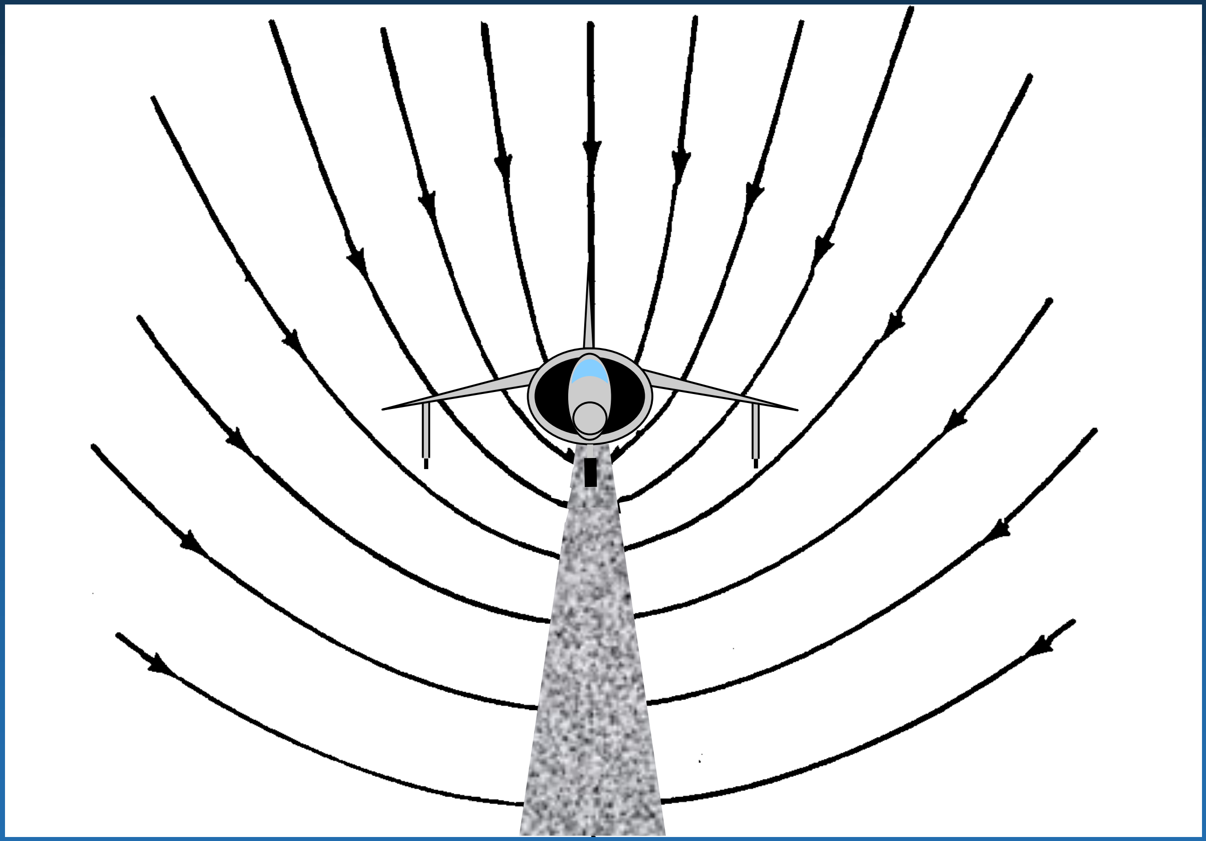
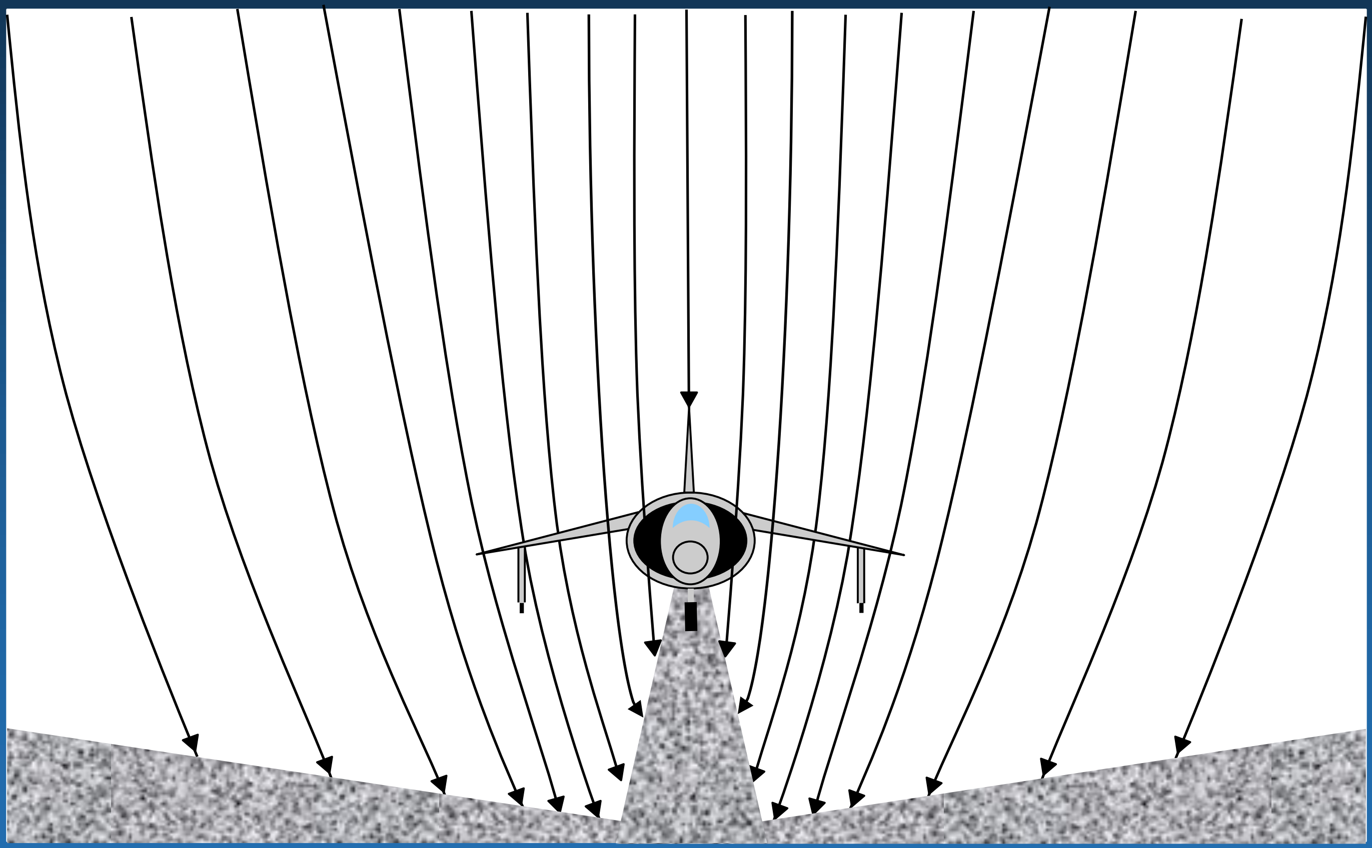
Jet Drag: Lift Jet Induced Suckdown

