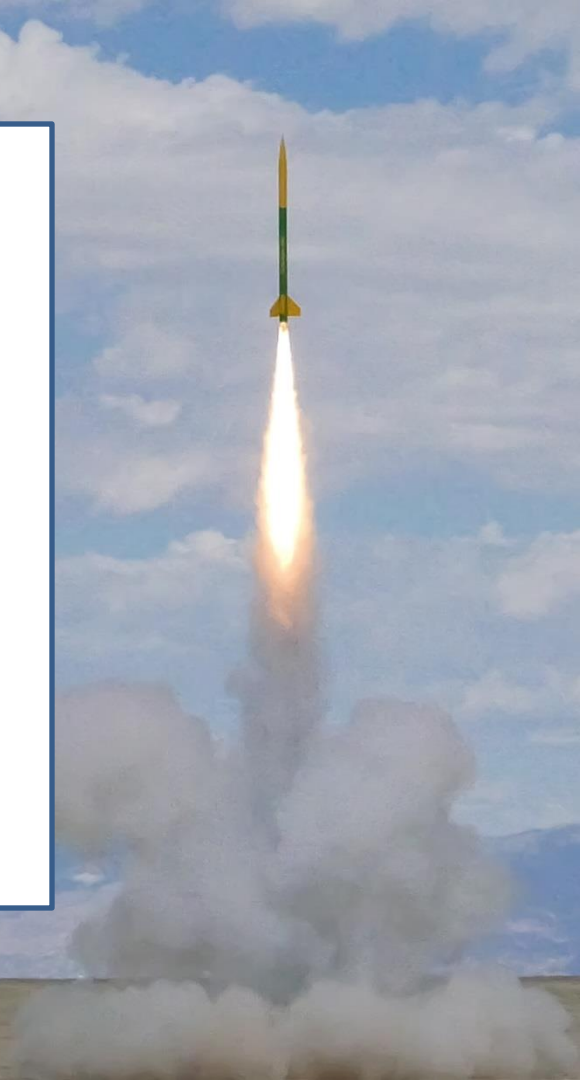
Ammonium Perchlorate Oxidizer (AP)

- 90 micron, 200 micron, 400 micron

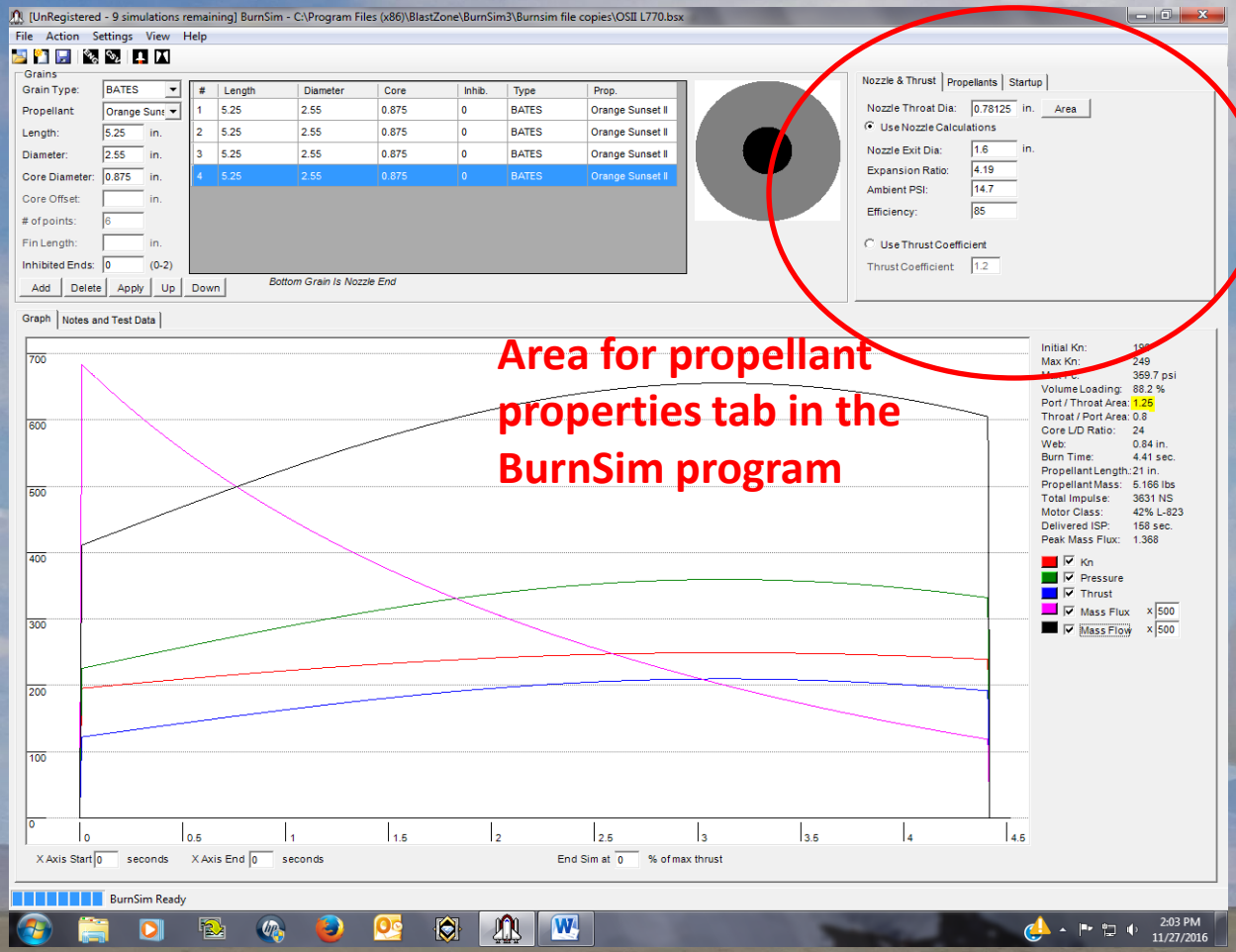
Curatives (Diisocyanates)

