

Pyrotechnic Worksheet 5

Test title: AP/AL/HTPB propellant, Bates Grain

Date: 16. June 2000

Like Pyrotechnic Worksheet nr. 4 but more Al-powder (the larger 12 mm throat should not be blocked anymore), predicted combustion pressure = 7.5 MPa

Batch Composition:

Ingredients	%	grams	Notes
R45M, HTPB Resin	15	90	Resin & Fuel
Soja-Lecithin	0.5	3	Processing agent, viscosity reducer
Wacker anti foam agent SH, # 16525	2 drop		Anti foam agent (Silicone Oil)
Castor Oil (Ricinus Oil)	0.25	1.5	Pot life extender, improves elastomeric properties tensile of the cured propellant
Tepanol, HX 878	0.2	1.2	Bonding agent AP-Matrix
2-Ethyhexyl Acrylat	3.0	18	Plasticizers
AL powder 400 Mesh	6	36	Thermic fuel
Fe2O3	0.5	3	Burning rate Catalyst
AP, particle size 200 um	50	300	
AP, particle size 90 um	22	135	AP together: 72%, 90um AP -> grind a little in a mortar (it baked together)
ISONATE 143L Diphenylmethane 4,4 Diisocyanate	2	12	Curing Agent
TOTAL	100%	601gr	

Processing:

1. Adding Lecitin, Anti foaming Agent, Plasticizer (not more than 50% of the amount of R45 resin) to the R45M Resin
2. Machine mixing 1 Min.
3. Add small parts Aluminum powder, stir it slowly (not by machine!) under the resin. Next part Alu. Etc
4. Add Burning Catalyst (Fe2O3)
5. Mixing 2 min, degasing (the fine AL and Fe2O3 Powder entraps a lot of air which is difficult to get out later when the grain has a higher viscosity!)
6. Adding AP, 90um AP -> grind a little in a mortar (it baked together)
7. Machine mixing 5 min.
8. Adding 2 % of the amount of the curing Agent to react with the moisture (0.25 grams), it will be consumed by the reaction with the moisture.
9. Machine mixing 20 min (3 x stirring down the mix from the wall of the bowl).
10. Degasing and vibrating under vacuum 30 min., let it in the vacuum chamber for half a day, the vacuum chamber resides in the climate chamber (50° C) during this time, vibrating again.
11. Preheat the casting form to 50° C.
12. Adding curing agents 143L (not more than 11 % of the content of HTPB!)
13. Mixing the warm Mix 5 min
14. Degasing 10 min (preferably together with vibrating)
15. Casting into the warm casting form with a „Vermiselle“ press, vibrating (Casting form coated with wax and silicon grease which will be dissolved by the resin/plasticizer)
16. Curing in climate chamber 40° C



Curing:

Curing in climate chamber 40° C. It need 2 days for complete curing.



Preparing considerations:

The propellant was casted into one phenolic tube fitting into the SPL BATES burner.

Charge #1 : Propellant weight [kg]: 0.445
 Case weight [kg]: 0.0534
 Length of grain [m]: 0.21
 Diameter of Grain [m]: 0.047m
 Density (Grain) [kg/m3]: 1550 kg/m3

Ignition: 6 g KP/Al Flash igniter (Rüfennacht Igniter), 1.3 Ohm, ignited by 12-Accu

Prediction from ProPEP Simulation (at 7.5 Mpa Chamber pressure):

Case 1 of 1 24 May 2000 at 7:58:24.88 pm

CODE	WEIGHT	D-H	DENS	COMPOSITION
137 AMMONIUM PERCHLORATE (AP)	432.000	-602	0.07040	1CL 4H 1N 4O
63 ALUMINUM (PURE CRYSTALLINE)	36.000	0	0.09760	1AL
541 IRON OXIDE	6.000	-1230	0.18400	3O 2FE
846 R45M	108.000	-30	0.04330	667C 999H 5O
396 ETHYL ACRYLATE	18.000	-877	0.00001	5C 8H 2O

THE PROPELLANT DENSITY IS 0.00033 LB/CU-IN OR 0.0092 GM/CC
 THE TOTAL PROPELLANT WEIGHT IS **600.0000 GRAMS**

NUMBER OF GRAM ATOMS OF EACH ELEMENT PRESENT IN INGREDIENTS

28.003487 H	8.816428 C	3.676690 N	15.238394 O
1.334322 AL	3.676690 CL	0.075141 FE	



*****CHAMBER RESULTS FOLLOW *****

T(K)	T(F)	P(ATM)	P(PSI)	ENTHALPY	ENTROPY	CP/CV	GAS	RT/V
2480.	4005.	74.83	1100.00	-286.47	1464.79	1.2308	26.520	2.821

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL= 9.436 10.339
 NUMBER MOLS GAS AND CONDENSED= 26.5203 0.6653

