Program IB_RM_M0 – Internal Ballistics of Rocket Motor

Short Presentation

The program is implemented based the unsteady state zero-dimensional model of the solid propellant rocket motor. It can be used for the analysis and design of small rocket motors, such as rocket motors for light antitank weapons and the rocket assisted artillery projectiles and preliminary design of the medium size rocket motors for small and medium range artillery rockets.

The program can calculate all important internal ballistic parameters of the solid propellant rocket motors. It can also be used for:

- the design of igniters for the chosen propellant grain,
- the design of the propellant grain with variation of grain geometry,
- the analysis of the influence of the temperature of the propellant grain on internal ballistic parameters,
- the analysis of the effects of erosive burning in the rocket motor chamber,
- other purposes concerning rocket motor analysis and design.

Burning process is modeled by four differential equations of the first order. Equations are solved numerically by fourth order Runge-Kutta method.

Burning surface with burned depth can be entered through specified separate file or calculated in the program for common geometry.

Burning rate can be specified in power low, or alternatively it can be entered through specified separate file.

Program is written in Matlab. It automatically prints all characteristic functions of the process in time and produces graphs. It also calculates integral characteristics of the process.

Example: Analysis of the artillery rocket motor with an approximately steady-state process and operating time around 3.2 s.

Input Data

```
%  I N P U T  D A T A  for program IBRocketMotor_M0
WeaponID = 'AP HE 155mm-RA-BB ';    %  - projectile identifier
GrainID  = 'Six arms star';         %  - grain shape identifier
GeomStar6RM155mm_V0;
%
%  CHARACTERISTICS OF THE PROPELLANT AND GAS BURNING PRODUCT
%massp   = 2.725;          %  [kg]     - mass of propellant
rhop     = 1598;           %  [kg/m³] - density of propellant
Cheatp   = 1955;           %  [J/kgK] - specific heat of propellant
Rgas     = 345.0;          %  [J/kgK] - gas constant
Tflame   = 2320;           %  [K]      - burning (flame) temperature
kappa    = 1.241;          %  [-]      - ratio of gas specific heats
etath    = 0.990;          %  [-]      - coef. of thermal reduction
cetad    = 0.980;          %  [-]      - coef. of discharge efficiency
%
%  BURNING RATE LOW
burnRateID = 0;            %  [-]      - burning rate method
brb        = 2.76e-5;      %  [m/s/(Pa^nrb)] - coef. in burning law
nrb        = 0.374;        %  [-]      - exponent in burning rate law
betarb     = 0.0015;       %  [1/K]    - coef. of the influence of
                                          prop. temp. on burning rate
krp        = 1.000;        %  [-]      - coef. of the influence of
                                          spin rate on burning rate
delta      = 1;            %  [-]      - parameter for identification
                                          of erosive burning
keps       = 0.122;        %  [-]      - coef. of erosive burning
Ilim       = 15.8;         %  [-]      - limiting parameter of erosive
                                          burning appearance
mu         = 6.25E-5;      %  [-]      - dynamic viscosity of products

%  PROPELLANT TEMPERATURES
PropTempMat  =[-30 21 55];%  [°C]     - array of propellant temp.
PropTemp     = 21;         %  [°C]     - propellant temperature
PropTempID   = 1;          %  [-]      - propellant temper. method ID
PlotBurningRate();
%
%  NOZZLE DATA
At      = 1.76E-4;         %  [m²]     - nozzle throat area
Ae      = 11.34E-4;        %  [m²]     - nozzle exit area
etaF     = 0.970;          %  [-]      - nozzle efficiency factor
```

```
lambda   = 0.983;          %  [-]      - correction factor for nozzle
                                         divergence loss
CosTheta = 1.000;          %  [-]      - cosine of the nozzle axis
                                         angle (cant angle);
patm     = 1.00E5;         %  [pa]     - ambient pressure
%
%  INITIAL CONDITIONS
P0c      = 35E5;           %  [Pa]     - maximal ignition pressure
Rgi      = 311.0;          %  [J/kgK]  - gas constant of igniter
                                         burning gas product
Tfli     = 2340.0;         %  [K]      - burning temper. of igniter
rho0c    = P0c / (Rgi * Tfli); %       - density of igniter burning
                                         gas products
Vol0c    = 0.484E-3;       %  [m³]     - chamber initial free volume
Pplug    = 70E5;           %  [Pa]     - plug ejection  pressure
%
%  SIMULATION PARAMETERS
Ts       = 2E-3;           %  [s]      - integration step
jprint   = 50;             %  [-]      - printing step ratio
tfinal   = 6.0 ;           %  [s]      - final time of calculation
tUnitID  = 1;              %  [-]      - identifier for output time
                                         units: =0 - [ms],  =1 - [s]
PrintToFileID = 1;         %  [-]      - Output file Identifier (=1 -
                                         Results printed in file)
%
%  LAUNCHER CHARACTERISTICS
LauncherID = 0;            %  [-]      - launcher identifier: =1 -
                                         exist, =0 - not exist
s0         = 3.0;          %  [m]      - launcher length
m0         = 70.0;         %  [kg]     - initial projectile mass
flock      = 5.00;         %  [-]      - launcher specific lock =
                                         Flock/mg
friccoef   = 0.30;         %  [-]      - friction coefficient
Theta0     = 51.0;         %  [deg]    - initial elevation
%
%-------------------------- EOF --------------------------------
```