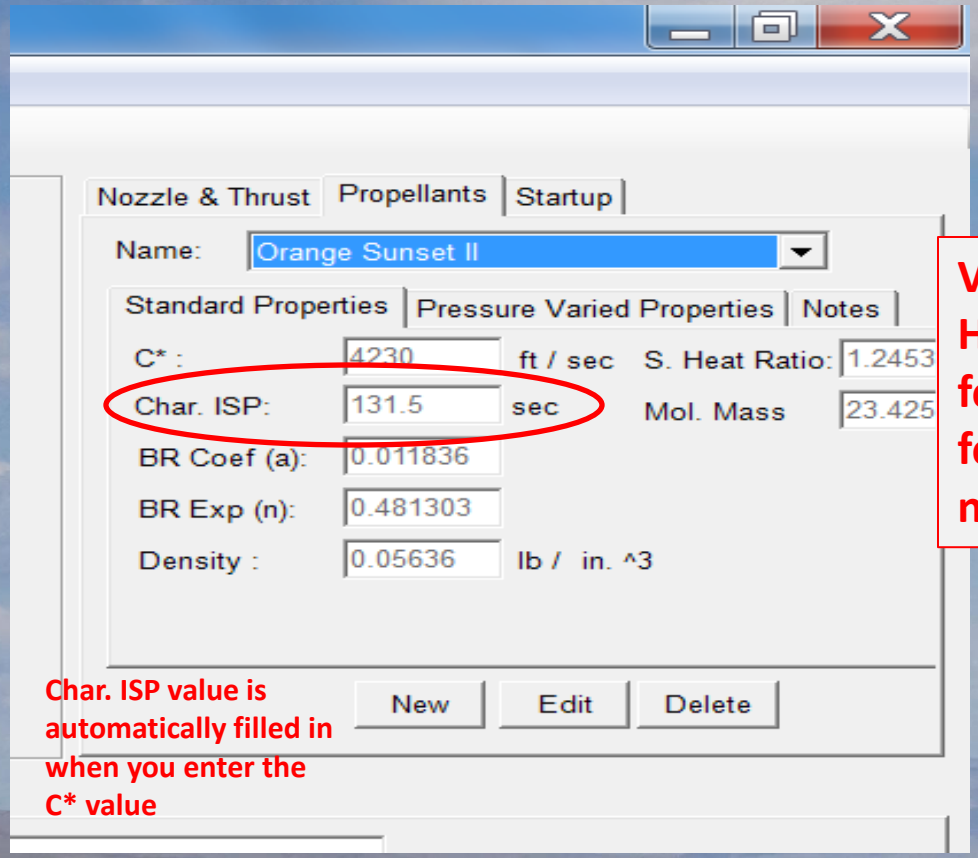
- MDI, IPDI, DDI, HDI, TDI, E744

Vacuum Processing



Cast Propellant & Cure time

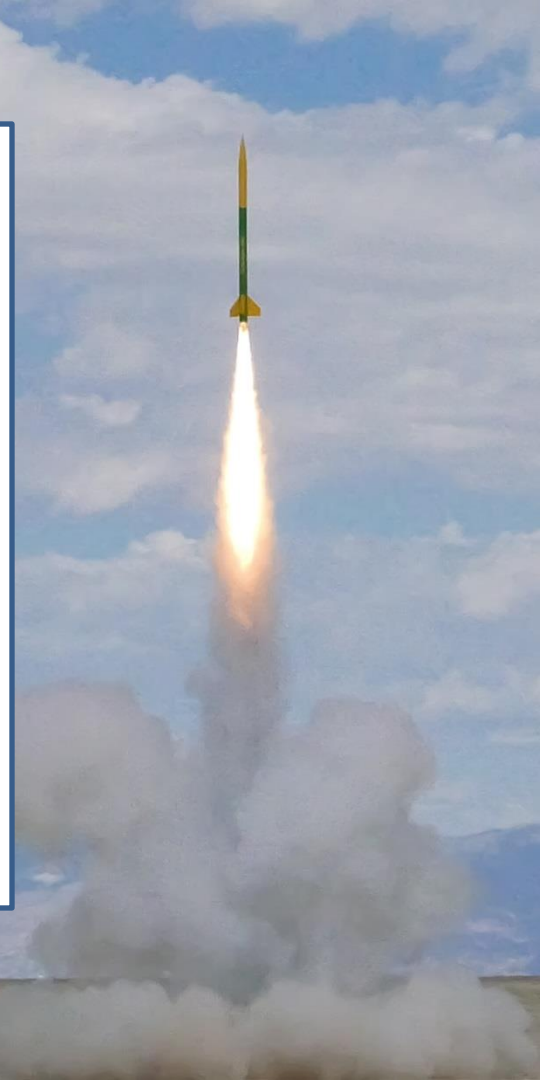

[UnRegistered - 9 simulations remaining] BurnSim - C:\Program Files (x86)\BlastZone\BurnSim3\Burnsim file copies\OSII L770.bsx
File Action Settings View Help
Grains
Grain Type: BATES
Propellant: Orange Sunt
Length: 5.25 in.
Diameter: 2.55 in.
Core Diameter: 0.875 in.
Core Offset: in.
# of points: 6
Fin Length: in.
Inhibited Ends: 0 (0-2)
Add Delete Apply Up Down
Length Diameter Core Inhib. Type Prop.
1 5.25 2.55 0.875 0 BATES Orange Sunset II
2 5.25 2.55 0.875 0 BATES Orange Sunset II
3 5.25 2.55 0.875 0 BATES Orange Sunset II
4 5.25 2.55 0.875 0 BATES Orange Sunset II
Bottom Grain Is Nozzle End
Nozzle & Thrust Propellants Startup
Nozzle Throat Dia: 0.78125 in. Area
Use Nozzle Calculations
Nozzle Exit Dia: 1.6 in.
Expansion Ratio: 4.19
Ambient PSI: 14.7
Efficiency: 85
Use Thrust Coefficient
Thrust Coefficient 1.2
Graph Notes and Test Data
Area for propellant properties tab in the BurnSim program
Initial Kn:
Max Kn: 249
359.7 psi
Volume Loading: 88.2 %
Port / Throat Area: 1.25
Throat / Port Area: 0.8
Core L/D Ratio: 24
Web: 0.84 in.
Burn Time: 4.41 sec.
Propellant Length: 21 in.
Propellant Mass: 5.166 lbs
Total Impulse: 3631 NS
Motor Class: 42% L-823
Delivered ISP: 158 sec.
Peak Mass Flux: 1.368
Kn
Pressure
Thrust
Mass Flux x 500
Mass Flow x 500
X Axis Start 0 seconds X Axis End 0 seconds
End Sim at 0 % of max thrust
BurnSim Ready
2:03 PM
11/27/2016



Char. ISP value is automatically filled in when you enter the C* value

Values for C*, (a), (n), Density, Heat Ratio & Molar Mass are found in the steps on the following slides. These are needed to run motor sims.

Measure the actual density of your mixed & cast propellant



E24 | grams

DETERMINATION OF DENSITY OF PROPELLANT

To determine density, fill a graduated cylinder about half full of water. Record the volume.
Weigh several pieces of propellant that will fit easily in the cylinder. Record the total weight.
Carefully drop (without splashing) the pieces of propellant in the water. Record the new volume.

Volume of water initially	7.2	milliliters
Weight of propellant added to cylinder	25.5	grams
New volume of propellant and water together	24.8	milliliters

Density	1.4489	grams/mL
	0.05234	lb/cu.in.

Or you can get a fair value for density by weighing a given propellant grain. You must also know the weight of an empty casting tube (it doesn't have to be the same length as your grain)

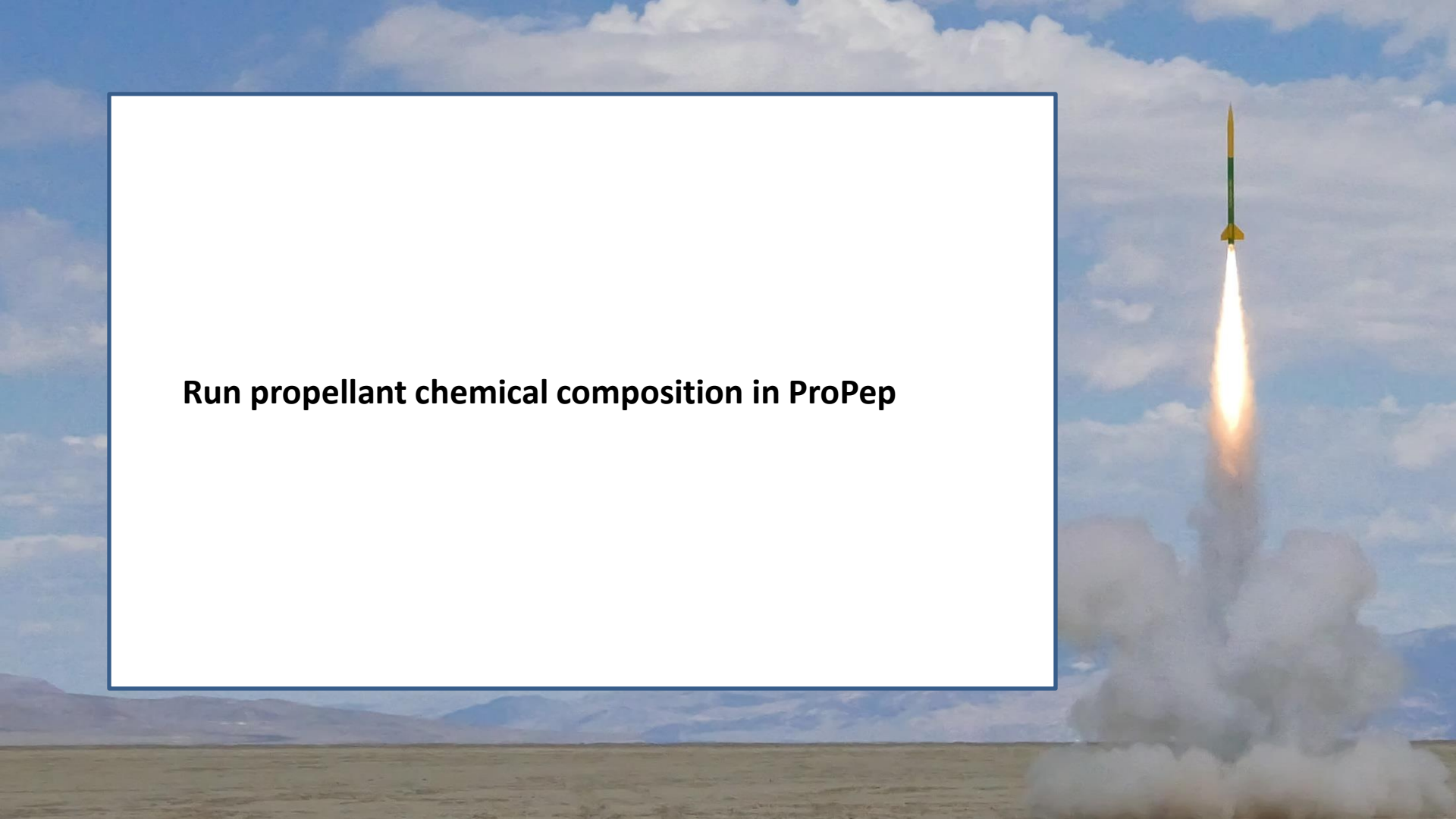
Length of paper casting tube	21	inches	Tubing weight is	3.690476 grams/inch
Weight of paper casting tube	77.5	grams		

O.D. of propellant (i.d. of tube)	2.535	inches
Diameter of core	0.875	
Length of grain	21	
Weight of grain	2515.2	grams

Density	1.593	grams/mL
	0.05756	lb/cu.in.

OSII

Run propellant chemical composition in ProPep



ProPepMain

File Options Multiple Runs Notes About

Propellant Formulation | Grain Information | Test Burns | Compute A & N

Ingredients

Name	Weight (gr)
AMMONIUM PERCHLORATE	75.00
AMMONIUM CHLORIDE	2.00
ZINC	2.00
CALCIUM CARBONATE (CACO3)	6.00
HTPB (R-45M)	12.50
DIOCTYL ADIPATE	5.00
MDI (PAPI 94)	1.74
	0.00
	0.00
	0.00
	0.00
	0.00
	0.00
	0.00
	0.00
Total Wt. (grams)	104.24

Enter formula data here

Operating Conditions

Temp. of Ingredients (K)	298
Chamber Pressure (PSI)	700
Exhaust Pressure (PSI)	14.70

☐ Boost Velocity and Nozzle Design

Calculate

Isp*	163.8863
C*	4222.455
Density	0.0597394
Molecular Wt.	23.42465
Chamber CP/CV	1.246553
Chamber Temp.	2022.875