8.41288 H2	8.20427 CO	3.81110 H2O	3.50689 HCl
1.83744 N2	0.66505 Al2O3*	0.61100 CO2	0.07417 FeCl2
0.03987 H	0.01172 Cl	0.00373 HO	0.00188 AlCl3
1.14E-03 AlCl2	1.02E-03 NH3	6.13E-04 AlCl	3.44E-04 Fe
3.43E-04 CNH	2.83E-04 AlOCl	2.83E-04 FeH2O2	1.32E-04 CHO
1.16E-04 CH2O	1.14E-04 NO	1.08E-04 FeCl	7.62E-05 FeCl3
7.00E-05 AlHO2	5.43E-05 COCl	4.06E-05 AlHO	3.66E-05 Cl2
3.38E-05 CH4	2.20E-05 CNHO	1.59E-05 NH2	1.15E-05 O
7.92E-06 Fe2Cl4	7.88E-06 FeO		

THE MOLECULAR WEIGHT OF THE MIXTURE IS 22.071

*****EXHAUST RESULTS FOLLOW *****

T(K)	T(F)	P(ATM)	P(PSI)	ENTHALPY	ENTROPY	CP/CV	GAS	RT/V
1092.	1507.	1.00	14.69	-677.97	1464.79	1.2802	26.467	0.038

SPECIFIC HEAT (MOLAR) OF GAS AND TOTAL= 8.315 8.855
 NUMBER MOLS GAS AND CONDENSED= 26.4668 0.6673

9.64705 H2	6.93313 CO	3.52621 HCl	2.56418 H2O
1.86961 CO2	1.83793 N2	0.66704 Al2O3&	0.07385 FeCl2
0.01320 CH4	0.00055 Fe2Cl4	0.00051 NH3	0.00002 FeCl3
8.17E-06 CNH			

THE MOLECULAR WEIGHT OF THE MIXTURE IS 22.112

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

IMPULSE	IS EX	T*	P*	C*	ISP*	OPT-EX	D-ISP	A*M	EX-T
235.2	1.2531	2202.	41.48	4724.8		8.59	2.2	0.13353	1037.
238.3	1.2472	2276.	40.87	4906.3	187.7	8.59	2.2	0.13866	1092.

Estimation of Kn and throat diameter:

$$P_{\text{chamber}} = Kn \cdot I_{sp}^* \cdot r \cdot \rho_{\text{Grain}}$$

P_{chamber} : Pressure in Combustion chamber [Mpa]
 Kn: Burning surface / Area Throat
 I_{sp}^* : [m/s]
 $\tilde{\rho}_{\text{Grain}}$: Density of grain [kg/m3]
 D_{throat} : Diameter Throat [m]
 A_{burn} : Burning surface
 r: burning rate [m/s]

$$Kn = \frac{P_{\text{chamber}}}{I_{sp}^* \cdot r \cdot \rho_{\text{Grain}}}$$

$$D_{\text{throat}} = \sqrt{\frac{4 \cdot A_{\text{burn}} \cdot I_{sp}^* \cdot r \cdot \tilde{\rho}_{\text{Grain}}}{P_{\text{chamber}} \cdot p}}$$

Estimated burning rate: 0.01 m/s (1 cm/s)
 Desired chamber pressure: 7.5 MPa (75 bar)
 I_{sp}^* : 1870 m/s
 A_{burn} : 0.0290 m²



