Appendix B

Notes on Using OVERINT for Incompressible Flows

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OVERINT can be used to compute force/moment coefficients for incompressible flow as follows. It is assumed that the flow variables discussed in Section A3 of Appendix A of the user's manual are non-dimensionalized by the free stream speed V_∞ instead of the free stream sound speed c_∞.

$$\hat{u} = \frac{u}{V_\infty}, \quad \hat{\rho} = \frac{\rho}{\rho_\infty}, \quad \hat{\mu} = \frac{\mu}{\mu_\infty}, \quad \hat{p} = \frac{p}{\rho_\infty V_\infty^2}, \quad \hat{\sigma} = \frac{\sigma}{\rho_\infty V_\infty^2}, \tag{B.1}$$

where $\hat{\rho} = \rho = \rho_\infty = 1$ for incompressible flow. Eqn. (A.3.3.b) becomes

$$\hat{\sigma} \sim -\hat{p} + \frac{\mu_\infty}{\rho_\infty V_\infty L} \frac{\partial \hat{u}}{\partial \hat{x}} \tag{B.2}$$

It is also assumed that the laminar viscosity is constant for incompressible flow, i.e. $\mu = \mu_\infty$ or $\hat{\mu} = 1$. The Reynolds number is still defined as

$$Re \equiv \frac{\rho_\infty V_\infty L}{\mu_\infty}. \tag{B.3}$$

Hence Eqn. (A.3.5) becomes

$$\sigma_{ij} = -p\delta_{ij} + \frac{\mu}{Re}\left[\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right) - \frac{2}{3}\delta_{ij}\frac{\partial u_k}{\partial x_k}\right] \tag{B.4}$$

So Re appears in (B.4) instead of Re/M_∞ for compressible flow. The force coefficients are defined by

$$C_f = \frac{\hat{\mathcal{F}}}{\hat{Q}_\infty \hat{A}_{\text{ref}}}, \tag{B.5}$$

where

$$\hat{Q}_\infty = \frac{1}{2}\hat{\rho}_\infty \hat{V}_\infty^2 = \frac{1}{2}, \tag{B.6}$$

since $\hat{\rho}_\infty = \hat{V}_\infty = 1$. Note that for compressible flow, $\hat{Q}_\infty = \frac{1}{2}M_\infty^2$, since $\hat{V}_\infty = \frac{V_\infty}{c_\infty} = M_\infty$.

In the procedure described so far, computing the coefficients for incompressible flow is equivalent to setting $M_\infty = 1$ and $\hat{\mu} = 1$. We have to be a little more careful with the pressure computation though. For compressible flow, OVERINT currently integrates $(\hat{p} - \hat{p}_\infty)$ where $\hat{p}$ is computed from the dependent variables in the input *q.save* file as follows.

$$\hat{p} = (\gamma - 1)\left[\hat{e} - \frac{1}{2}\hat{\rho}(\hat{u}^2 + \hat{v}^2 + \hat{w}^2)\right]. \tag{B.7}$$

For compressible flow, the dependent variables in the input *q.save* file are $(\hat{\rho}, \hat{\rho}\hat{u}, \hat{\rho}\hat{v}, \hat{\rho}\hat{w}, \hat{e})$. For incompressible flow, $\hat{\rho} = 1$ and $\hat{e}$ is computed from

$$\hat{e} = \frac{\Delta\hat{p}}{0.4} + \frac{1}{2}(\hat{u}^2 + \hat{v}^2 + \hat{w}^2), \tag{B.8}$$

where γ has been set to 1.4, and $\Delta\hat{p} = \hat{p} - \hat{p}_{\text{ref}}$ where $\hat{p}_{\text{ref}}$ is the reference pressure used by the incompressible flow solver. Therefore, if OVERINT uses (B.7) to compute $\hat{p}$, it is actually computing a pressure difference. Hence integration should be performed on $\hat{p}$ and not $(\hat{p} - \hat{p}_\infty)$ for incompressible flow. Note that for a closed body, integrating the pressure or pressure difference should produce the same result. For an open body, the user should be aware of the value of $\hat{p}_{\text{ref}}$ employed by the flow solver and interpret the computed force/moment coefficients appropriately.

To summarize, in order to use OVERINT for incompressible flow, the user needs to do the following:

(1) Store the 5 variables in the *q.save* file as $(1.0, \hat{u}, \hat{v}, \hat{w}, \hat{e})$ where $\hat{u}, \hat{v}, \hat{w}$ are the x, y, z velocity components non-dimensionalized by the free stream speed, and $\hat{e}$ is computed using Eqn. (B.8).

(2) Set FSMACH to 0.0 in the input parameters file which will tell OVERINT to obtain the true FSMACH from the *q.save* file. Also set FSMACH in the *q.save* file to 0.0 which will tell OVERINT that this is an incompressible solution. OVERINT will then automatically set FSMACH to 1.0 internally, and integrate $\hat{p}$ instead of $(\hat{p} - \hat{p}_\infty)$.

(3) Set GAMINF to 1.4 in the input parameters file.