(C Star) value

Molar Mass

Value for heat ratio

Display Results

Display Nozzle Graphs

Display Results gives next slide data

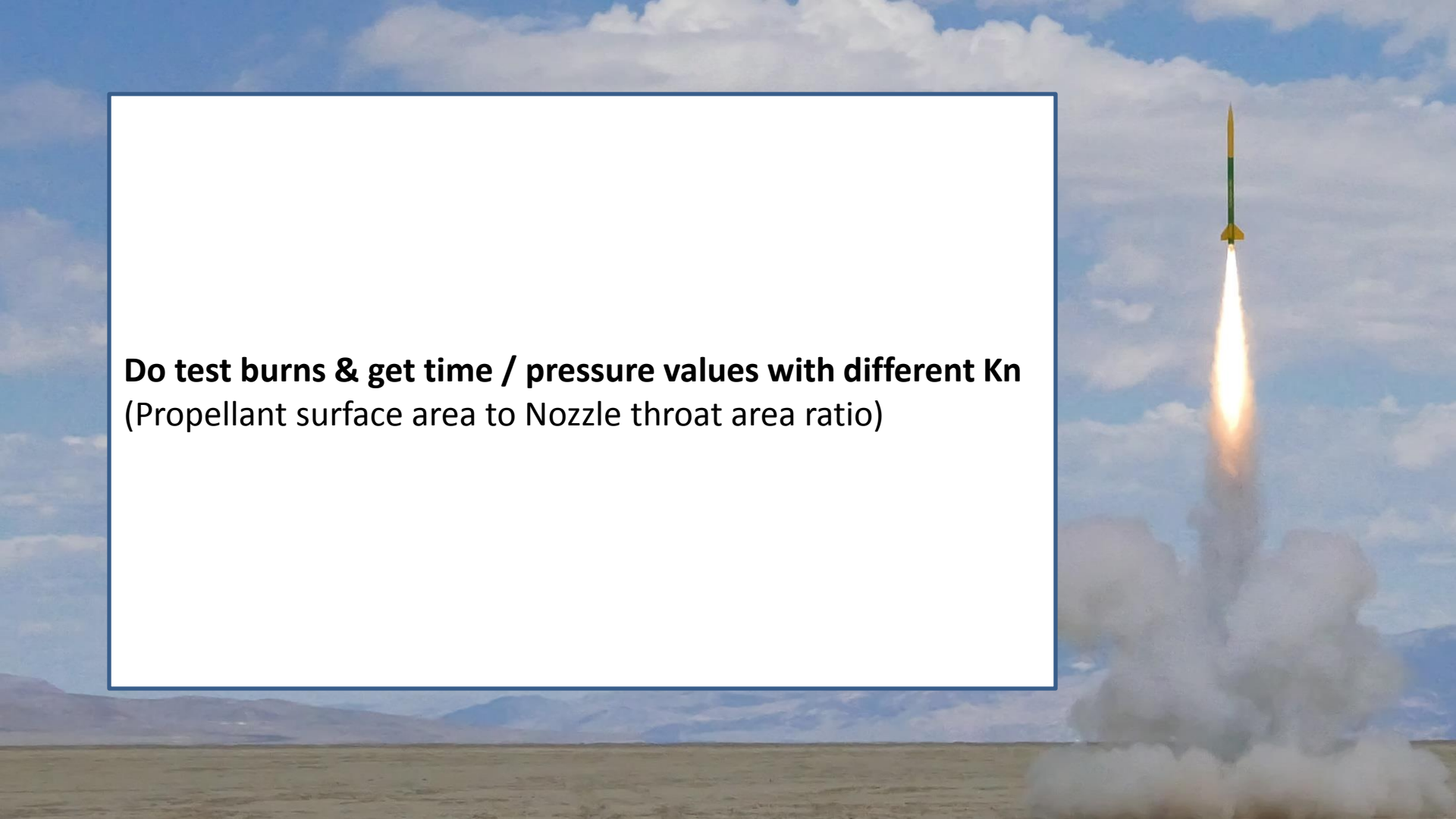
Results

Copy Results to a File Copy Results to Clipboard

```
      0 AMMONIUM PERCHLORATE              75.000    -601  0.07040   1 CL   4 H    1 N    4 O
      0 AMMONIUM CHLORIDE                  2.000   -1410  0.05510   1 N    4 H    1 CL
      0 ZINC                               2.000       0  0.25790   1 ZN
      0 CALCIUM CARBONATE (CACO3)          6.000   -2895  0.09790   1 C    3 O    1 CA
      0 HTPB (R-45M)                      12.500    -367  0.03250 200 C  302 H    2 O
      0 DIOCTYL ADIPATE                    5.000    -817  0.03320  22 C   42 H    4 O
      0 MDI (PAPI 94)                      1.740    -202  0.04460 224 C  155 H   27 O   27 N

THE PROPELLANT DENSITY IS  0.05974 LB/CU-IN OR   1.6536 GM/CC
THE TOTAL PROPELLANT WEIGHT IS  104.2400 GRAMS

NUMBER OF GRAM ATOMS OF EACH ELEMENT PRESENT IN INGREDIENTS

    4.721664 H
    1.376230 C
    0.688546 N
    2.809039 O
    0.675700 CL
    0.059945 CA
    0.030590 ZN

****************************CHAMBER RESULTS FOLLOW   ******************************
  T(K)  T(F)  P(ATM)   P(PSI) ENTHALPY  ENTROPY   CP/CV    GAS   RT/V
  2023  3182    47.62   700.00   -74.29   244.99  1.2466  4.419   10.777

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL =     9.871     9.976
NUMBER MOLS GAS AND CONDENSED =     4.419     0.031

 1.145734e+000 H2O        1.089160e+000 CO         9.367644e-001 H2         5.555652e-001 HCl
 3.441857e-001 N2         2.869813e-001 CO2        3.141666e-002 CaCl2*     3.058831e-002 Zn
 2.850117e-002 CaCl2      5.599058e-004 H          2.457290e-004 Cl         1.135983e-004 NH3
 7.277895e-005 HO         1.150830e-005 CaH2O2     9.347618e-006 CNH        7.200974e-006 CH2O
 3.500012e-006 CH4        2.559028e-006 CaCl       2.145202e-006 CHO        1.590116e-006 NO
   1.3919E-06 CNHO         1.3919E-06 CNHO

THE MOLECULAR WEIGHT OF THE MIXTURE IS    23.425

****************************EXHAUST RESULTS FOLLOW   ******************************
  T(K)  T(F)  P(ATM)   P(PSI) ENTHALPY  ENTROPY   CP/CV    GAS   RT/V
   993  1327     1.00    14.70  -123.13   244.99  1.2806  4.380    0.228

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL =     8.739     8.898
NUMBER MOLS GAS AND CONDENSED =     4.380     0.060

 1.287532e+000 H2         7.856770e-001 H2O        7.195303e-001 CO         6.518751e-001 CO2
 5.557878e-001 HCl        3.441871e-001 N2         5.912877e-002 CaCl2&     3.058831e-002 Zn
   0.00475604 CH4          0.00475604 CH4

THE MOLECULAR WEIGHT OF THE MIXTURE IS    23.477

 **********PERFORMANCE:  FROZEN ON FIRST LINE, SHIFTING ON SECOND LINE**********

 IMPULSE   IS EX      T*      P*      C*    ISP*  OPT-EX  D-ISP      A*M   EX-T
   198.6  1.2718    1781   26.23  4160.6          6.02  328.4  0.18478    886
   201.9  1.2337    1814   26.57  4222.5   163.9  6.48  333.9  0.18753    930
```

Top line C* value for small motors, bottom line C* value for large motors

Do test burns & get time / pressure values with different Kn
(Propellant surface area to Nozzle throat area ratio)



DETERMINATION OF NOZZLE DIAMETER OR AREA RATIO

(all grains are assumed to burn on ends as well as in the core)

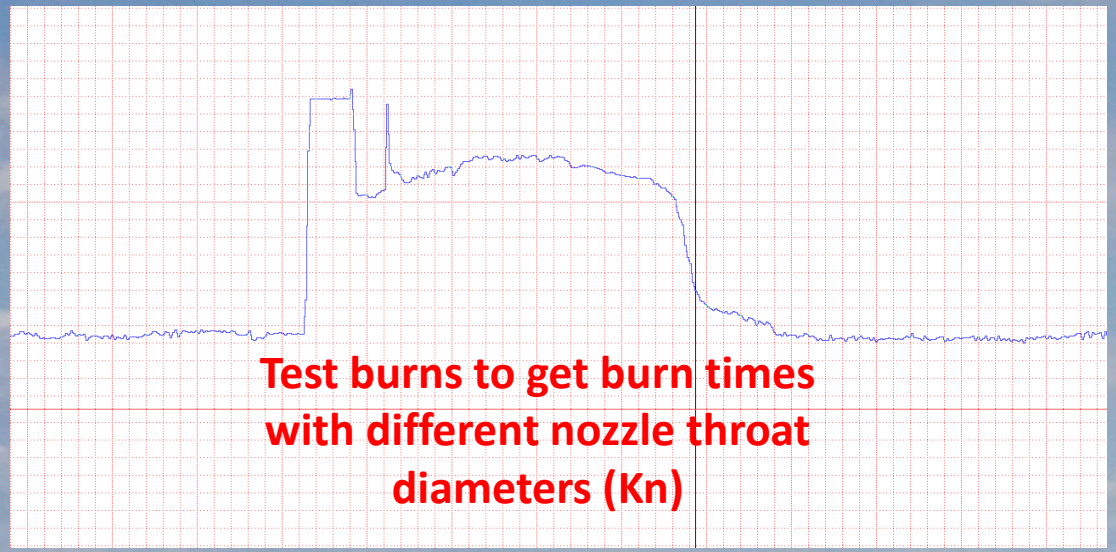
For Bates, core, and moon grains

Number of grains	4	2	2	4	5	6	7	4	1	1
O.D. of propellant	3.25	0.95	1.4	3.25	0.92	0.92	0.92	3.25	0.92	0.92
Dia. of core	1.25	0.375	0.5	1.25	0.385	0.385	0.385	1.25	0.385	0.385
Length of each grain	6	1.515	1.825	6	1.5	1.5	1.5	6	1.5	1.5
Desired Kn	335	125	175	350	190	200	210	228	230	240
Nozzle throat (inches)	0.7571	0.2465	0.2843	0.7407	0.3123	0.3335	0.3515	0.9177	0.1269	0.1243
OR in 64ths inch	48.45	15.77	18.19	47.40	19.99	21.34	22.50	58.73	8.12	7.95

Number of grains	4	2	2	2	1	2	1	1	1	1
O.D. of propellant	3.25	1.14	1.14	1.14	0.92	0.95	0.92	0.92	0.92	0.92
Dia. of core	1.25	0.375	0.375	0.375	0.385	0.375	0.385	0.385	0.385	0.385
Length of each grain	6	1.825	1.825	1.825	1.5	1.517	1.5	1.5	1.5	1.5
Nozzle throat dia.	0.75	0.25	0.266	0.281	0.14	0.182	0.16	0.17	0.18	0.19
Area ratio Kn =	341.3	161.8	142.9	128.0	189.1	229.4	144.8	128.2	114.4	102.7

Note: you don't have to fill in every box. Multiple boxes are given to allow you to see differences in Kn/nozzle throat with different dimensions

Use this sheet to find your Kn ratios



Test burns to get burn times with different nozzle throat diameters (Kn)

Rob G PROPEL Formula.x

File | Home | Insert | Page Layout | Formulas | Data | Review | View | Add-Ins

Paste | Cut | Copy | Format Painter | Clipboard | Arial | 10 | Font | Wrap Text | Merge & Center | Alignment | General | Number | Conditional Formatting

H67

DETERMINATION OF BURN RATE COEFFICIENT AND EXPONENT

Bates grains should be neutral (length about 1.6 times the diameter) for best results
Record time as accurately as possible (use a camcorder if thrust stand is unavailable)
If Isp is not known use: 150 for propellant using KP oxidizer
175 for propellant using AN plus Mg, or just AP.
190 for propellant using AP plus Al or Mg