\tilde{n}_{Grain} : 1550 kg/m³

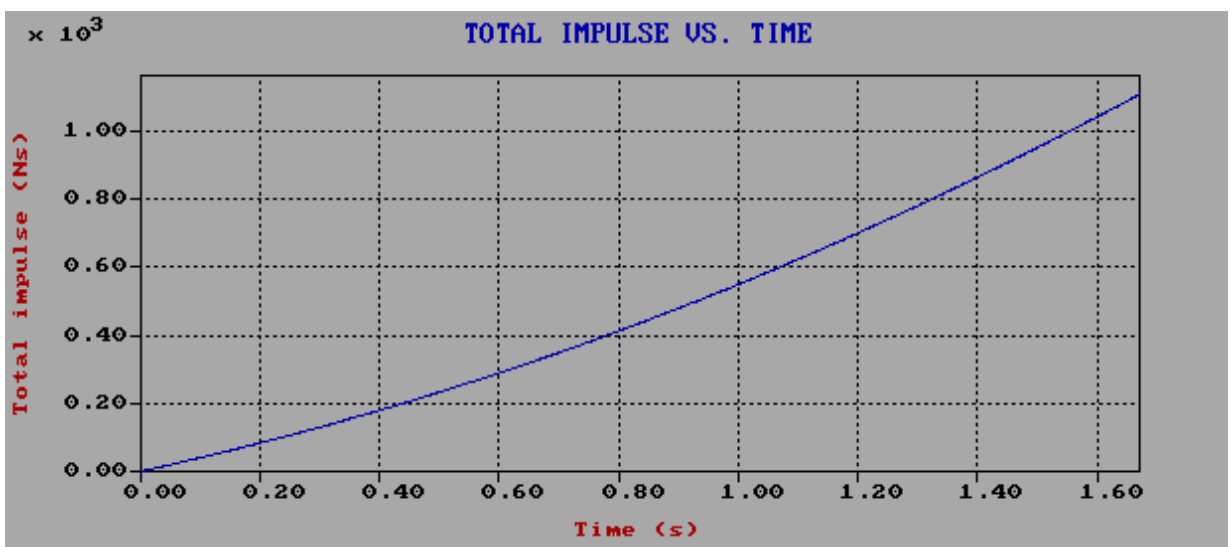
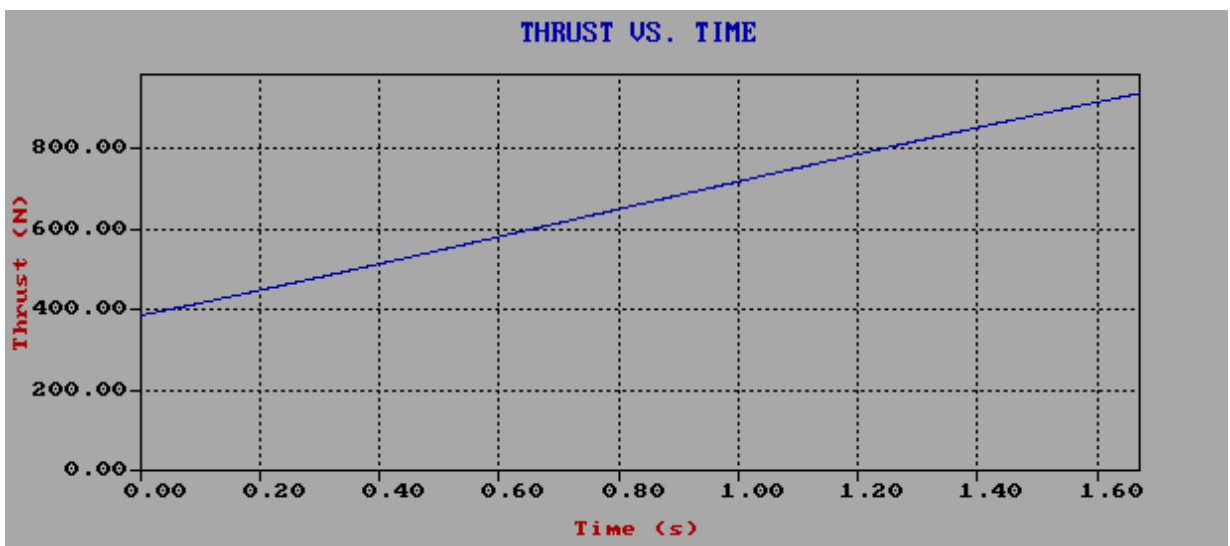
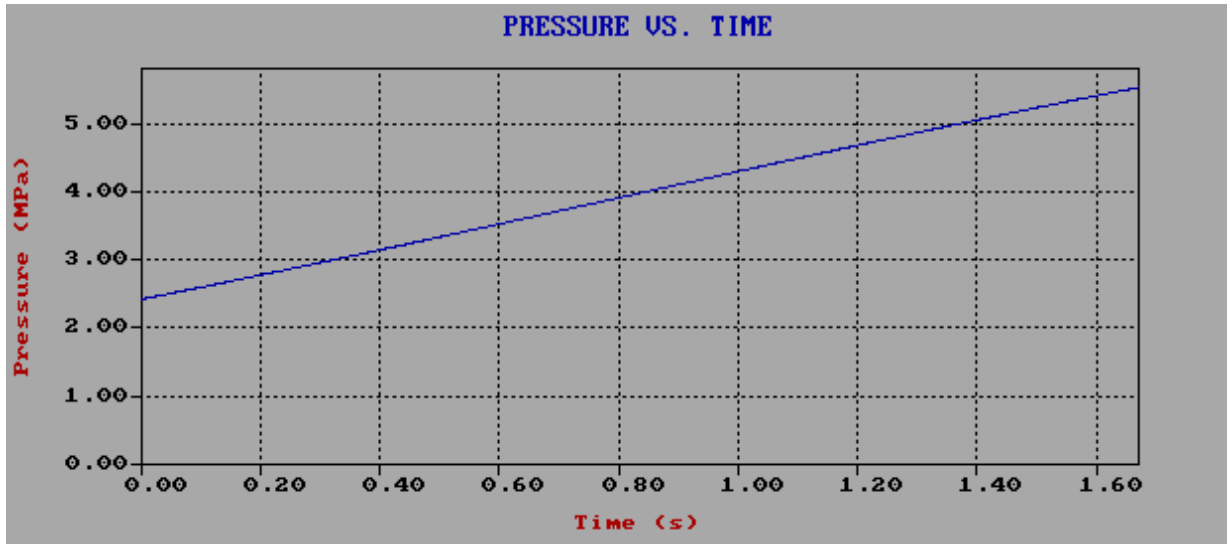
Kn = 258

D_{throat}: 1.19 E-2 m (12mm)

=> chosen throat is 12 mmm (it already exists)