Grain Geometry

```
%=====================================================================
function GeomStar6RM155mm_V0
%
%  Calculation of burning area of a six star grain
```

Function not shown here!

Output of the Calculation

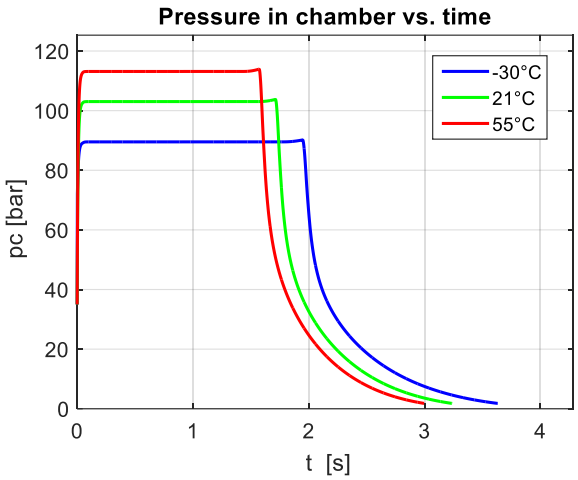
```
                        O U T P U T  O F  T H E  P R O G R A M
IBRocketMotor_M0.m
-------------------------------------------------------------------------------


   Weapon   = Artillery Rocket-Assisted Projectile
   Grain    = Six arms star


 Propellant Characteristics in Motor at Standard Conditions
 ----------------------------------------------------------
   PropTemp =     20.0 °C
   pc       =   70.931 bar
   patm     =    1.013 bar
   alpha    =     15.0 deg
   IspStd   =   2115.3 Ns/kg
   IspStd/g =    215.7 s
   CFStd    =    1.552 -
   CstarStd =   1363.0 m/s
   rburnStd =     10.1 mm/s


 Motor Performances at Design Conditions
 ---------------------------------------
   PropTemp =     21.0 °C
   PropMass =   2.5982 kg
   Itot     =   5351.7 Ns
   Isp      =   2059.8 Ns/kg
   ttot     =     3.24 s
   Fxmax    =   2744.9 N
   Pcmax    =    103.8 bar
   Ipress   =   202.59 bar×s
   tomean   =     1.81 s
   pcmean   =    112.2 bar
   Fxmean   =   2963.3 N
   Gamma    =    0.656 -
   CF0      =    1.533 -
   CF       =    1.501 -
   Cstar    =   1372.4 m/s
   Ue       =   1943.7 m/s
```