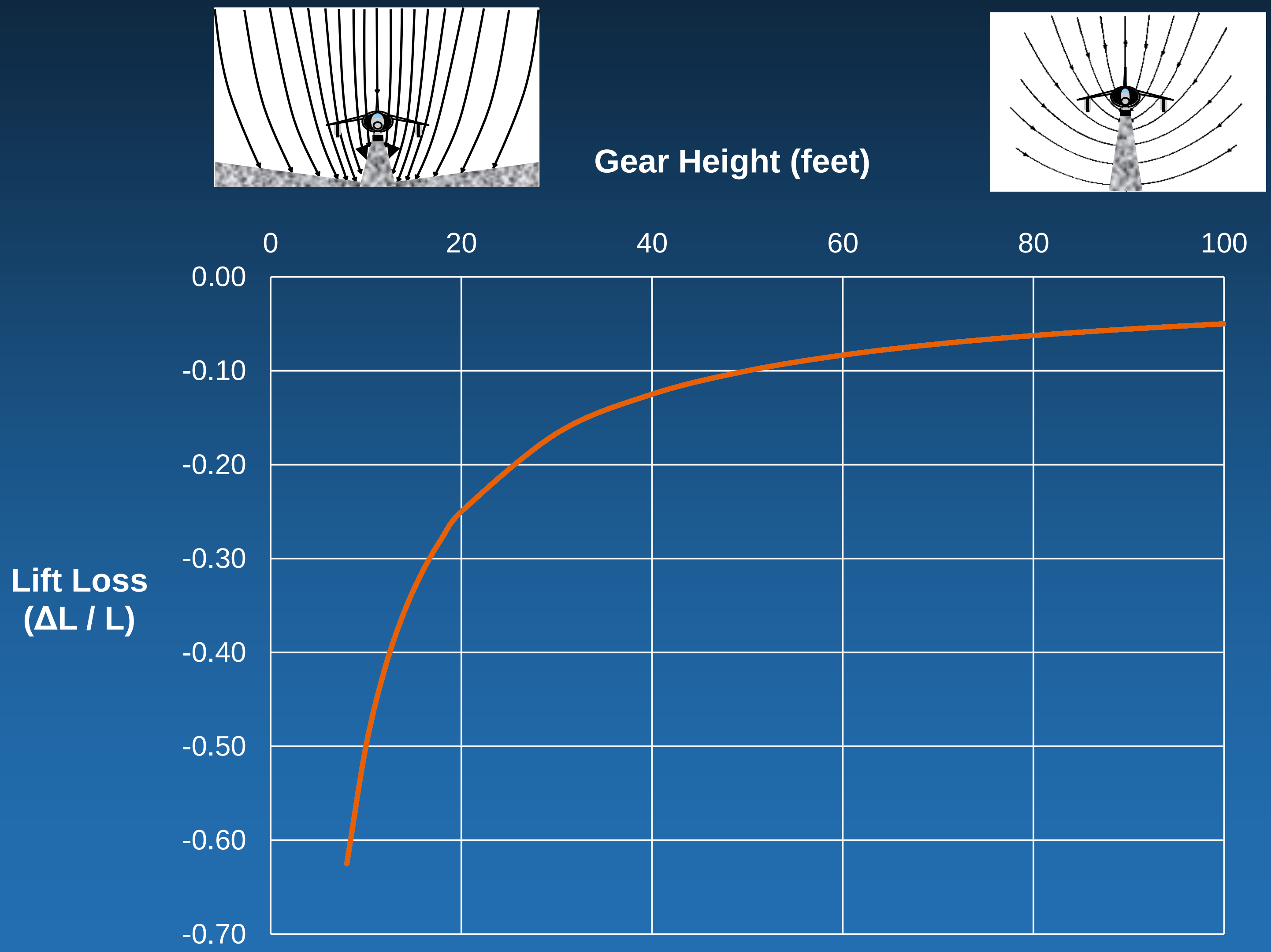


Dr. Paul M Bevilaqua

Ground Jet Increases Suckdown

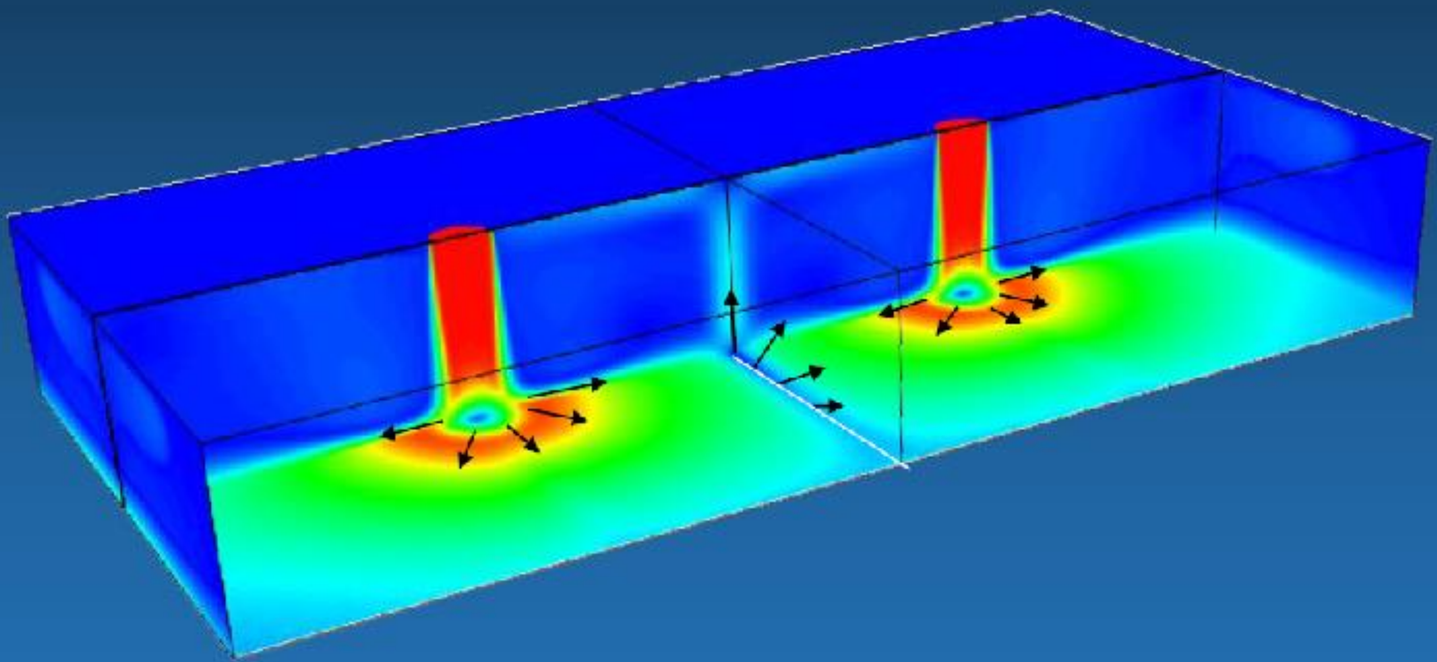