BATES grains

TEST MOTOR DATA	Motor 1	Motor 2	
Grain dia	1.14	1.14	inches
Grain length	1.75	1.75	inches
Core dia	0.375	0.375	inches
Number of grains	2	2	
Nozzle throat dia	0.185	0.161	inches
Propellant Isp	131.5	131.5	seconds
Density	0.0546	0.0546	lb/cu.in.
Burn time	1.75	1.25	seconds
PROPELLANT RESULTS			
Burn rate	0.219	0.306	in/sec
Kn	288.9	381.4	
Chamber pressure	453.3	837.9	lb/sq.in.
Burn rate coefficient		0.0077	
Burn rate exponent		0.5477	

For more accurate determination of burn rate coefficient and exponent, see below

CAUTION: if the nozzle throat is more than half the core diameter results may be incorrect due to erosion

Two burns times can get you a basic 'a' (BR-coefficient) and 'n' (BR-exponent)

Rob G PROPEL Formula.xlsx - Microsoft Excel

File | Home | Insert | Page Layout | Formulas | Data | Review | View | Add-Ins

Normal | Page Layout | Page Break Preview | Custom Views | Full Screen | Workbook Views

Ruler | Formula Bar | Gridlines | Headings | Show

Zoom | 100% | Zoom to Selection | Zoom

New Window | Arrange All | Freeze Panes | Split | Hide | Unhide | View Side by Side | Synchronous Scrolling | Reset Window Position | Save Workspace | Switch Windows | Window

Macros

H67

37 Under Output Options click 'New Worksheet ply' & give a name for Propellant Characterization sheet.
38 Values from Prop Char page 'Intercept'/'Coefficient' (17/B) goes in 'Constant' (E/62)
39 Values from 'X Variable' / 'Coefficient' (18/B) goes into 'X Coefficient' (E/68)
40 Only use as many numbers in those columns as you have data for
41 The burnrate coefficient and exponent appear below, in red

Multiple burn times gives more accuracy

44 Propellant Isp = 131.3 OSII
45 Propellant density = 0.0546 lb/cu.in

48 BATES grains	Grain dia.	Grain length	Core dia	Number of grains	Dia. of Nozzle throat	Burn time	Burn rate	Kn	Chamber pressure	log (rate)	log (pressure)
49 TEST MOTOR DATA											
50 Motor #1	1.14	1.75	0.375	2	0.221	2.25	0.170	202.4	246.6823	-0.76955	2.392138
51 Motor #2	1.14	1.75	0.375	2	0.21	2.1	0.182	224.2	292.7165	-0.73959	2.466447
52 Motor #3	1.14	1.75	0.375	2	0.185	1.75	0.219	288.9	452.6093	-0.66041	2.655724
53 Motor #4	1.14	1.75	0.375	2	0.161	1.25	0.306	381.4	836.6489	-0.51428	2.922543
54 Motor #5							#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
55 Motor #6							#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
56 Motor #7							#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
57 Motor #8							#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
58 Motor #9							#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
59 Motor #10							#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

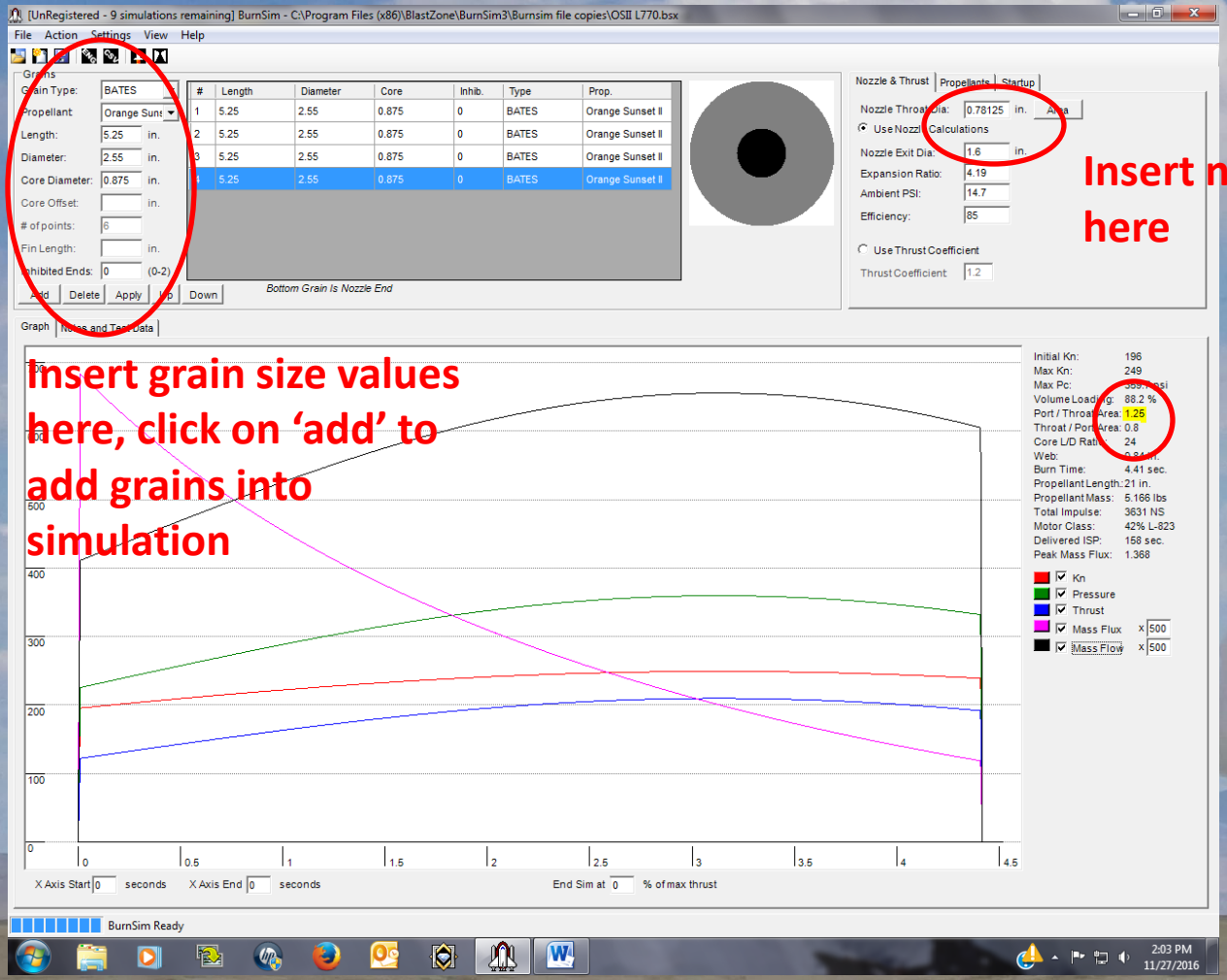
61 Regression Output:

62 Constant	-1.92678
63 Std Err of Y Est	0.002525
64 R Squared	0.989382
65 No. of Observations	6
66 Degrees of Freedom	4
67	
68 X Coefficient(s)	0.481303
69 Std Err of Coef.	0.016705

Burnrate coefficien 0.011836
Burnrate exponent= 0.481303

Orange Sunset II+Papi | OSII + E744 | OSII Ballistic info | OSII Char | Original Orange Sunset | Wayside White | Slow White+E744 | Sk

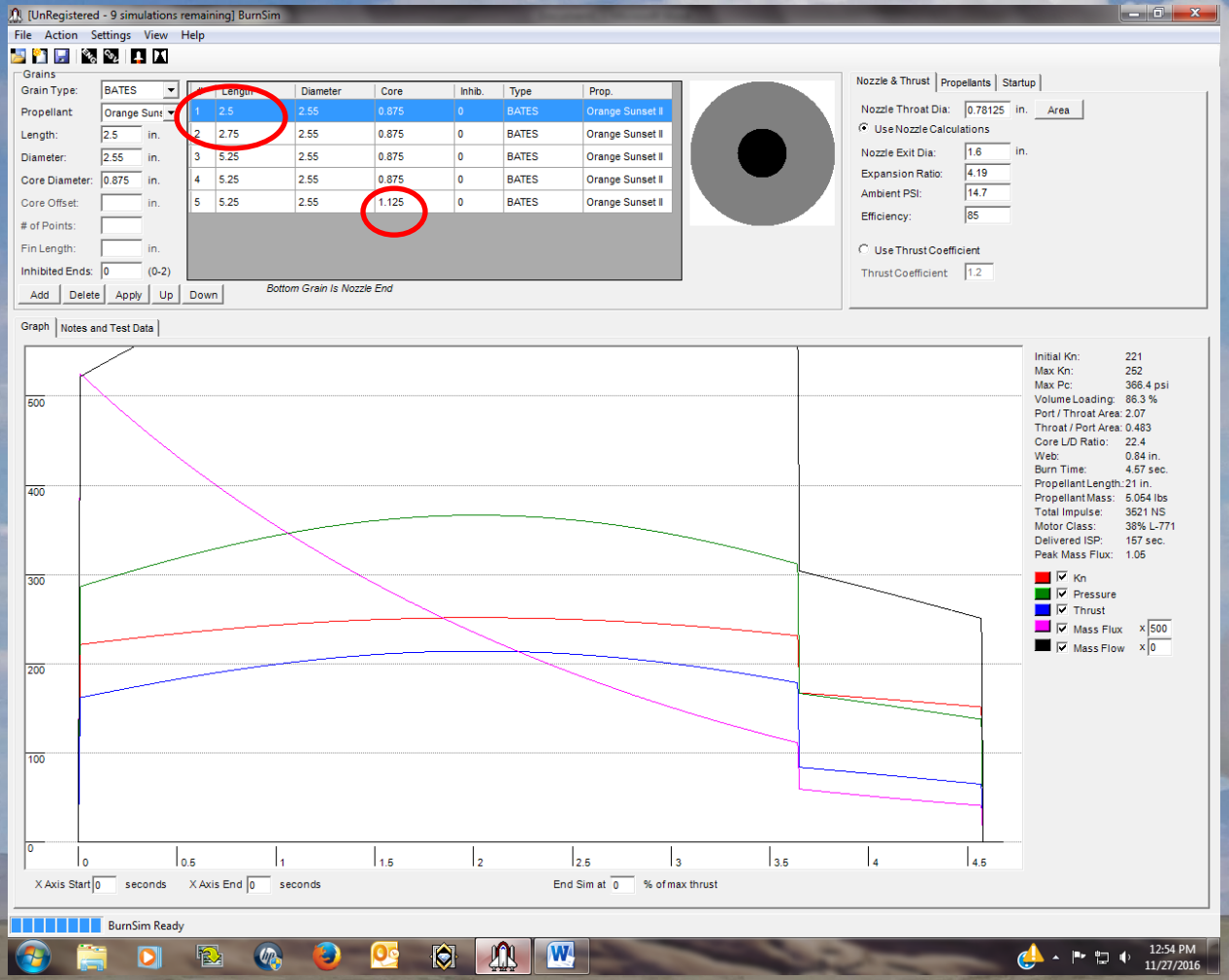
With the last of these values you can now start to model motors in the BurnSim program



