Errata to: Powered Flight

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Errata to:
D. R. Greatrix, *Powered Flight*,
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1. There is a possibility of an extra page 333 and 334 in some copies of the book. Please ignore.
2. The original version of Chap. 6, Fig. 6.62 contained incorrect caption. The corrected caption is as follows: Schematic diagrams illustrating the nominal forward-thrust setup for the rear of a jet engine in flight (at *left*), and at *right*, the temporary deployment of external buckets at the rear of the engine in order to provide a reverse thrust capability for the airplane as it decelerates in a landing ground roll.
3. In Chap. 9, Eq. 9.29 should appear as

$$\frac{A_t}{A_e} = \frac{Ma_e}{Ma_t}\left[\frac{2+(\gamma-1)Ma_t^2}{2+(\gamma-1)Ma_e^2}\right]^{\frac{\gamma+1}{2(\gamma-1)}} \tag{9.29}$$

4. Bottom of p. 294, should appear as:

$$\ldots,\text{air density } \Delta = \mathrm{f}(h)\ldots$$

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5. In Chap. 10, Eq. (10.10) should appear as:

$$r_e = \frac{h(T_F - T_S)}{\rho_s[C_s(T_S - T_i) - \Delta H_s]} \tag{10.10}$$

6. Middle of p. 220, solution for Prob. 6.3, p_{05} value is shown as 193 kPa in the solution of the equation for finding p_{06}, but that value should be 183 kPa, as per Prob. 6.2. Note that the value for p_{06} is correct as shown (172 kPa).
7. Near the bottom of p. 229 for the sample solution of Prob. 6.9, one sees the solution for the exiting mass flow, which should be shown as follows:

$$\dot{m}_e = \rho_e V_e A_e = 44.4\,\mathrm{kg/s}$$

8. Near the bottom of p. 491 (Appendix III), should be as follows:

$$1\,\mathrm{kg/m^3} = \cdots = 3.61\,\mathrm{H}\,10^{-5}\mathrm{lbm/in^3}$$

9. Near the bottom of p. 432 (solution, Prob. 12.4), in the equation for flame zone thickness $*_o$, the wrong value was used for solid specific heat C_s (should be 2000, not 1100). As a result, the actual end solution for total burning rate r_b should be 0.00742 m/s (not 0.019 m/s) for that first iteration using the initial guess for r_b as 0.019 m/s. By repeated guesses for different values for r_b, one can eventually show that the converged value for r_b is 0.0173 m/s, and the axial mass-flux (base) burning rate at 500 g is 0.00703 m/s (as compared to 0.01165 m/s at 0 g).

In addition to the above corrections below text is revised content of Chap. 12:

Book Practice Problem Solution

12.4 (revised June 9, 2013)

Looking at a hybrid rocket fuel's burning rate under mass flux and acceleration. Worst case is that there is sufficient oxidizer available for complete r_b augmentation due to a_n.

We will need to iterate between the two mechanisms of burning, given that each mechanism is dependent on the other mechanism as a base burning rate.

Effect of mass flux G:

From Prob. 12.3 (b),

$$h^* = \frac{k}{d}\mathrm{Re}_d\mathrm{Pr}^{1/3}\frac{f}{8} = \frac{0.205}{0.08}4.926 \times 10^6\left(0.73^{0.333}\right)\frac{0.0118}{8} = 16766\,\mathrm{W/m^2}$$
$$\cong \mathrm{K},\ \text{remains constant.}$$

Begin iteration, guess r_b = 1.63 × 0.01165 m/s = 0.019 m/s:

$$h = \frac{\rho_s r_b C_p}{\exp\left(\frac{\rho_s r_b C_p}{h^*}\right) - 1} = \frac{1100(2083)r_b}{\exp\left(\frac{1100(2083)r_b}{16766}\right) - 1} = \frac{2.291 \times 10^6 r_b}{\exp(136.66 r_b) - 1} = 3506\,\mathrm{W/m^2 \cong K}$$

$$\begin{aligned} r_b &= r_{o,a_n} + \frac{h(T_F - T_S)}{\rho_s C_s (T_S - T_i) - \rho_s \Delta H_S} \\ &= r_{o,a_n} + \frac{h(2725 - 800)}{1100(2000)(800 - 288) - 0} = r_{o,a_n} + 1.709 \times 10^{-6} h \\ &= r_{o,a_n} + 0.006 = (0.019 - 0.006) + 0.006 = 0.013 + 0.006 \\ &= 0.019\,\mathrm{m/s}, \text{tentatively.} \end{aligned}$$