Lift Loss Due to Suckdown



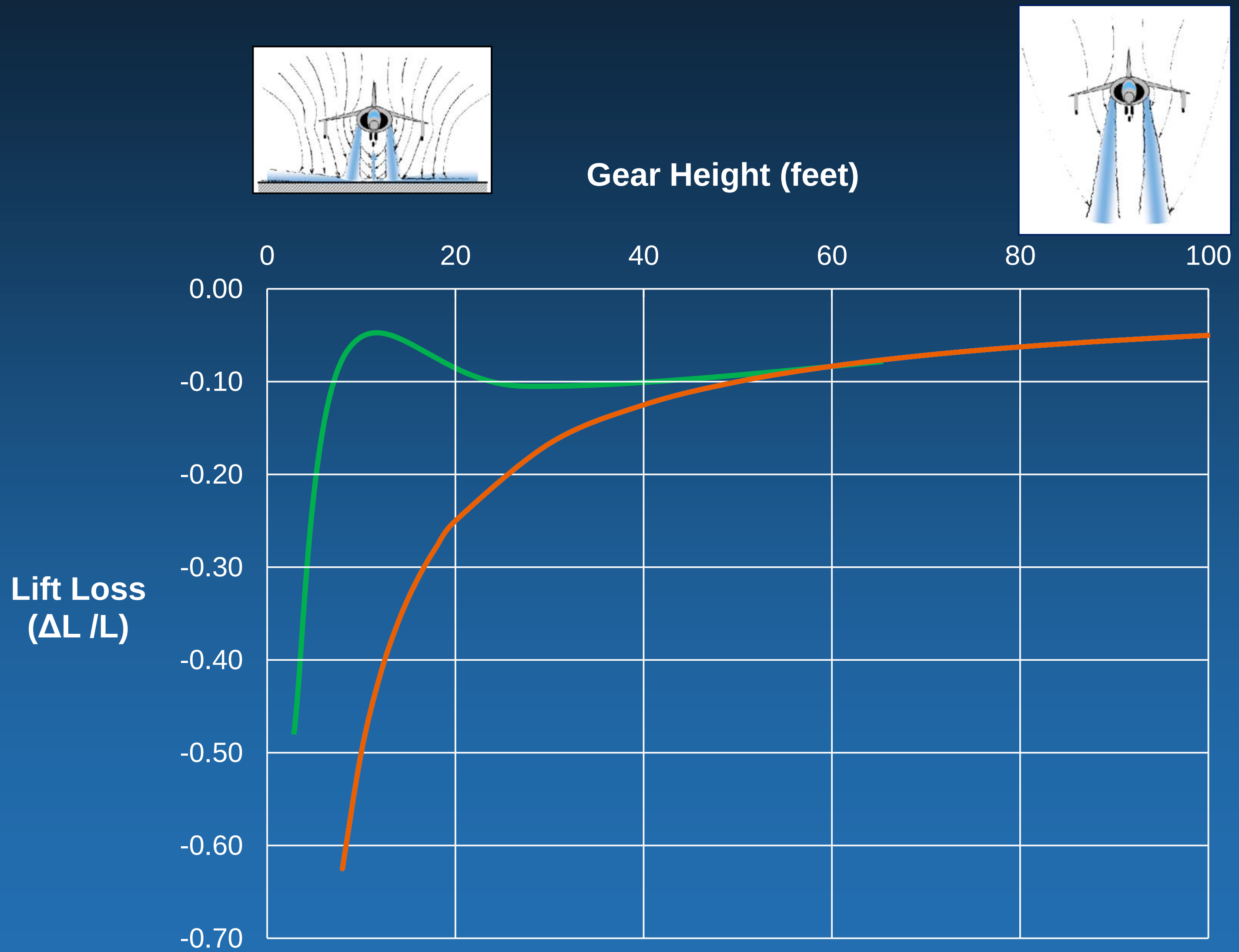
Multiple Lift Jets

Fountain Jets