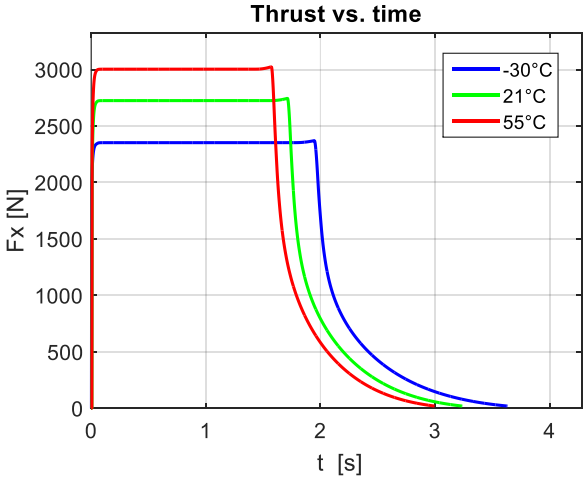
Time	Dens	pc	Volc	Ab	mburnt	yb	rburn	Fx	pex	medot	Time
[s]	[kg/m³]	[bar]	[cm³]	[cm²]	[kg]	[mm]	[mm/s]	[N]	[bar]	[kg/s]	[s]
0.00	4.81	35.0	484.0	701.3	0.000	0.000	7.75	0.0	1.00	0.00	0.00
0.10	13.00	103.0	564.0	706.9	0.128	1.134	11.60	2724.7	2.11	1.31	0.10
0.20	13.00	103.0	646.0	706.9	0.259	2.294	11.60	2724.8	2.11	1.31	0.20
0.30	13.00	103.0	728.0	706.9	0.390	3.454	11.60	2724.8	2.11	1.31	0.30
0.40	13.00	103.0	810.0	706.9	0.521	4.614	11.60	2724.8	2.11	1.31	0.40
0.50	13.00	103.0	892.0	706.9	0.652	5.774	11.60	2724.8	2.11	1.31	0.50
0.60	13.00	103.0	974.0	706.9	0.783	6.934	11.60	2724.8	2.11	1.31	0.60
0.70	13.00	103.0	1056.0	706.9	0.914	8.094	11.60	2724.8	2.11	1.31	0.70
0.80	13.00	103.0	1138.0	706.9	1.045	9.254	11.60	2724.8	2.11	1.31	0.80
0.90	13.00	103.0	1220.0	706.9	1.176	10.414	11.60	2724.8	2.11	1.31	0.90
1.00	13.00	103.0	1301.9	706.9	1.307	11.574	11.60	2724.8	2.11	1.31	1.00
1.10	13.00	103.0	1383.9	706.9	1.438	12.733	11.60	2724.9	2.11	1.31	1.10
1.20	13.00	103.0	1465.9	706.9	1.569	13.893	11.60	2724.9	2.11	1.31	1.20
1.30	13.00	103.0	1547.9	706.9	1.700	15.053	11.60	2724.9	2.11	1.31	1.30
1.40	13.00	103.0	1629.9	706.9	1.831	16.213	11.60	2724.9	2.11	1.31	1.40
1.50	13.00	103.0	1711.9	706.9	1.962	17.373	11.60	2724.9	2.11	1.31	1.50
1.60	13.00	103.1	1793.9	707.3	2.093	18.533	11.60	2725.9	2.11	1.31	1.60
1.70	13.07	103.7	1876.2	710.5	2.225	19.694	11.63	2741.8	2.12	1.32	1.70
1.80	7.66	59.2	1936.6	453.9	2.321	20.761	9.43	1517.0	1.21	0.75	1.80
1.90	5.30	41.5	1973.0	380.8	2.379	21.638	8.26	1032.8	1.00	0.53	1.90
2.00	4.16	32.7	2001.0	330.6	2.424	22.427	7.55	793.8	1.00	0.42	2.00
2.10	3.36	26.4	2023.4	290.0	2.460	23.152	6.97	627.2	1.00	0.34	2.10
2.20	2.74	21.5	2041.7	255.3	2.489	23.823	6.46	499.6	1.00	0.27	2.20
2.30	2.24	17.6	2056.7	224.8	2.513	24.445	5.99	397.8	1.00	0.22	2.30
2.40	1.82	14.3	2068.8	197.6	2.533	25.021	5.55	315.2	1.00	0.18	2.40
2.50	1.48	11.6	2078.7	173.2	2.548	25.555	5.13	247.8	1.00	0.15	2.50
2.60	1.19	9.4	2086.7	151.0	2.561	26.047	4.73	192.6	1.00	0.12	2.60
2.70	0.95	7.5	2093.1	131.0	2.571	26.501	4.35	147.5	1.00	0.10	2.70
2.80	0.75	5.9	2098.2	112.9	2.579	26.918	3.99	110.8	1.00	0.08	2.80
2.90	0.59	4.6	2102.2	96.5	2.586	27.299	3.63	81.3	1.00	0.06	2.90
3.00	0.46	3.6	2105.2	81.7	2.591	27.645	3.30	57.8	1.00	0.05	3.00
3.10	0.35	2.7	2107.6	68.4	2.594	27.959	2.97	39.3	1.00	0.03	3.10
3.20	0.26	2.0	2109.4	56.6	2.597	28.240	2.66	24.8	1.00	0.03	3.20
3.24	0.23	1.8	2109.9	52.5	2.598	28.339	2.55	20.2	1.00	0.02	3.24