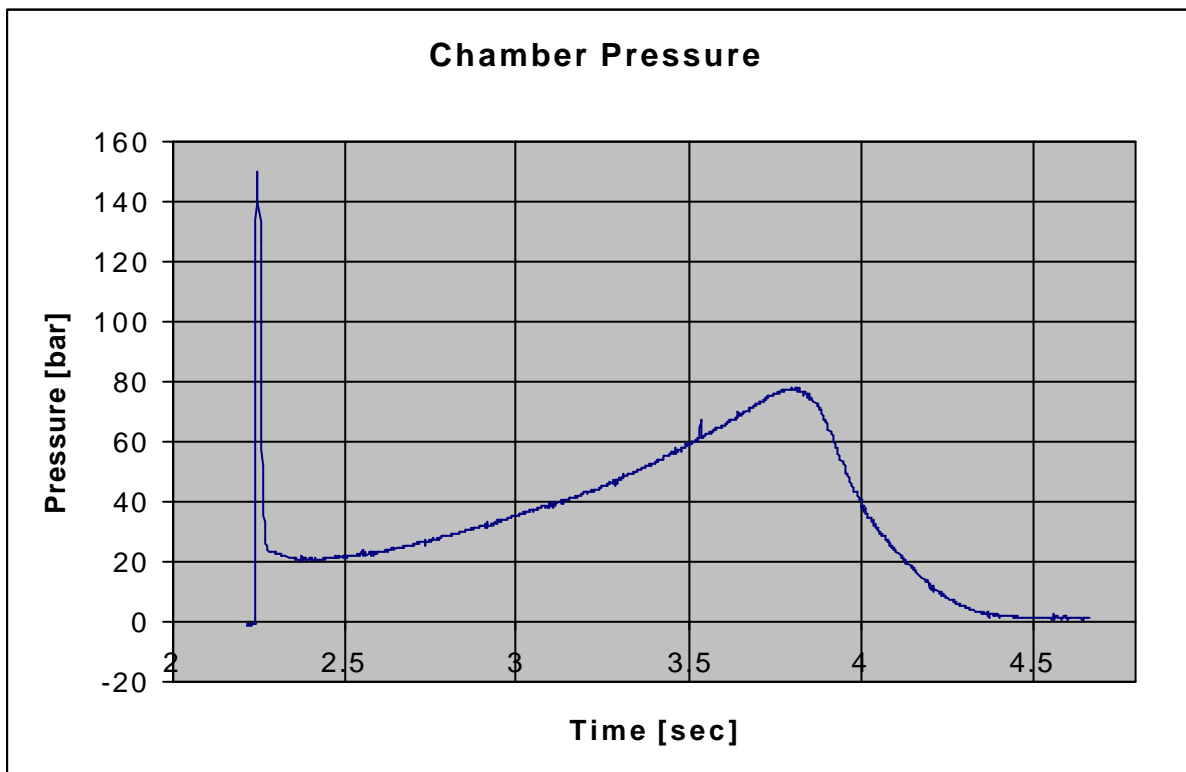
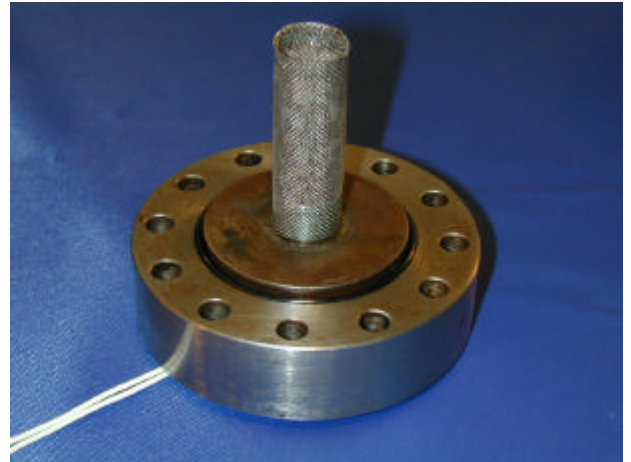
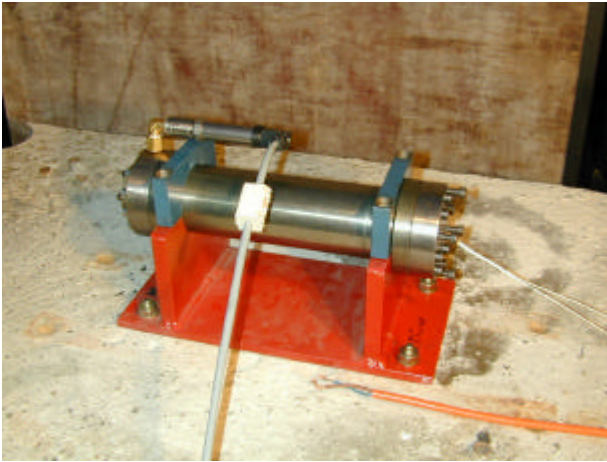
Simulation with GDPL (detailed output see Appendix A):





Results:

Fired 23. June 2000 in Langenthal. Instant (10 msec!) Ignition with Flash igniter (6 gram 50% Flash/50% BP). Flash powder was 60% KP/40% Al. The Bates chamber was used:

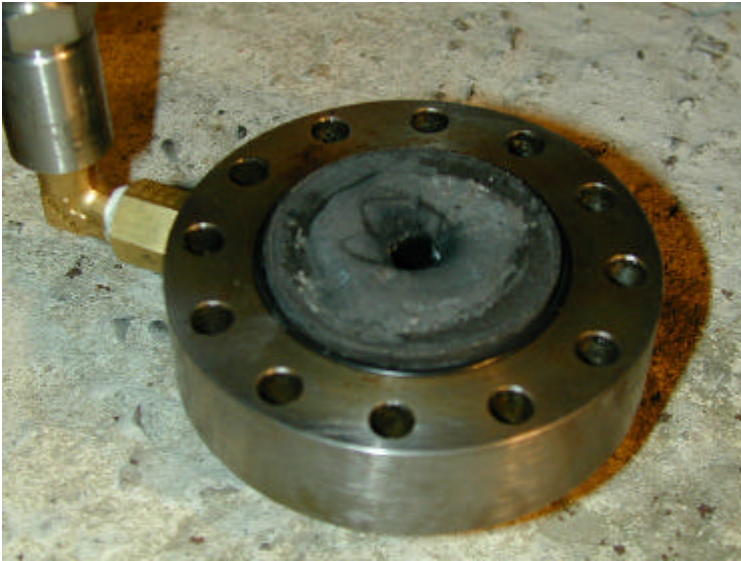


Propellant characteristics:

$r = 0.00645 \text{ m/s}$
 $a = 5.00 \text{ E-5 m/s}$
 $n = 0.35$



Somme clogging of the nozzle occurred. Al₂O₃ reduced the nozzle diameter to about 11 mm.



Conclusions:

Perfect ignition! The igniter charge was too heavy, next firing will use only 4.5g Powder (1.8g Flash, 2.7 BP).



Appendix A

Output from GDPL

G-Light: Grain Design Program
Version 2.0, (11 September 1999)
Copyright (C) 1997 Mountain View Software, All Rights Reserved

Licence information:

- Last name : BERGER
- First name : BRUNO
- City name : BERN
- Country name : SWITZERLAND
- License type : LIGHT
- Serial number: TQCYVGJH-19992012

File : BATES1.REP
Creation date : Tue, 4 Jul 2000
Creation time : 19:56:57

DEBUG MODE: uses expanded printout

Part 1 Project: BATES1

--- MAIN PROJECT DATA ---
~~~~~

| Files in project: | creation date | creation time | file size   |
|-------------------|---------------|---------------|-------------|
| - BATES1.PRJ      | 4 Jul 2000    | 19:56:52      | 6660        |
| - BATES1.GEO      | 26 Jun 2000   | 23:08:36      | 1198        |
| - BATES1.GMX      | -not found-   | -not found-   | -not found- |
| - BATES1.SBA      | 4 Jul 2000    | 19:53:00      | 48024       |
| - BATES1.BRN      | 4 Jul 2000    | 19:53:10      | 535360      |

.PRJ header : Grain Design Program - project file  
.PRJ file ID : GDPRJ-01  
Project descr. : Bates Grain, 24.4.00,6%Al

-----  
Part 2 Project: BATES1

--- MAIN PROPELLANT DATA ---  
~~~~~

Every grain segment can define its own propellant data!

Name : 6 % Al, 1 % Fe2O3, 71 % AP+ HTPB
Family : AP/Al
Remark : Burned in SPL Bates Grain

Propellant density	:	1.6300000000000E+03	kg/m3
Gamma (=Cp/Cv)	:	1.2299999999999E+00	-
Molecular mass	:	2.2049999999998E+01	g/mol
Flame temperature, Tf	:	2.4800000000000E+03	K
> C star value, C*	:	1.4779618136620E+03	m/s
> Choked flow pressure ratio	:	1.7898546693849E+00	-
> Cp value	:	2.0164918071618E+03	J/kgK
> Cv value	:	1.6394242334655E+03	J/kgK
> Specific gas constant, Rs	:	3.7706757369634E+02	J/kgK
> Speed of sound, c	:	1.0724770052560E+03	m/s
> Vandekerckhove value	:	6.5429291919427E-01	-
> Specific impulse (for Pc/Pe=68)	:	2.3823838609748E+02	s



> Specific impulse (for Pc/Pe=70) : 2.3876641186465E+02 s
 > Volumetric impulse (for Pc/Pe=70) : 3.8918925133938E+05 (kg.s)/m3

Main burn rate information:

Note: Correlation used: $r = a \cdot P^n$ (r in mm/s and P in MPa)

Number of burn rate intervals : 5
 Interval 1:
 Valid to pressure : 1.0000000000000E-04 MPa
 Burn rate prefactor, a : 5.0000000000000E+00
 Burn rate exponent, n : 3.4999999999991E-01
 Temperature sensitivity, Sigma_p : 1.5000000000009E-01 %/K
 > Temperature sensitivity, Pi_k : 2.3076923076934E-01 %/K
 Reference temperature, T_ref : 2.9310000000009E+02 K

Interval 2 is not used!
 Interval 3 is not used!
 Interval 4 is not used!
 Interval 5 is not used!