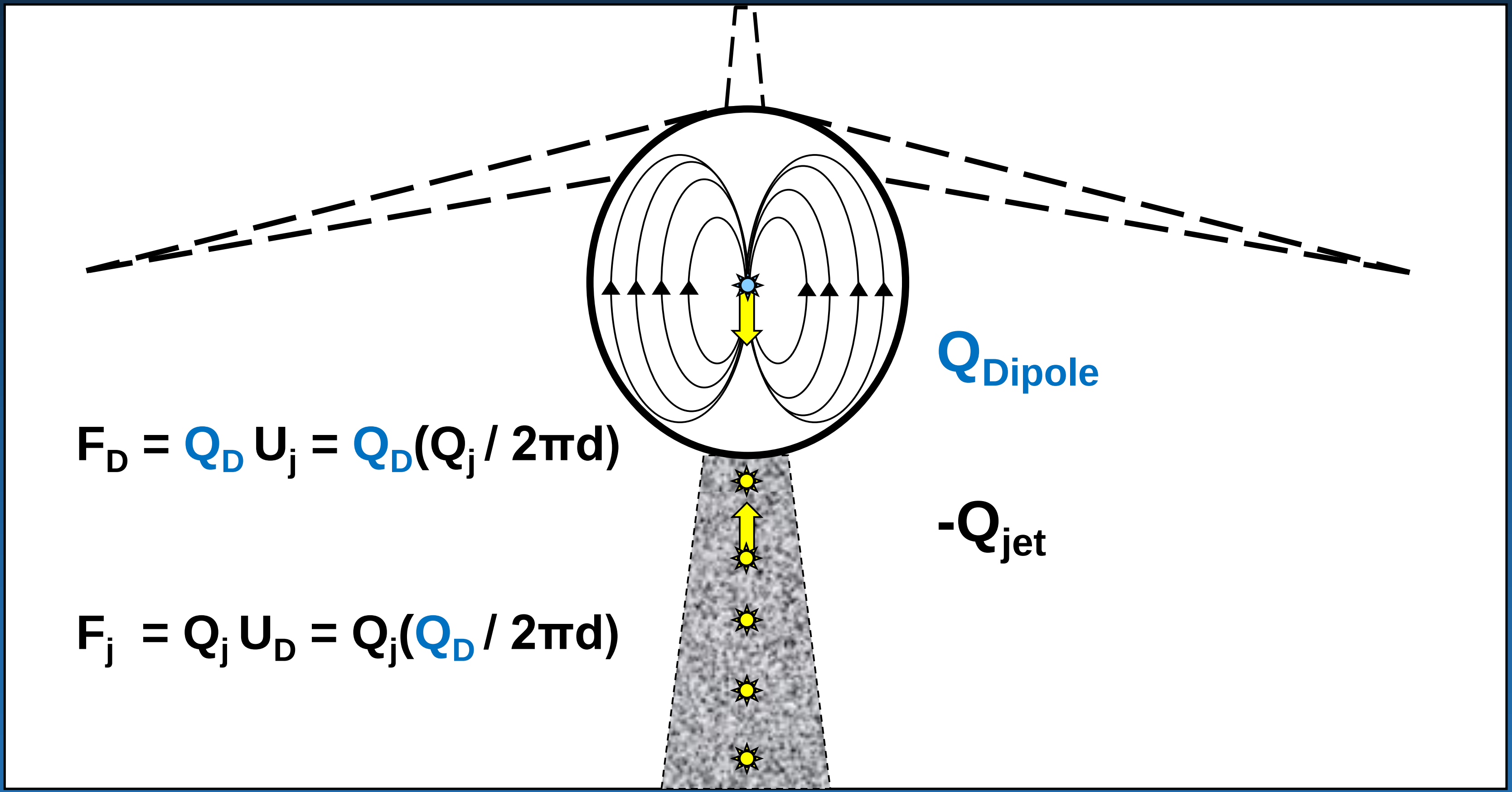


Infrared Visualization of Lift Jets

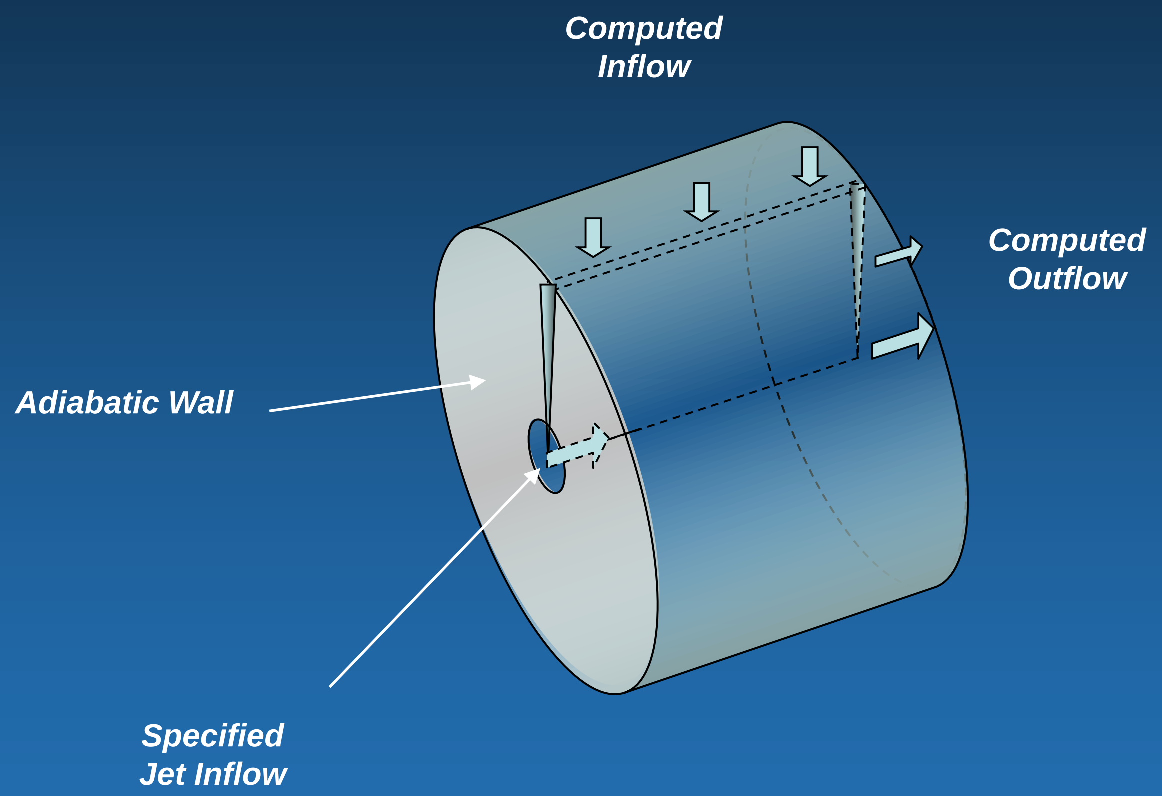