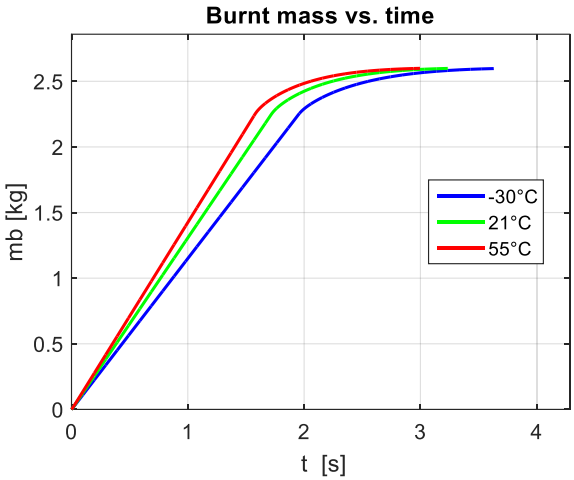
Influence of Propellant Temperature

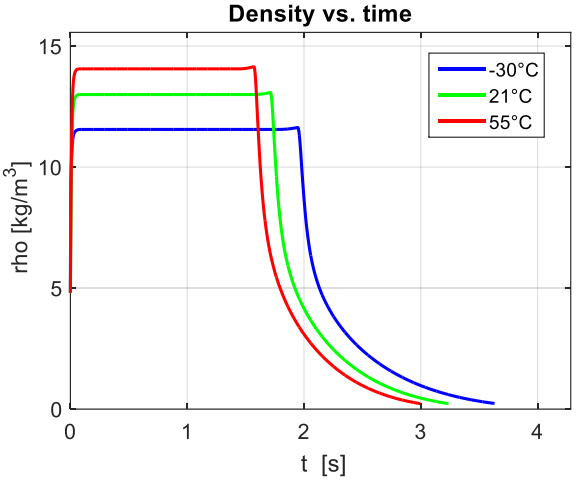
Tprop	Itot	tomean	Isp	pcmax
[°C]	[Ns]	[s]	[Ns/kg]	[bar]
55.0	5419.8	1.66	2085.5	113.9
21.0	5351.7	1.81	2059.8	103.8
-30.0	5254.2	2.05	2023.2	90.2

