Solid Rockets

Solid Motor Components

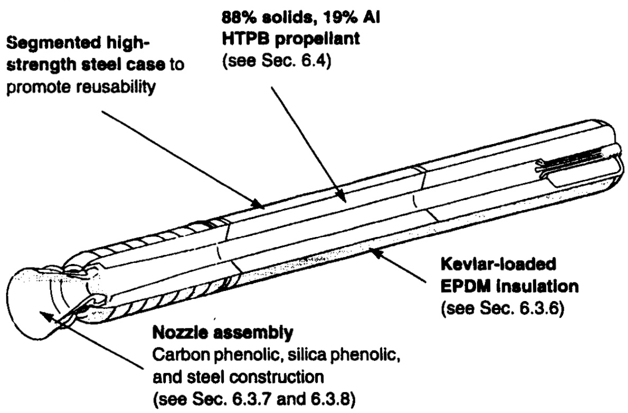


Fig. 6.2. Schematic of ASRM (Advanced Solid Rocket Motor). Courtesy of Aerojet Corporation.

From Humble

Solid Propellants

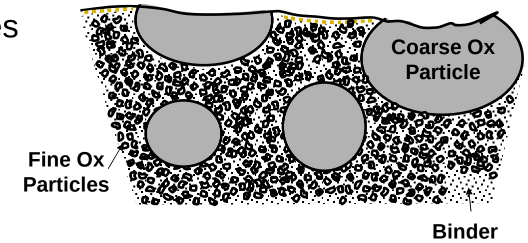
- Two basic types
- Homogeneous
  - reactants (fuel, oxidizer) mixed at molecular level
  - e.g., double-base propellants
- Heterogeneous
  - fuel and oxidizer are “macroscopically” separated
  - e.g., composite propellants

Double-Base Propellant

- Nitrocellulose + Nitroglycerine
  - see Table 12.6 Sutton
- Used in early modern rockets, e.g. at JPL
  - replaced gun/black powder
  - used in WWII JATOs and early Sidewinders

Composite Propellants

- "Oxidizer" particles held together in polymer (fuel)
- Ground oxid. crystals
  - materials
- Binder
  - materials
- Curing agents
- Other fuels (metals) and catalysts



see Table 12-7 Sutton

Mass "Production" Rate

- Propellant converted to gas at rate given by

  (VI.1) $\dot{m} = r\rho_s A_b$

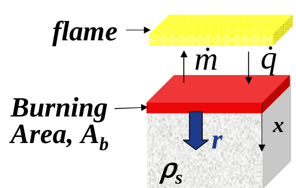
- (Surface) **Regression Rate *r***

  $r = dx/dt$ *sometimes* $\dot{r}_b$

  - standard model (Burning Rate "Law" or St. Robert's "Law")

    (VI.2) $r = ap_o^n$ *with* $a=f(T,\ldots)$

  - also, $r = c + bp_o^n$ etc.



Solid Propellant Burning Rate

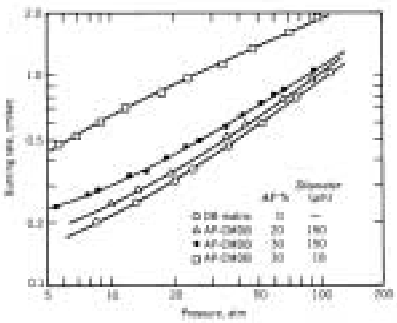


FIGURE 11–7. Measured burning rate characteristics of a double-base (DB) propellant and three composite-modified double-base (CMDB) propellants which contain an increasing percentage of small diameter (159 µm) particles of ammonium perchlorate (AP). When the size of the AP particles is reduced or the percentage of AP is increased, an increase in burning rate is observed. None of these data form straight lines.

$$\boxed{\ln r \cong \ln a + n \ln p}$$

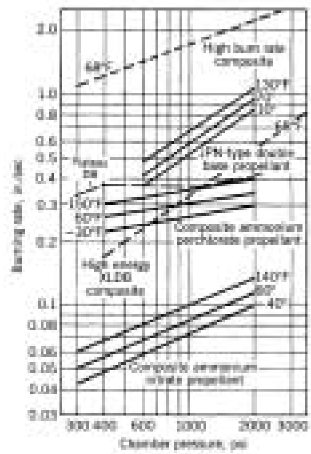


FIGURE 11–6.

From Sutton

Motor Internal Ballistics

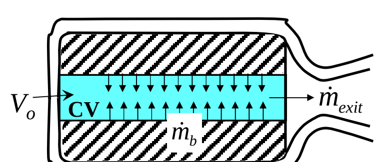
- What governs motor internal conditions?
- Examine mass conservation

$$0 = \frac{dm_{CV}}{dt} + \int \rho(\vec{u}\cdot\hat{n})dA$$

$$0 = \underbrace{\frac{d}{dt}(\rho_o V_o)}_{} + \dot{m}_{exit} - \dot{m}_b$$

$$V_o \frac{d\rho_o}{dt} + \rho_o \frac{dV_o}{dt} \qquad r\rho_s A_b$$

$$\frac{1}{RT_o}\frac{dp_o}{dt} \qquad \rho_o(A_b r) \qquad \frac{p_o}{\sqrt{RT_o}}\sqrt{\gamma}\left(\frac{2}{\gamma+1}\right)^{\gamma+1/2(\gamma-1)} A_t$$