Effect of Fountain Jet



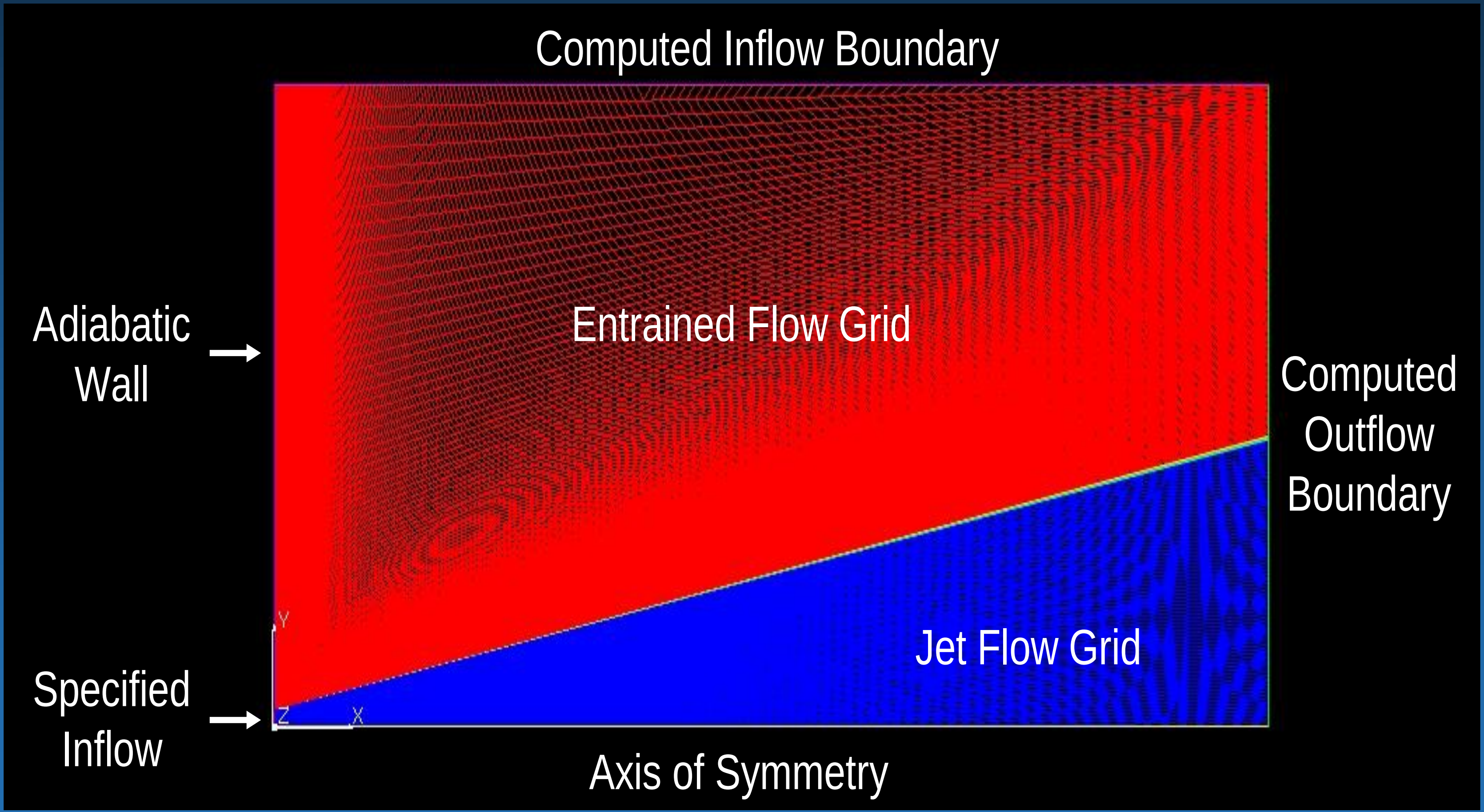
Equal and Opposite Forces on the Body and Jet