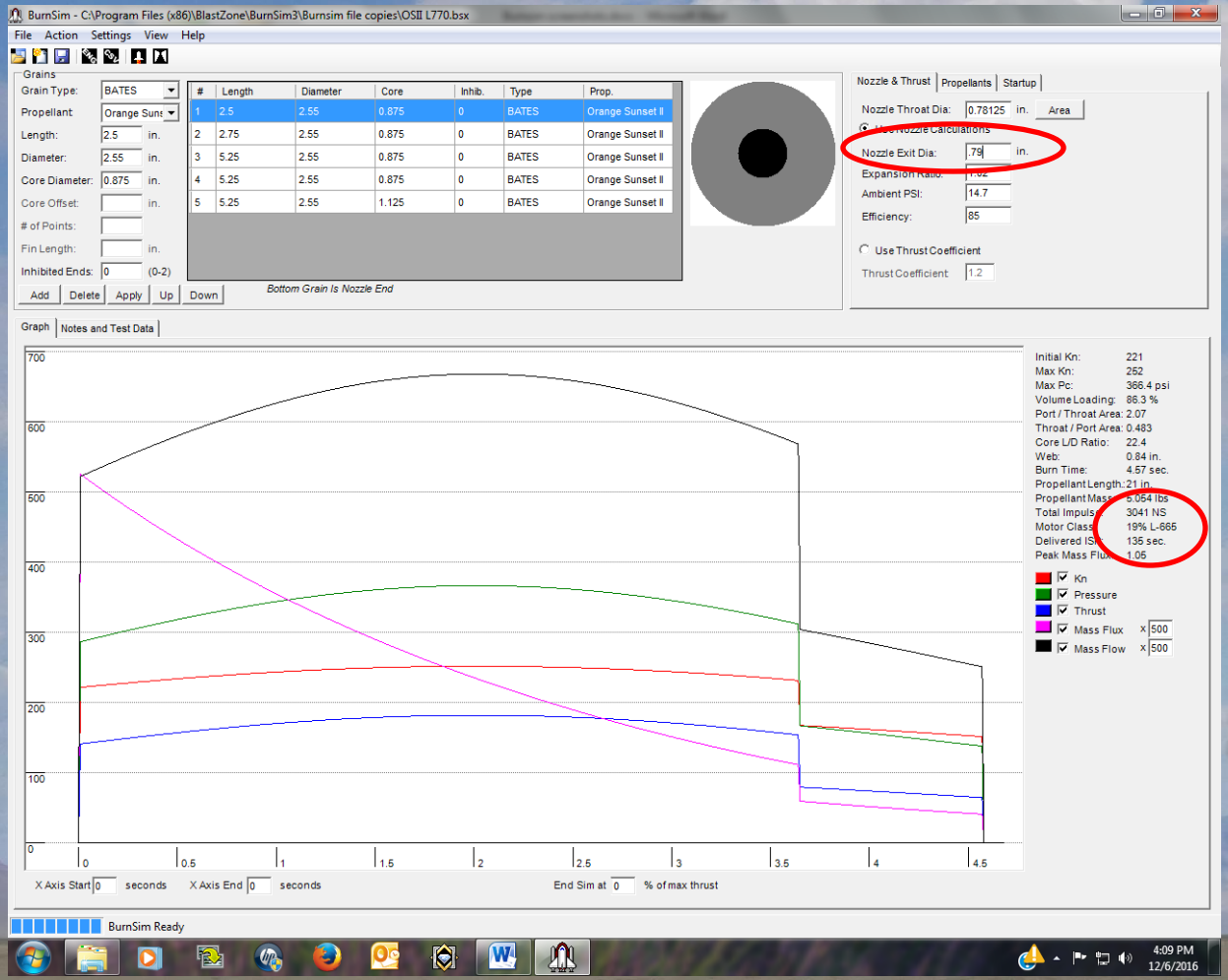
Insert grain size values here, click on 'add' to add grains into simulation

Insert nozzle values here

Note the yellow warning of approaching erosion



Cutting the top grain almost in half, and drilling the bottom core larger gets rid of the erosion warning



Having no expansion on the nozzle shows the difference having no thrust coefficient. It goes from 38% L motor to 19% L

[UnRegistered - 9 simulations remaining] BurnSim

File Action Settings View Help

Grains

Grain Type: Star
Propellant: Orange Sunt
Length: 24 in.
Diameter: 2.55 in.
Major width: 1.5 in.
Minor width: 0.75 in.
# of points: 6
Fin Length: in.
Inhibited Ends: 0 (0-2)

#	Length	Diameter	Core	Inhib.	Type	Prop.
1	24	2.55	1.5	0	Star	Orange Sunset II

Add Delete Apply Up Down

Bottom Grain Is Nozzle End

Nozzle & Thrust | Propellants | Startup

Nozzle Throat Dia: .8 in. Area

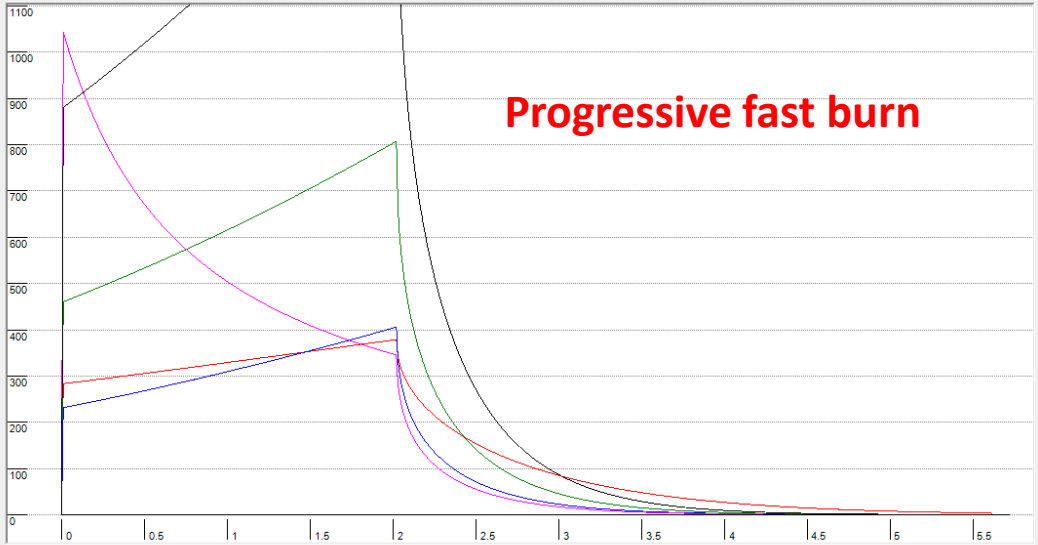
Use Nozzle Calculations

Nozzle Exit Dia: in.
Expansion Ratio:
Ambient PSI: 14.7
Efficiency: 85

Use Thrust Coefficient

Thrust Coefficient: 1.2

Graph | Notes and Test Data



Initial Kn: 283
Max Kn: 379
Max Pc: 807.2 psi
Volume Loading: 83.5 %
Port / Throat Area: 1.68
Throat / Port Area: 0.595
Core L/D Ratio: 16
Web: 0.52 in.
Burn Time: 5.61 sec.
Propellant Length: 24 in.
Propellant Mass: 5.587 lbs
Total Impulse: 3272 NS
Motor Class: 28% L-583
Delivered ISP: 132 sec.
Peak Mass Flux: 2.087

Kn
Pressure
Thrust
Mass Flux x 500
Mass Flow x 0

X Axis Start 0 seconds X Axis End 0 seconds End Sim at 0 % of max thrust

BurnSim Ready

1:08 PM
11/27/2016

[UnRegistered - 9 simulations remaining] BurnSim - C:\Program Files (x86)\BlastZone\BurnSim3\Burnsim file copies\EC M-2100 spike.bsx

File Action Settings View Help

Grains

Grain Type: BATES
Propellant: Everclear
Length: 6.375 in.
Diameter: 3.25 in.
Core Diameter: 1.25 in.
Minor width: in.
# of points: 6
Fin Length: in.
Inhibited Ends: 0 (0-2)

#	Length	Diameter	Core	Inhib.	Type	Prop.
1	6.375	3.25	1.25	0	BATES	Everclear
2	6.375	3.25	1.25	0	BATES	Everclear
3	6.375	3.25	1.25	0	BATES	Everclear
4	6.375	3.25	1.25	0	BATES	Everclear