Consistency check (20 deg C data):

Burn rate for P = 0.1 MPa : 2.2433946224453E+00 mm/s
 Burn rate for P = 1.0 MPa : 4.9992500562465E+00 mm/s
 Burn rate for P = 5.0 MPa : 8.7810077747701E+00 mm/s
 Burn rate for P = 6.9 MPa (1000 psi): 9.8263415343407E+00 mm/s
 Burn rate for P = 7.0 MPa : 9.8784583743787E+00 mm/s
 Burn rate for P = 10.0 MPa : 1.1191926777906E+01 mm/s
 Burn rate for P = 15.0 MPa : 1.2898428507457E+01 mm/s
 Burn rate for P = 20.0 MPa : 1.4264789214958E+01 mm/s
 Burn rate for P = 25.0 MPa : 1.5423532864540E+01 mm/s
 Burn rate for P = 30.0 MPa : 1.6439829129896E+01 mm/s

 Part 3 Project: BATES1
 --- NOZZLE AND BLAST TUBE DATA ---
 ~~~~~

Total throat area, At : 1.1309733552923E-04 m<sup>2</sup>  
 Corresponding single nozzle diameter : 1.2000000000000E-02 m  
 Use a nozzle erosion table : NO  
 Nozzle expansion ratio : 4.0000000000000E+00 -  
 Nozzle discharge coefficient : 1.0000000000000E+00 -  
 Nozzle divergence loss factor : 9.8296300000000E-01 -  
 > Corresponding half cone angle : 1.4999961544887E+01 degrees  
 Thrust coefficient efficiency : 1.0000000000000E+00 -

Burst disc pressure difference : 1.0100000000000E-01 MPa  
 Non propellant grain free volume : 3.9000000000011E-05 m3

-----  
 Part 4 Project: BATES1  
 --- ATMOSPHERIC CONDITIONS ---  
 ~~~~~

Motor temperature : 2.9414999999991E+02 K
 Ambient pressure : 1.0132500000000E-01 MPa
 Use an ambient pressure table : NO

 Part 5 Project: BATES1
 --- IGNITER DATA ---
 ~~~~~

Igniter massflow duration : 1.0000000000000E-01 s  
 Igniter mass flow profile type : Constant massflow  
 Total igniter propellant mass : 1.0000000000000E-01 kg  
 Igniter uses main propellant : NO  
 Gamma (=Cp/Cv) : 1.2000000000000E+00 -



```

Molecular mass           : 2.5000000000000E+01 g/mol
Flame temperature,Tf    : 3.0000000000000E+03 K
> C star value, C*     : 1.5401877273332E+03 m/s
> Choked flow pressure ratio : 1.7715610000000E+00 -
> Cp value              : 1.9954416000000E+03 J/kgK
> Cv value              : 1.6628680000000E+03 J/kgK
> Specific gas constant, Rs : 3.3257360000000E+02 J/kgK
> Speed of sound, c     : 1.0941960336247E+03 m/s
> Vandekerckhove value  : 6.4853117070629E-01 -
> Specific impulse (for Pc/Pe=68) : 2.5075275467525E+02 s
> Specific impulse (for Pc/Pe=70) : 2.5133608045788E+02 s

```

```

-----
Part 6                                     Project: BATES1
      --- PROPELLANT GRAIN SEGMENT DATA, SUMMARY ---
      ~~~~~

```

```
Total number of segments : 1
```

```
Segment data at t=0 s:
```

| #<br>(-) | Type<br>(-) | Length<br>(m) | Prop.vol.<br>(m3) | Free vol.<br>(m3) | Port area<br>(m2) |
|----------|-------------|---------------|-------------------|-------------------|-------------------|
| 1        | Cylinder    | 2.2000E-01    | 3.1257E-04        | 6.9115E-05        | 3.1416E-04        |

```
Data for t=0 s:
```

```

- Total length of all segments : 2.2000000000000E-01 m
- Total propellant volume : 3.1257276106892E-04 m3
- Total grain free volume : 6.9115038378975E-05 m3
- > Grain volumetric loading : 8.1892258940697E+01 %
- System free volume : 1.0811503837899E-04 m3
- > System volumetric loading : 7.4300410299307E+01 %
- Minimum port area : 3.1415926535898E-04 m2
- Minimum port area segment number : 1
- > Min.J-value (=At/port area) : 3.6000000000000E-01 -
- Maximum port area : 3.1415926535898E-04 m2
- Maximum port area segment number : 1
- > Max.J-value (=At/port area) : 3.6000000000000E-01 -
- > L* value (=Free volume/At) : 9.5594682114365E-01 m

```

```
Segment propellant mass at t=0 s:
```

```
(* = locally defined propellant)
```

| # | Type     | Force the use of main propellant only |                     |
|---|----------|---------------------------------------|---------------------|
|   |          | NO (kg)                               | YES (kg)            |
| 1 | Cylinder | 5.0949360054233E-01                   | 5.0949360054233E-01 |

```
Propellant mass available at t=0 s:
```

```

- allow use of local propellant : 5.0949360054233E-01 kg
- force use of main propellant : 5.0949360054233E-01 kg

```