Computational Domain for a Jet From a Flat Plate

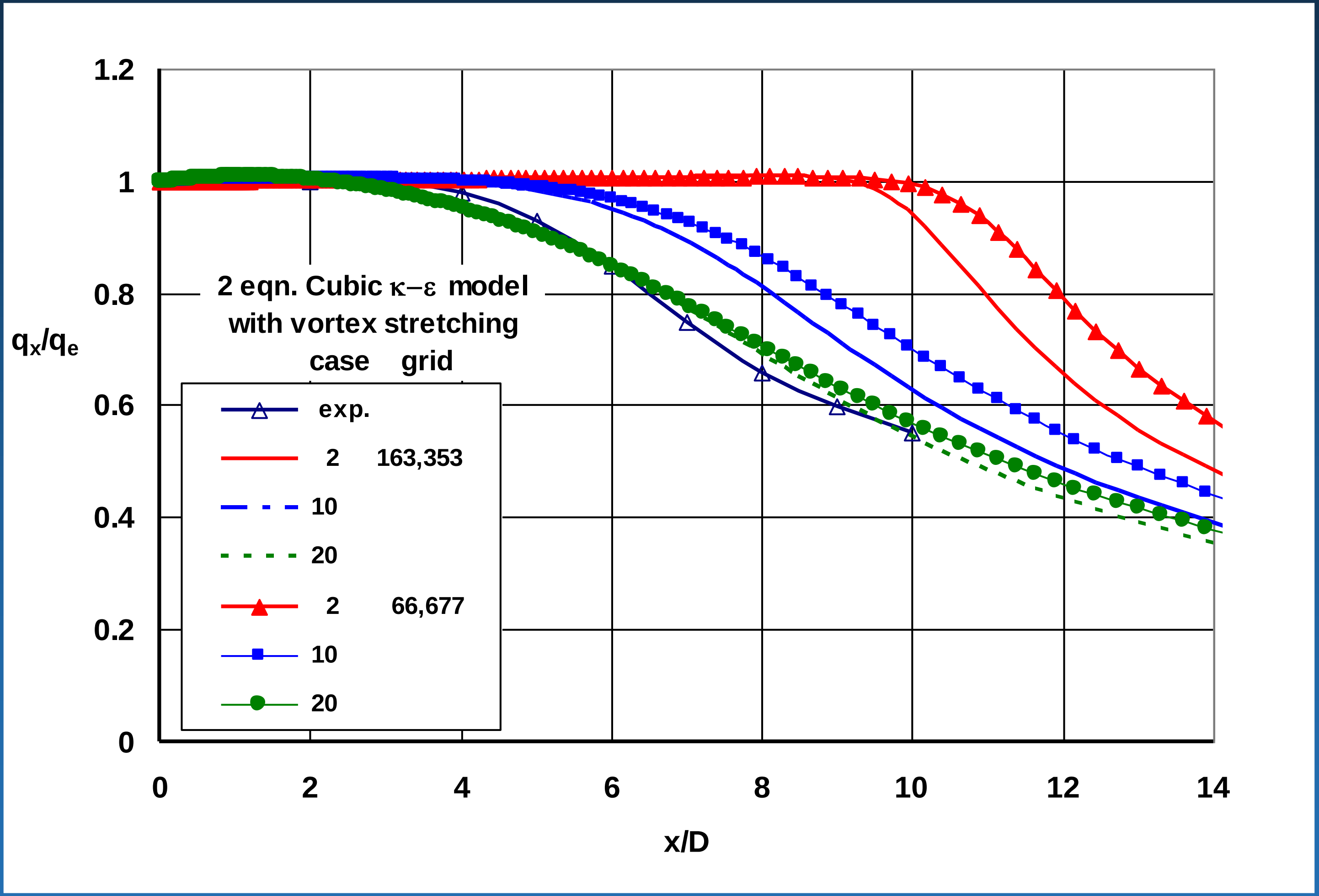


Computational Grid for a Jet From a Flat Plate



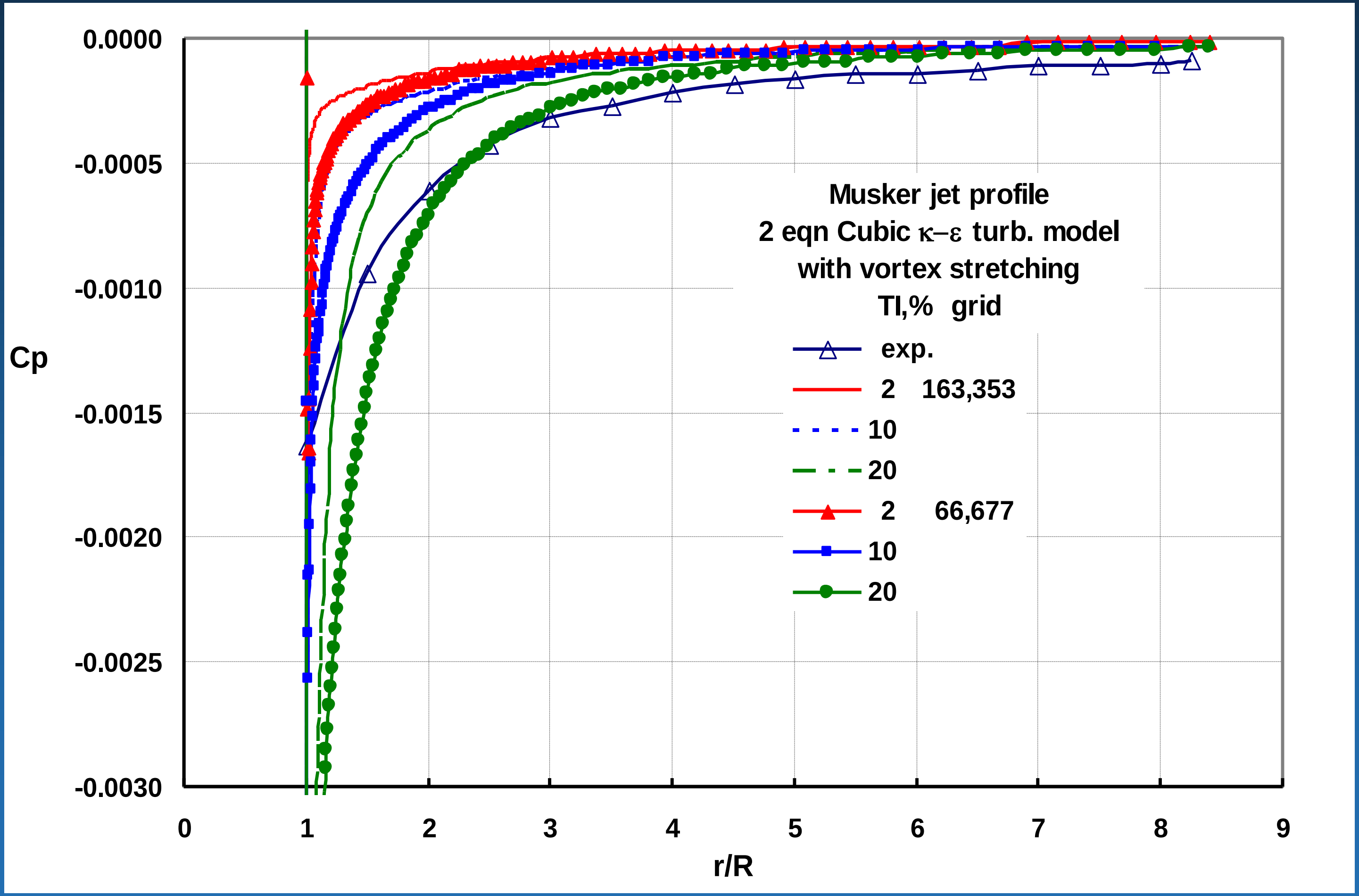
Effect of Grid Size and Turbulence Intensity