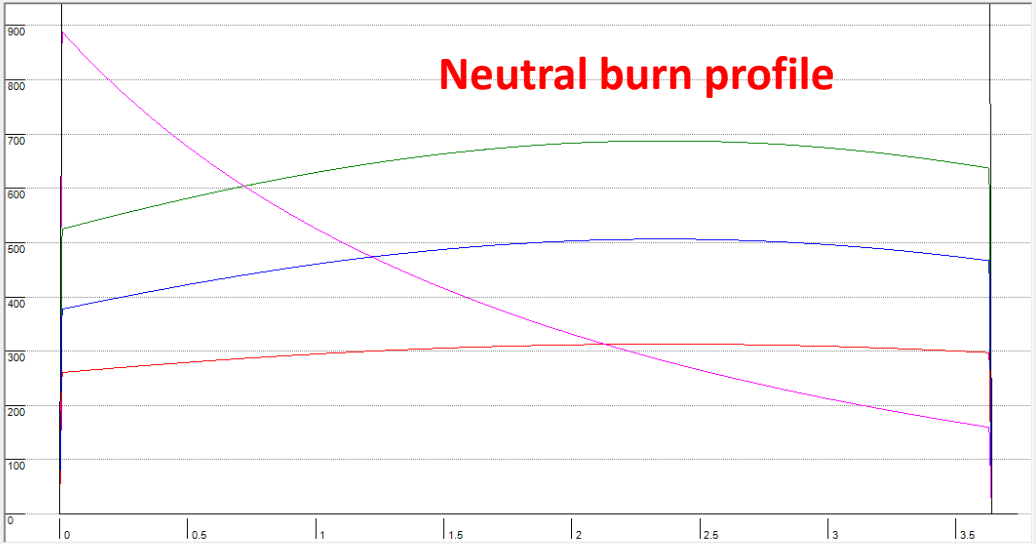
Add Delete Apply Up Down

Bottom Grain Is Nozzle End

Nozzle & Thrust | Propellants | Startup

Nozzle Throat Dia: 0.875 in. Area
Use Nozzle Calculations
Nozzle Exit Dia: 2.1 in.
Expansion Ratio: 5.76
Ambient PSI: 14.2
Efficiency: 80
Use Thrust Coefficient
Thrust Coefficient 1.2

Graph | Notes and Test Data



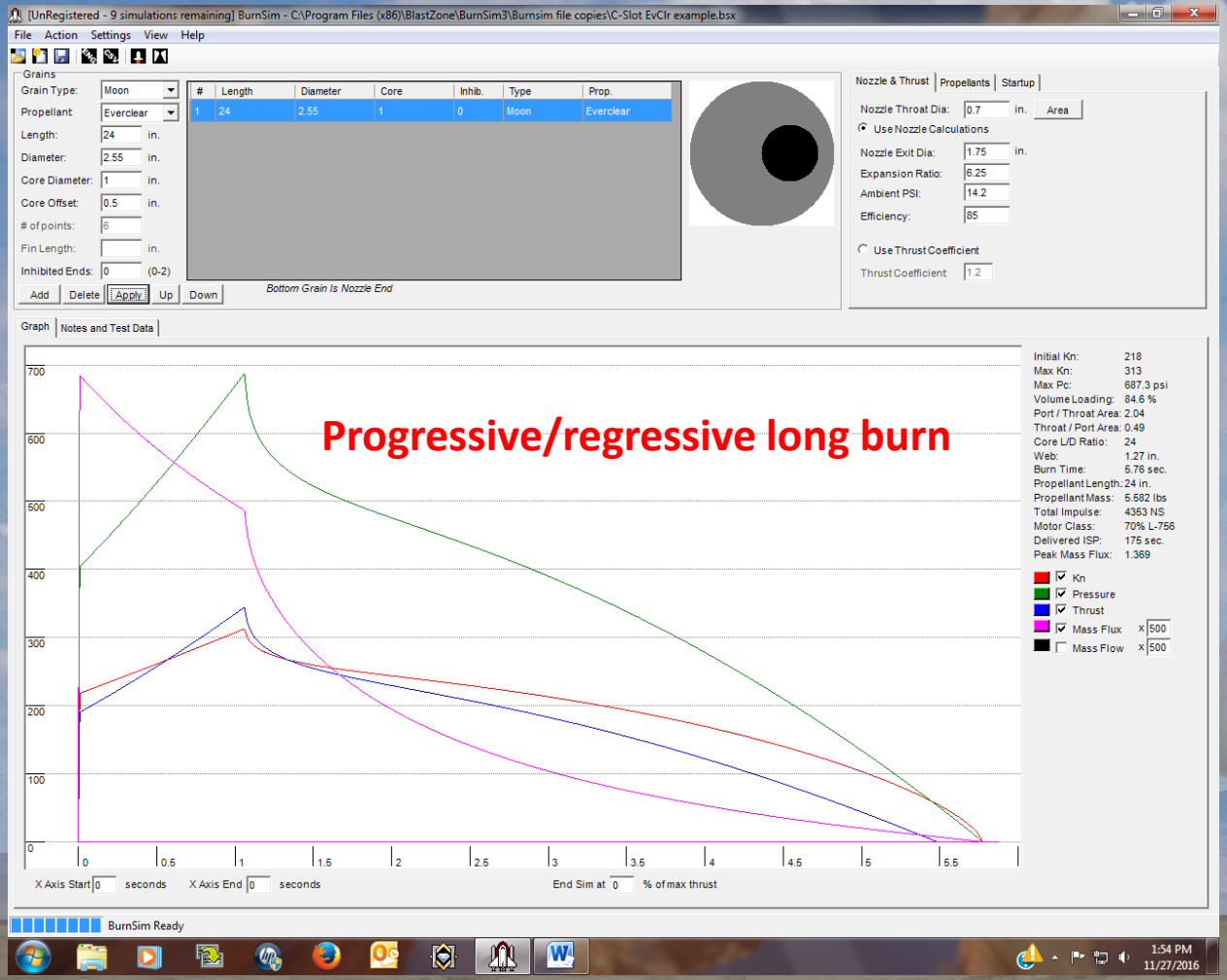
Initial Kn: 261
Max Kn: 313
Max Pc: 687.5 psi
Volume Loading: 85.2 %
Port / Throat Area: 2.04
Throat / Port Area: 0.49
Core L/D Ratio: 20.4
Web: 1 in.
Burn Time: 3.63 sec.
Propellant Length: 25.5 in.
Propellant Mass: 9.701 lbs
Total Impulse: 7632 NS
Motor Class: 49% M-2103
Delivered ISP: 177 sec.
Peak Mass Flux: 1.777

Kn
Pressure
Thrust
Mass Flux x 500
Mass Flow x 0

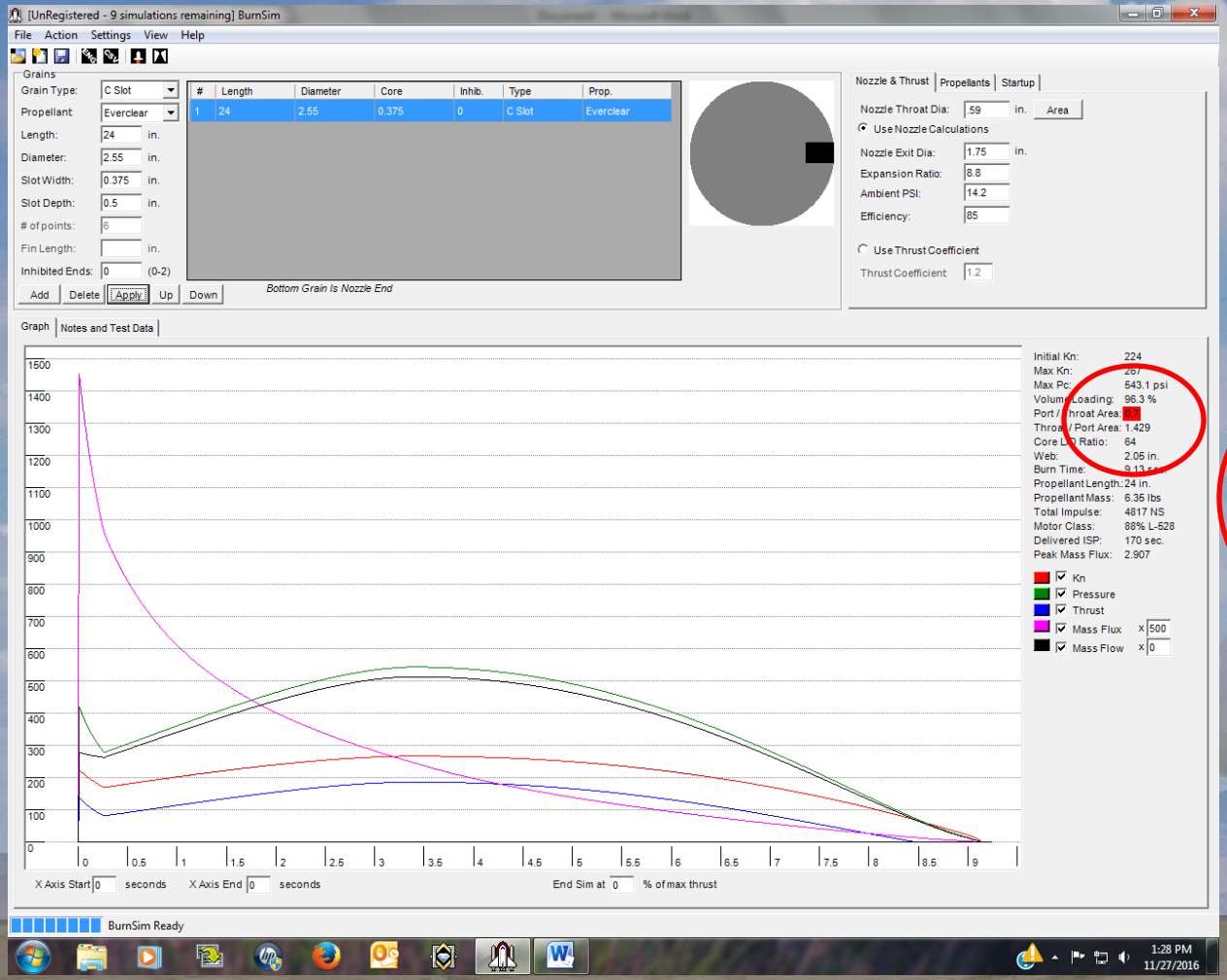
X Axis Start 0 seconds X Axis End 0 seconds End Sim at 0 % of max thrust