```

Part 7 Project: BATES1
 --- PROPELLANT GRAIN SEGMENT DATA, DETAILS ---
      ~~~~~

```

```
Total number of segments : 1
```

```

Segment number           : 1
Segment type             : CYLINDER
  Length                  : 2.2000000000000E-01 m
  Inner radius             : 1.0000000000000E-02 m
  Web thickness            : 1.3500000000000E-02 m
  > Outer radius           : 2.3500000000000E-02 m
  > Grain diameter         : 4.7000000000000E-02 m
  Left end inhibited      : NO
  Right end inhibited     : NO

```



```

Center port inhibited           : NO
External cylinder inhibited    : YES
> Length/diameter ratio       : 4.6808510638298E+00 -
> Web fraction                 : 5.7446808510638E-01 -
> Volume load                  : 8.1892258940697E+01 %
> Sliver                       : 0.0000000000000E+00 %
> Initial burn area           : 1.6664578230967E-02 m2
> Initial port area           : 3.1415926535898E-04 m2
> Initial free volume         : 6.9115038378975E-05 m3
> Initial propellant volume   : 3.1257276106892E-04 m3
> Initial propellant mass     : 5.0949360054233E-01 kg

```

```

Segment uses main propellant   : YES

```

```

Start of gas production:
Segment gas production starts
immediately after segment ignition time

```

```

-----
Part 8                                     Project: BATES1

```

```

--- SEGMENT BURN PROFILE DATA ---
~~~~~

```

```

Total number of segments : 1

```

```

Segment data at burn depth = 0 mm:

```

| #   | Type     | Web        | Burn area         | Free vol.         | Port area         |
|-----|----------|------------|-------------------|-------------------|-------------------|
| (-) | (-)      | (m)        | (m <sup>2</sup> ) | (m <sup>3</sup> ) | (m <sup>2</sup> ) |
| 1   | Cylinder | 1.3500E-02 | 1.6665E-02        | 6.9115E-05        | 3.1416E-04        |

```

(bd = burn depth)
Total burn area of segments (bd=0 mm): 1.6664578230967E-02 m2
Total grain free volume (bd=0 mm) : 6.9115038378975E-05 m3
System free volume (bd=0 mm) : 1.0811503837899E-04 m3
Minimum port area (bd=0 mm) : 3.1415926535898E-04 m2
Minimum port area segment number : 1
Maximum port area (bd=0 mm) : 3.1415926535898E-04 m2
Maximum port area segment number : 1

```

```

Segment burn profile characteristic values:

```

| #   | Minimum burn area | @ depth   | Maximum burn area | @ depth   | Maximum free vol. | Maximum port area |
|-----|-------------------|-----------|-------------------|-----------|-------------------|-------------------|
| (-) | (m <sup>2</sup> ) | (m)       | (m <sup>2</sup> ) | (m)       | (m <sup>3</sup> ) | (m <sup>2</sup> ) |
| 1   | 1.666E-02         | 0.000E+00 | 2.850E-02         | 1.350E-02 | 3.817E-04         | 1.735E-03         |

```

Remark: maximum free volume and maximum port area
will be at maximum burn depth.

```

```

Part 9 Project: BATES1

```

```

--- SYSTEM PERFORMANCE DATA ---
~~~~~

```

```

Settings for last system performance calculations:

```

```

Type of performance calculations : Steady state
Full recalculation of all segments : NO
Use only main propellant : YES
Show image burns on screen : YES
Time step between data points : fixed
(Initial) time step : 9.9999999999945E-04 s

```