Decay of the Jet Core

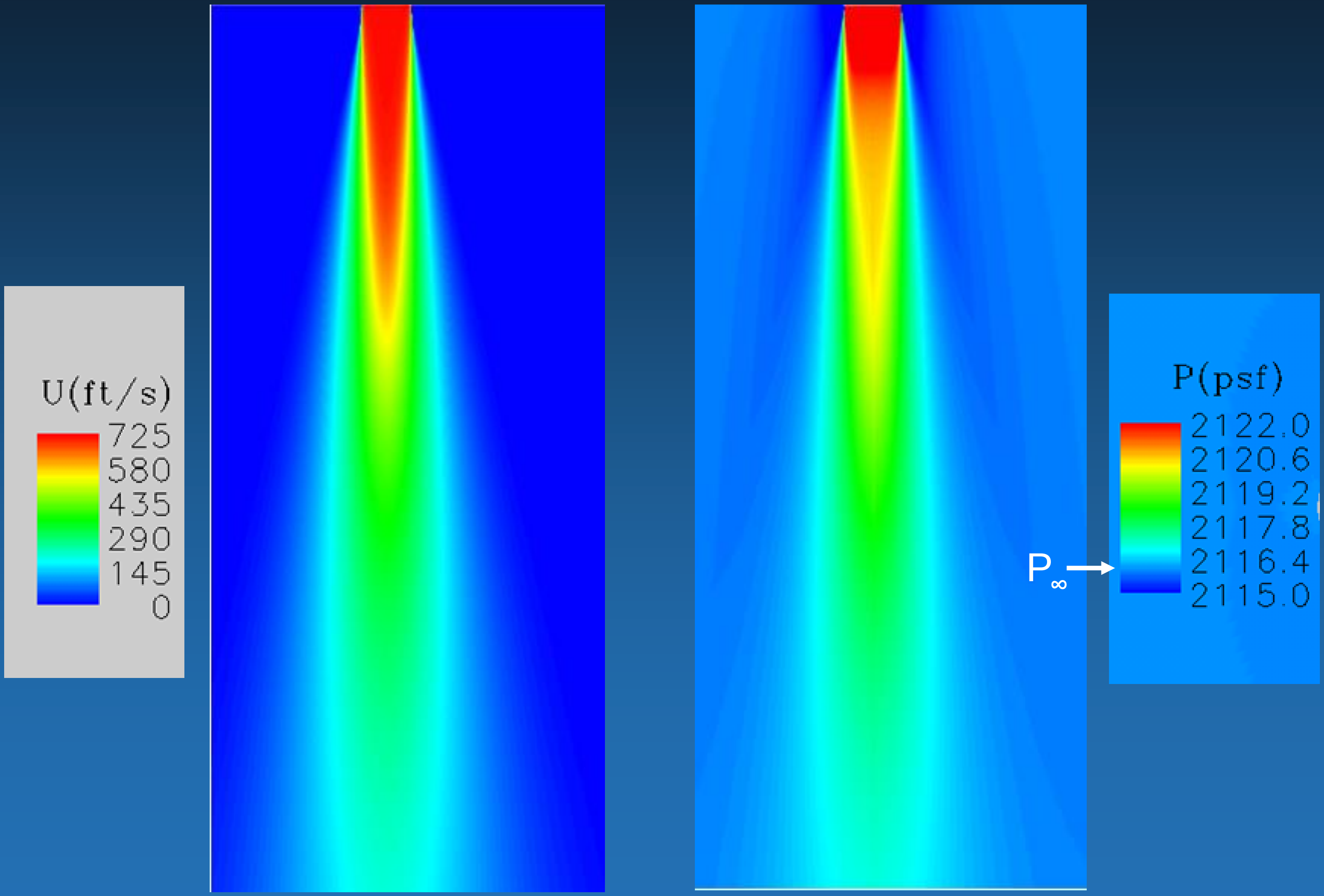


Effect of Grid Size and Turbulence Intensity

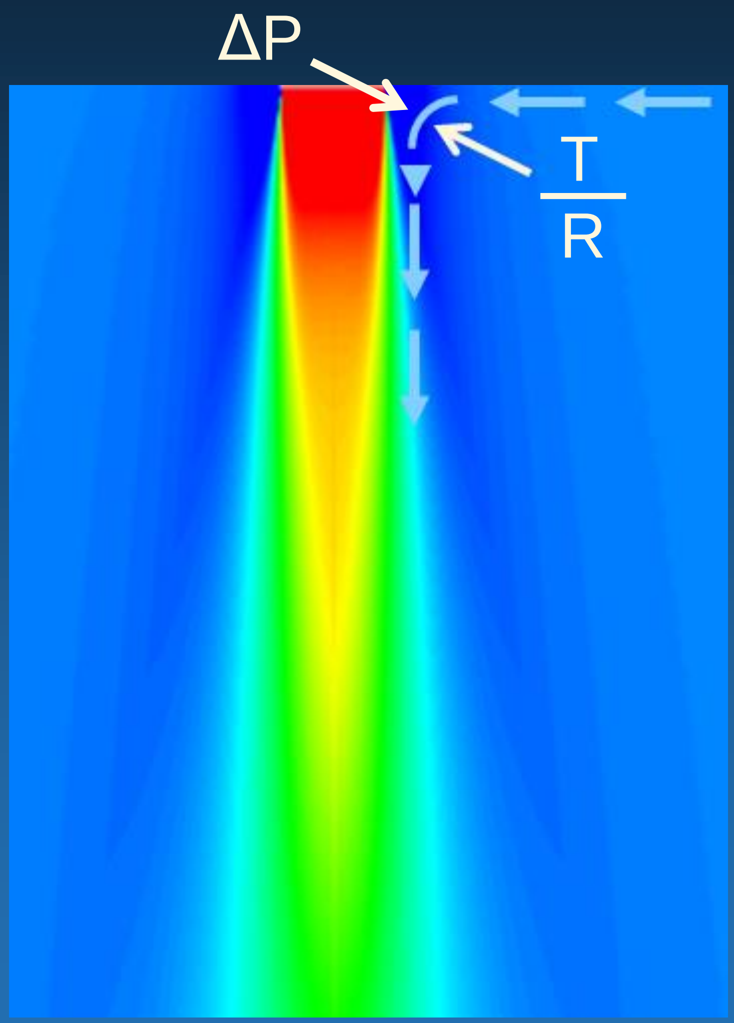
Pressure distribution on the flat plate