BurnSim Ready

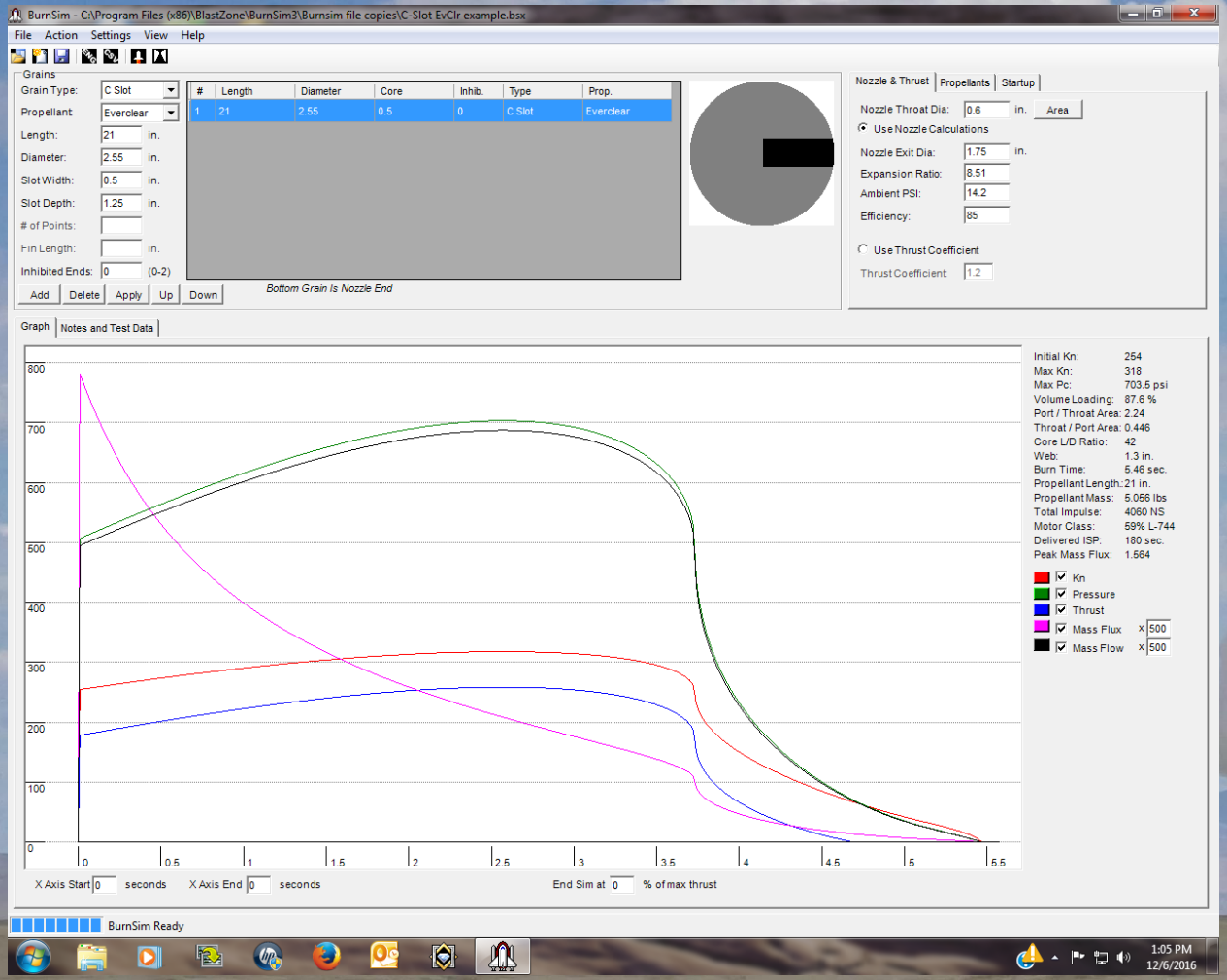
1:13 PM 11/27/2016



On a Moon burner the core diameter determines initial thrust, the core offset determines the peak pressure



This motor will overpressure on start up because of erosion



Larger core on 'C slot' and it will run well. The flow of hot gasses along the outside of the motor makes it harder to protect the case from burn-thru

[UnRegistered - 9 simulations remaining] BurnSim - C:\Program Files (x86)\BlastZone\BurnSim3\Burnsim file copies\SW O-3700 BALLS Rocket.bsx

File Action Settings View Help

Grains

Grain Type: BATES
Propellant: Slow White
Length: 9 in.
Diameter: 3.78 in.
Core Diameter: 1.375 in.
Slot Depth: in.
# of points: 6
Fin Length: in.
Inhibited Ends: 0 (0-2)

#	Length	Diameter	Core	Inhib.	Type	Prop.
1	9	3.78	1.375	0	BATES	Slow White
2	9	3.78	1.375	0	BATES	Slow White
3	9	3.78	1.375	0	BATES	Slow White
4	9	3.78	1.375	0	BATES	Slow White
5	9	3.78	1.5	0	BATES	Slow White
6	9	3.78	1.625	0	BATES	Slow White

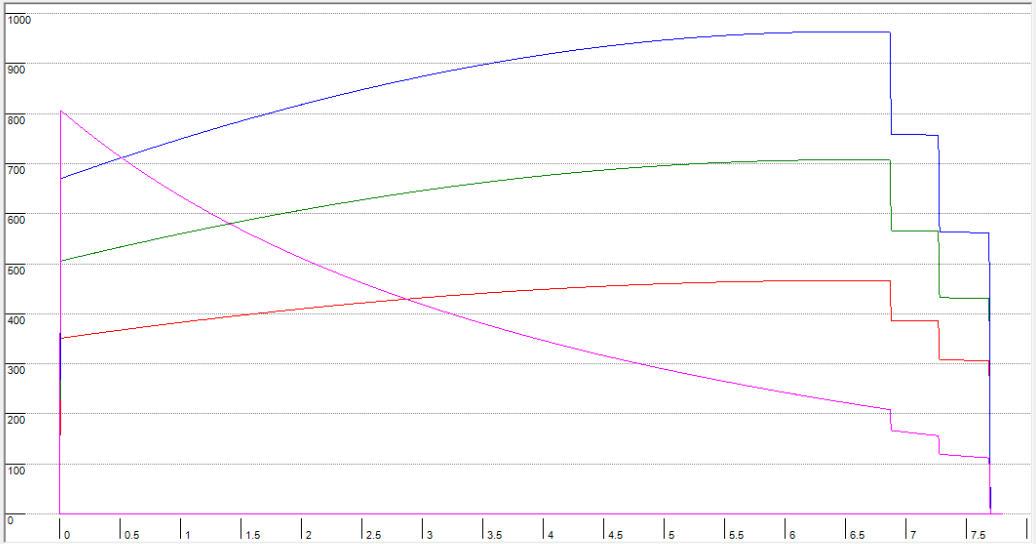
Add Delete Apply Up Down

Bottom Grain Is Nozzle End

Nozzle & Thrust | Propellants | Startup

Nozzle Throat Dia: 1.141 in. Area
Use Nozzle Calculations
Nozzle Exit Dia: 3.059 in.
Expansion Ratio: 7.19
Ambient PSI: 10.1
Efficiency: 85
Use Thrust Coefficient
Thrust Coefficient 0

Graph | Notes and Test Data



Initial Kn: 351
Max Kn: 466
Max Pc: 707.6 psi
Volume Loading: 85.5 %
Port / Throat Area: 2.03
Throat / Port Area: 0.493
Core L/D Ratio: 37.6
Web: 1.2 in.
Burn Time: 7.69 sec.
Propellant Length: 54 in.
Propellant Mass: 31.881 lbs
Total Impulse: 28955 NS
Motor Class: 41% O-3765
Delivered ISP: 204 sec.
Peak Mass Flux: 1.613

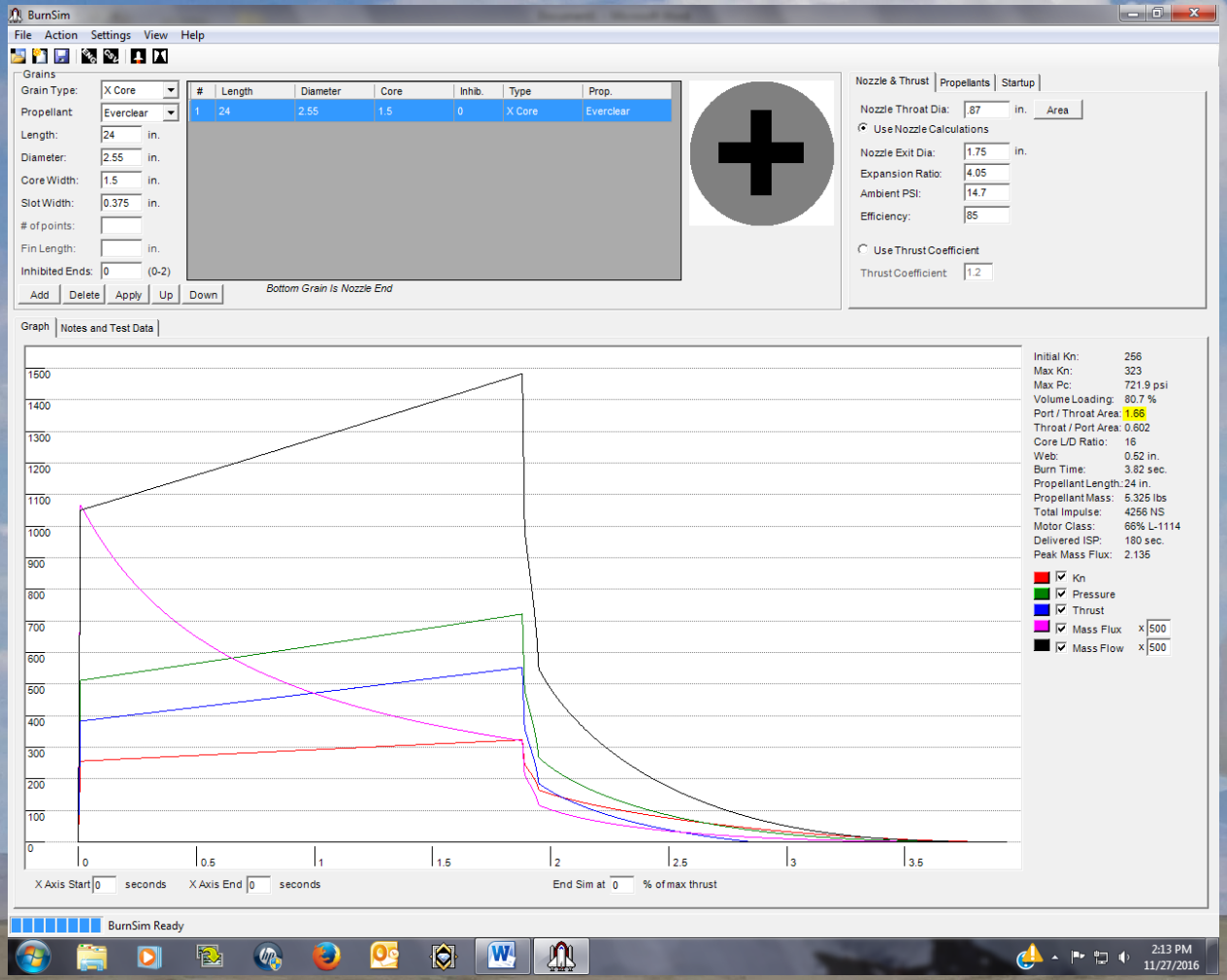
Kn
Pressure
Thrust
Mass Flux x 500
Mass Flow x 500