Need to check via remaining equations, to bring convergence to the solution. For now, $r_{o,G}$ = 0.006 m/s.

Effect of normal acceleration a_n:

$$\delta_0 = \frac{k}{\rho_s r_o C_p} \ell n\left[1 + \frac{C_p(T_F - T_S)}{C_S(T_S - T_i) - \Delta H_S}\right] = \frac{0.205}{1100(r_{o,G})2083} \ell n\left[1 + \frac{2083(1925)}{2000(512) - 0}\right]$$

$$= \frac{1.4255 \times 10^{-7}}{r_{o,G}} = 2.376 \times 10^{-5}\,\mathrm{m}$$

$$G_a = \frac{a_n p}{r_b} \frac{\delta_o}{RT_F} \frac{r_o}{r_b} = \frac{-4905(8.0 \times 10^6)}{r_b} \frac{1.4255 \times 10^{-7}}{361.5(2725) r_{o,G}} \frac{r_{o,G}}{r_b} = -\frac{5.678 \times 10^{-3}}{r_b^2}$$

$$= -15.73\,\mathrm{kg/s \cong m^2}$$

$$r_b = \frac{C_p(T_F - T_S)}{C_S(T_S - T_i) - \Delta H_S} \cdot \frac{r_b + G_a/\rho_s}{\exp\left[\frac{C_p \delta_o \rho_s}{k}(r_b + G_a/\rho_s)\right] - 1}$$

$$= 3.92 \cdot \frac{r_b - \dfrac{5.162 \times 10^{-6}}{r_b^2}}{\exp\left[\dfrac{2083(1.4255 \times 10^{-7})1100}{0.205 r_{o,G}}\left(r_b - \dfrac{5.162 \times 10^{-6}}{r_b^2}\right)\right] - 1}$$

$$= 3.92 \cdot \frac{r_b - \dfrac{5.162 \times 10^{-6}}{r_b^2}}{\exp\left[\dfrac{1.5934}{r_{o,G}}\left(r_b - \dfrac{5.162 \times 10^{-6}}{r_b^2}\right)\right] - 1} \cdot 0.00742\,\mathrm{m/s},$$

so guessed incorrectly on r_b.

To potentially speed things up a bit, one can note that there is a lower limit value for r_b at a given a_n, as prescribed by the above equation:

$$r_b - \frac{5.162 \times 10^{-6}}{r_b^2} = 0$$

or in other words,

$$r_{b,\mathrm{lim}} \approx \left\{ \frac{a_n p}{RT_F} \frac{k}{\rho_s^2 \cdot C_p} \ell n \left[1 + \frac{C_p (T_F - T_S)}{C_s (T_S - T_i) - \Delta H_s} \right] \right\}^{1/3}$$

Depending on the influence of other factors, the overall r_b may be at or above $r_{b,lim}$ for a given value of a_n. In this case, it turns out that r_b is at the $r_{b,lim}$ bound for 500 g, hence equal to 0.0173 m/s. The base burn rate (i.e., due to axial mass flux alone) for the 500 g case is 0.00703 m/s.

Thus, $\frac{r_b}{r_o} = \frac{0.0173}{0.00703} = 2.46$ as augmentation of burning rate due to radial vibration of 500 g.

Note how much mass-flux base burning was brought down by the vibration… from 0.01165 m/s down to 0.00703 m/s (about a 40 % decrease). Referencing the pre-vibration state, the augmentation ratio would in that case be 0.0173/ 0.01165 = 1.49.