Assuming:

1) *uniform gas prop's. in CV*
2) *TPG, CPG*
3) *T_o=constant (e.g., T_{ad})*
4) *p_o, A_b, r given at time t*

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Internal Ballistics (con't)

- Solve for rate of pressure change

$$\frac{V_o}{RT_o}\frac{dp_o}{dt} = rA_b(\rho_s - \rho_o) - p_o A_t \underbrace{\sqrt{\frac{\gamma}{RT_o}\left(\frac{2}{\gamma+1}\right)^{\gamma+1/\gamma-1}}}_{=1/c^*} \quad \text{(VI.3)}$$

- For steady (neutral) burning

$$\frac{dp_o}{dt} \equiv 0 \;\Rightarrow\; p_o = r\frac{A_b}{A_t}(\rho_s - \rho_o)c^* \quad \text{(VI.4)}$$

  - using standard burning rate law

$\sim\rho_s$ in many cases

$$p_o = a p_o^n \frac{A_b}{A_t}(\rho_s - \rho_o)c^* \;\Rightarrow\; p_o = \left[aK(\rho_s - \rho_o)c^*\right]^{1/1-n} \quad \text{(VI.5)}$$

$$A_b/A_t \equiv K$$

For steady burning (if a, n, T_o, γ, and A_t constant) then A_b must be constant

$$p_o \sim K^{1/1-n}$$

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Pressure Histories

- Motor designer can adjust pressure profile ("history") of a solid motor by arranging how burning area changes with time (**grain geometry**)
- Thrust given by $\tau = p_o A_t c_\tau$
  - so thrust history of motor essentially follows motor's pressure history
- Characterize pressure/thrust histories as generally
  - **progressive**: increase with time
  - **neutral**: constant with time
  - **regressive**: decrease with time
  - combinations

Grain Geometries and Thrust History

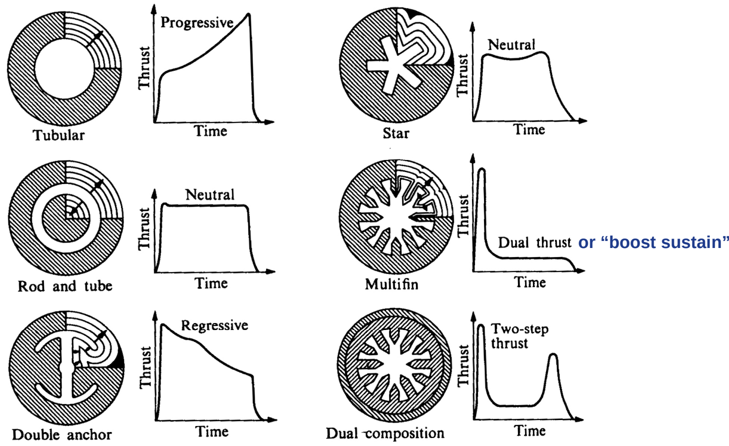
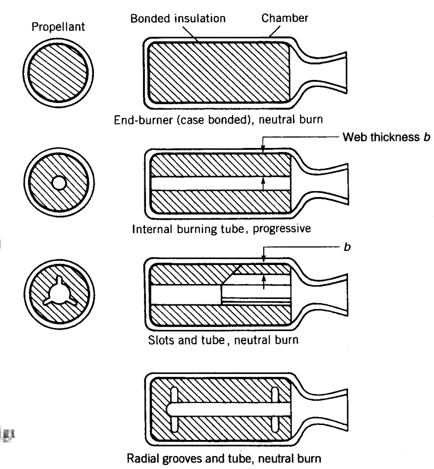


FIGURE 12.17 Internal-burning charge designs with their thrust-time programs. (Courtesy Shafer [18].)

From Hill and Peterson

More Solid Motor Grain Geometries

FIGURE 11–16. Simplified diagrams of several grain configu



From Sutton

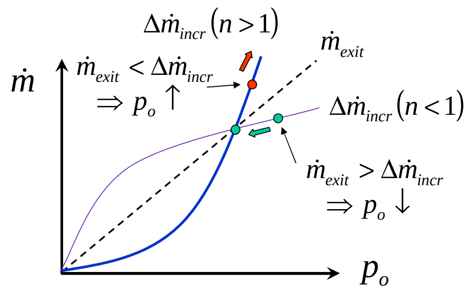
Motor Stability

- Recall mass conservation for steady operation (p_o=constant)

$$\dot{m}_{exit} = \dot{m}_b - \rho_o A_b r = A_b(\rho_s - \rho_o)r = \Delta\dot{m}_{incr}$$

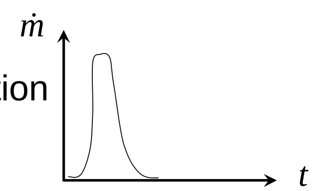
$$\dot{m}_{exit} \propto p_o \qquad \Delta\dot{m}_{incr} \propto p_o^n$$

- Is this condition (point) stable?
  - only if $n \leq 1$
  - normally use 0.3<n<0.7



Combustion Limits

- If n or p_o too low
  - do not get stable combustion
  - after ignition, propellant soon stops burning (r→0)



- At high p_o
  - possibility of erratic, unpredictable burning (usually > 5000 psi)