X Axis Start 0 seconds X Axis End 0 seconds End Sim at 0 % of max thrust

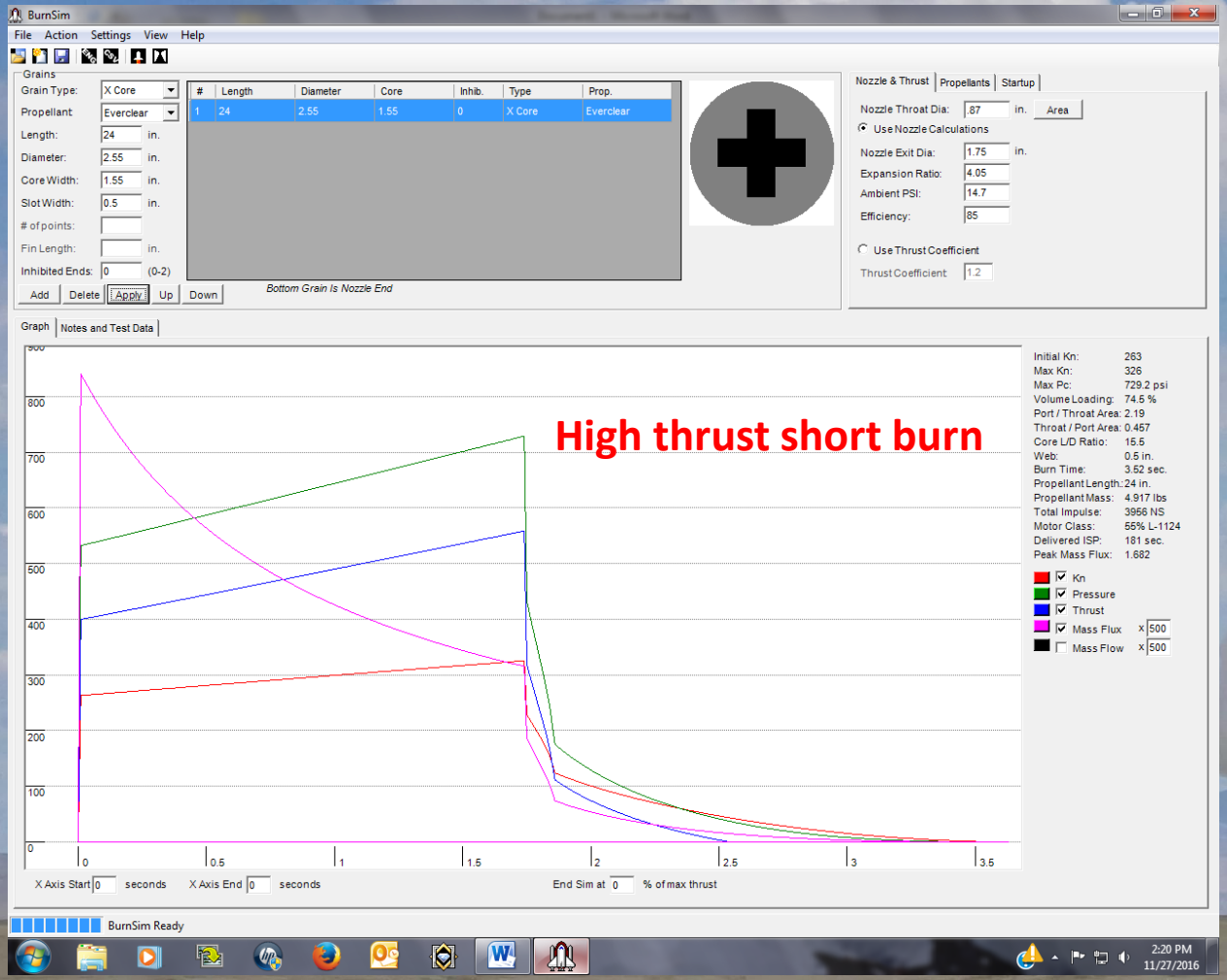
BurnSim Ready

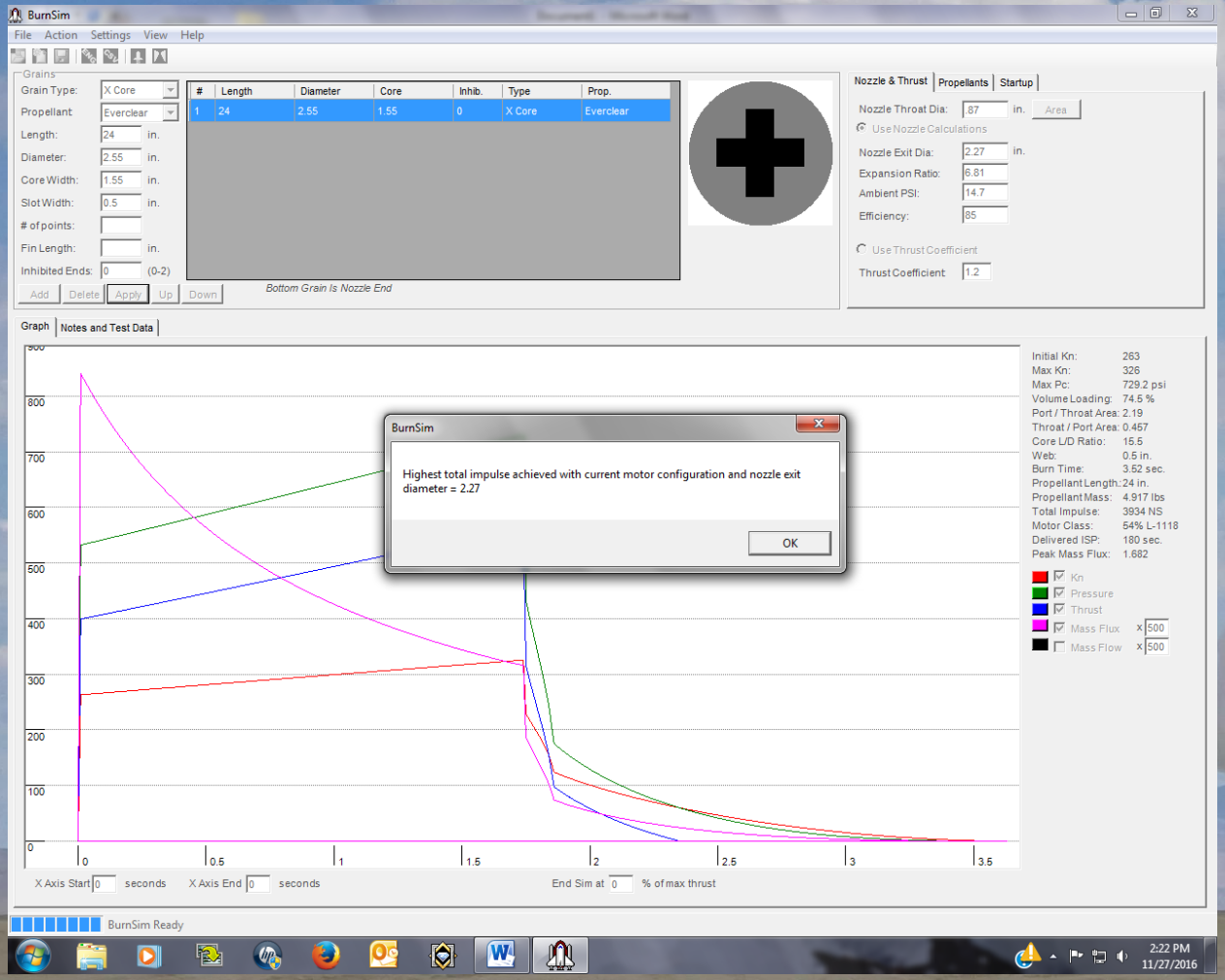
1:45 PM 11/27/2016

Long motor design with progressive grains using a slow propellant. Notice the larger cores on the bottom two grains.



Core is a little small on this slide, the next shows a better sized core.


BurnSim
File Action Settings View Help
Grains
Grain Type: X Core
Propellant: Everclear
Length: 24 in.
Diameter: 2.55 in.
Core Width: 1.55 in.
Slot Width: 0.5 in.
# of points:
Fin Length: in.
Inhibited Ends: 0 (0-2)
Length Diameter Core Inhib. Type Prop.
1 24 2.55 1.55 0 X Core Everclear
Add Delete Apply Up Down
Bottom Grain Is Nozzle End
Nozzle & Thrust Propellants Startup
Nozzle Throat Dia: .87 in. Area
Use Nozzle Calculations
Nozzle Exit Dia: 1.75 in.
Expansion Ratio: 4.05
Ambient PSI: 14.7
Efficiency: 85
Use Thrust Coefficient
Thrust Coefficient: 1.2
Graph Notes and Test Data
High thrust short burn
Initial Kn: 263
Max Kn: 326
Max Pc: 729.2 psi
Volume Loading: 74.5 %
Port / Throat Area: 2.19
Throat / Port Area: 0.457
Core L/D Ratio: 15.5
Web: 0.5 in.
Burn Time: 3.52 sec.
Propellant Length: 24 in.
Propellant Mass: 4.917 lbs
Total Impulse: 3956 NS
Motor Class: 55% L-1124
Delivered ISP: 181 sec.
Peak Mass Flux: 1.682
Kn
Pressure
Thrust
Mass Flux x 500
Mass Flow x 500
X Axis Start 0 seconds X Axis End 0 seconds
End Sim at 0 % of max thrust
BurnSim Ready
2:20 PM
11/27/2016



Under the 'Action' menu you can have the program run simulations to determine the most efficient exit diameter on the nozzle.

References

- Experimental Composite Propellant by Dr. Terry W. McCreary, Ph.D.
- Richard Nakka
- Defense Technical Information Center – Naval Weapons Center papers
- Wikipedia
- Charles E. Rogers
- John S. DeMar