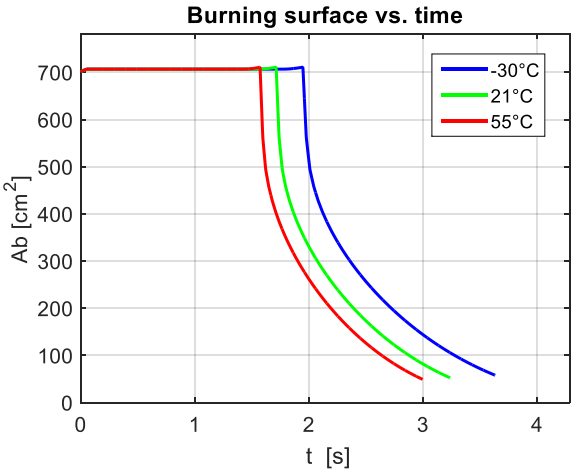
Graphs of the Basic Quantities

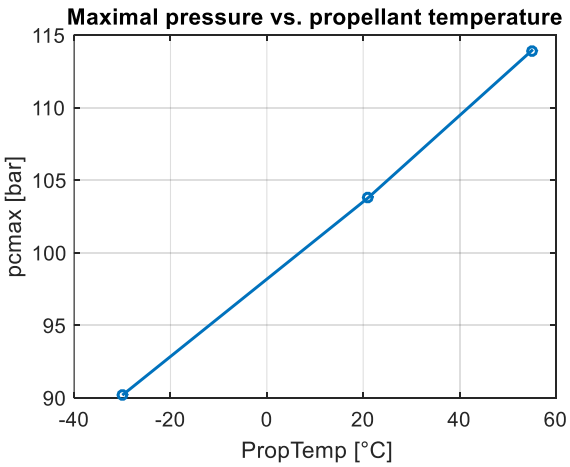


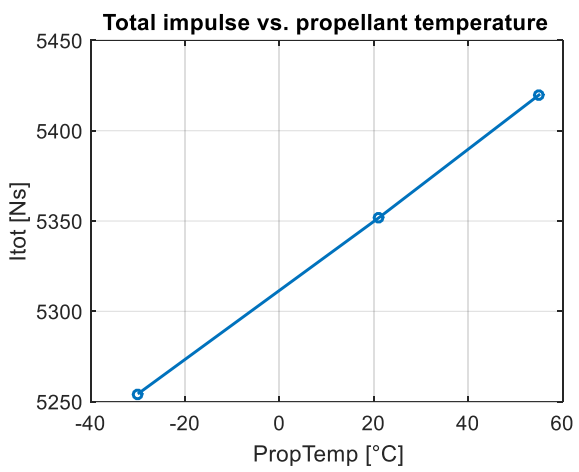


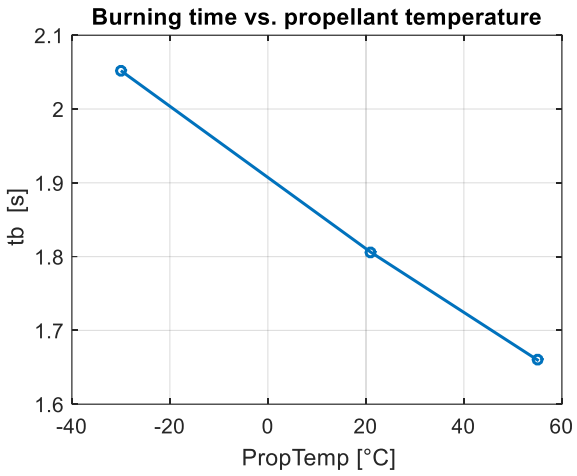









Total impulse vs. propellant temperature
Itot [Ns]
5450
5400
5350
5300
5250
-40
-20
0
20
40
60
PropTemp [°C]


Burning time vs. propellant temperature
tb [s]
2.1
2
1.9
1.8
1.7
1.6
-40
-20
0
20
40
60
PropTemp [°C]