```

Total grain mass for burn : 5.0949360054233E-01 kg
(excl. sliver)

```



Time required for core calculations : 00:00:11  
 Number of data points calculated : 1672 points  
 Speed of calculations : 1.4359072905660E+02 points/s

Motor burn time : 1.6709999999991E+00 s

Characteristic system performance data:

| Parameter                  |          | Minimum<br>@ time | Maximum<br>@ time | Average      |
|----------------------------|----------|-------------------|-------------------|--------------|
| --SEGMENT DETAILS--        |          |                   |                   |              |
| Total burn area            | (m2)     | 1.667229E-02      | 2.849341E-02      | 2.287042E-02 |
|                            | (s)      | 1.000000E-03      | 1.672000E+00      |              |
| Total free volume          | (m3)     | 1.082287E-04      | 4.205057E-04      | 2.437499E-04 |
|                            | (s)      | 1.000000E-03      | 1.672000E+00      |              |
| Active segments            | (-)      | 1.000000E+00      | 1.000000E+00      | 1.000000E+00 |
|                            | (s)      | 1.000000E-03      | 1.000000E-03      |              |
| Maximum burn rate          | (mm/s)   | 6.819336E+00      | 9.111302E+00      | 8.070340E+00 |
|                            | (s)      | 1.000000E-03      | 1.672000E+00      |              |
| Maximum burn depth         | (mm)     | 6.819336E-03      | 1.349361E+01      | 6.431015E+00 |
|                            | (s)      | 1.000000E-03      | 1.672000E+00      |              |
| --MOTOR INTERNALS--        |          |                   |                   |              |
| Pressure                   | (MPa)    | 2.421786E+00      | 5.529977E+00      | 3.980394E+00 |
|                            | (s)      | 1.000000E-03      | 1.672000E+00      |              |
| Gas temperature            | (K)      | 2.480000E+03      | 2.480000E+03      | 2.480000E+03 |
|                            | (s)      | 1.850000E-01      | 2.020000E-01      |              |
| Molecular mass             | (g/mol)  | 2.205000E+01      | 2.205000E+01      | 2.205000E+01 |
|                            | (s)      | 6.000000E-03      | 3.000000E-03      |              |
| Gamma (=Cp/Cv)             | (-)      | 1.230000E+00      | 1.230000E+00      | 1.230000E+00 |
|                            | (s)      | 1.400000E-02      | 5.000000E-03      |              |
| C star value (c*)          | (m/s)    | 1.477962E+03      | 1.477962E+03      | 1.477962E+03 |
|                            | (s)      | 5.000000E-03      | 6.000000E-03      |              |
| Maximum mass flux (kg/m2s) |          | 2.440412E+02      | 5.891816E+02      | 3.824672E+02 |
|                            | (s)      | 1.672000E+00      | 2.000000E-03      |              |
| Max.mass flux segment      | (-)      | 1.000000E+00      | 1.000000E+00      | 1.000000E+00 |
|                            | (s)      | 1.000000E-03      | 1.000000E-03      |              |
| --NOZZLE PARAMETERS--      |          |                   |                   |              |
| Effective throat area      | (m2)     | 1.130973E-04      | 1.130973E-04      | 1.130973E-04 |
|                            | (s)      | 1.000000E-03      | 1.000000E-03      |              |
| Eff. expansion ratio       | (-)      | 4.000000E+00      | 4.000000E+00      | 4.000000E+00 |
|                            | (s)      | 1.000000E-03      | 1.000000E-03      |              |
| Nozzle exit pressure       | (MPa)    | 9.944605E+04      | 2.270780E+05      | 1.634473E+05 |
|                            | (s)      | 1.000000E-03      | 1.672000E+00      |              |
| Nozzle exit velocity       | (m/s)    | 2.120424E+03      | 2.120424E+03      | 2.120424E+03 |
|                            | (s)      | 5.600000E-02      | 1.000000E-03      |              |
| Nozzle exit mach number    | (-)      | 2.664841E+00      | 2.664841E+00      | 2.664841E+00 |
|                            | (s)      | 1.400000E-02      | 1.000000E-03      |              |
| Nozzle exit temperature    | (K)      | 1.365144E+03      | 1.365144E+03      | 1.365144E+03 |
|                            | (s)      | 1.000000E-03      | 3.710000E-01      |              |
| Nozzle mass flux           | (kg/m2s) | 1.638598E+03      | 3.741624E+03      | 2.693164E+03 |
|                            | (s)      | 1.000000E-03      | 1.672000E+00      |              |
| --MOTOR OUTPUT--           |          |                   |                   |              |
| Mass flow                  | (kg/s)   | 1.853211E-01      | 4.231677E-01      | 3.045897E-01 |
|                            | (s)      | 1.000000E-03      | 1.672000E+00      |              |
| Thrust coefficient         | (-)      | 1.407148E+00      | 1.501213E+00      | 1.466778E+00 |
|                            | (s)      | 1.000000E-03      | 1.672000E+00      |              |
| Thrust                     | (N)      | 3.854144E+02      | 9.388968E+02      | 6.629592E+02 |
|                            | (s)      | 1.000000E-03      | 1.672000E+00      |              |
| Total impulse              | (Ns)     | 3.854144E-01      | 1.108468E+03      | 4.762233E+02 |
|                            | (s)      | 1.000000E-03      | 1.672000E+00      |              |
| Specific impulse           | (m/s)    | 2.079711E+03      | 2.218735E+03      | 2.167841E+03 |
|                            | (s)      | 1.000000E-03      | 1.672000E+00      |              |
| Specific impulse           | (s)      | 2.120715E+02      | 2.262479E+02      | 2.210583E+02 |
|                            | (s)      | 1.000000E-03      | 1.672000E+00      |              |



|                        |       |              |              |              |
|------------------------|-------|--------------|--------------|--------------|
| --MISCELLANEOUS--      |       |              |              |              |
| Ambient pressure       | (MPa) | 1.013250E-01 | 1.013250E-01 | 1.013250E-01 |
|                        | (s)   | 1.000000E-03 | 1.000000E-03 |              |
| Igniter mass perc.used | (%)   | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 |
|                        | (s)   | 1.000000E-03 | 1.000000E-03 |              |
| Propellant mass used   | (%)   | 3.040575E-02 | 8.355691E+01 | 3.627989E+01 |
|                        | (s)   | 1.000000E-03 | 1.672000E+00 |              |
| Total mass expelled    | (kg)  | 1.853211E-04 | 5.092740E-01 | 2.211236E-01 |
|                        | (s)   | 1.000000E-03 | 1.672000E+00 |              |

-----