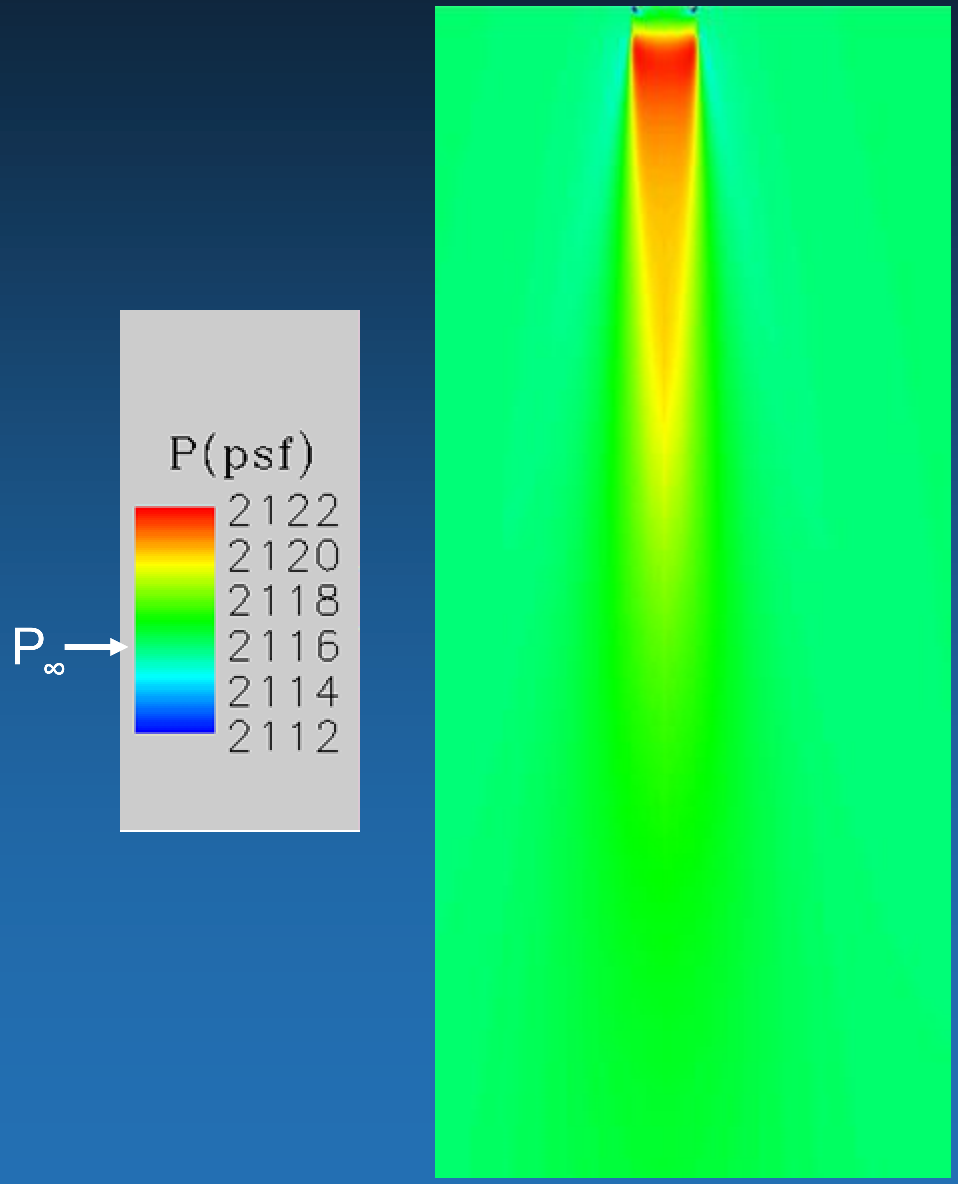
Jet from a Flat *Plate*



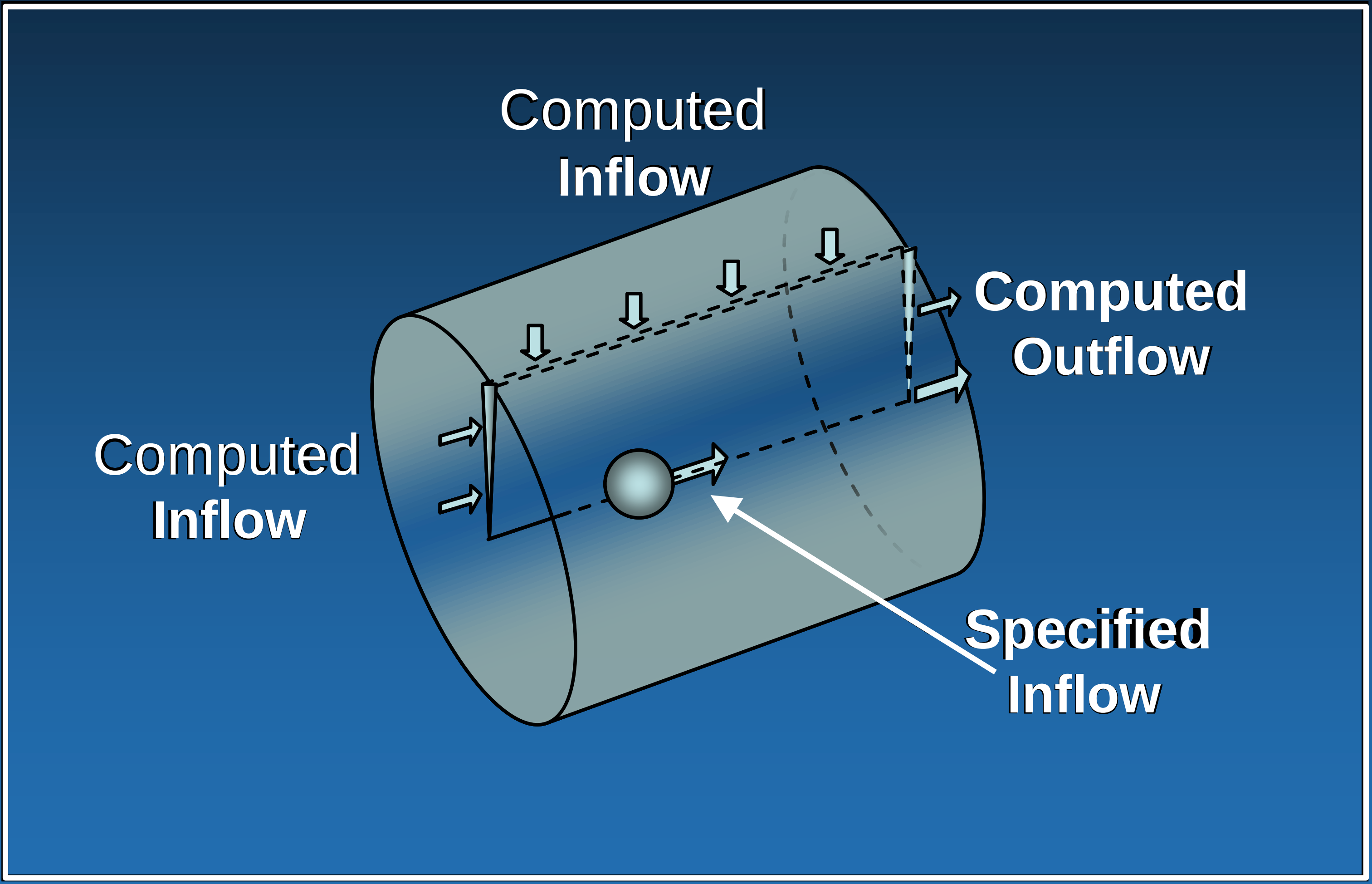
Centripetal Force Balance on an Entrained Streamtube



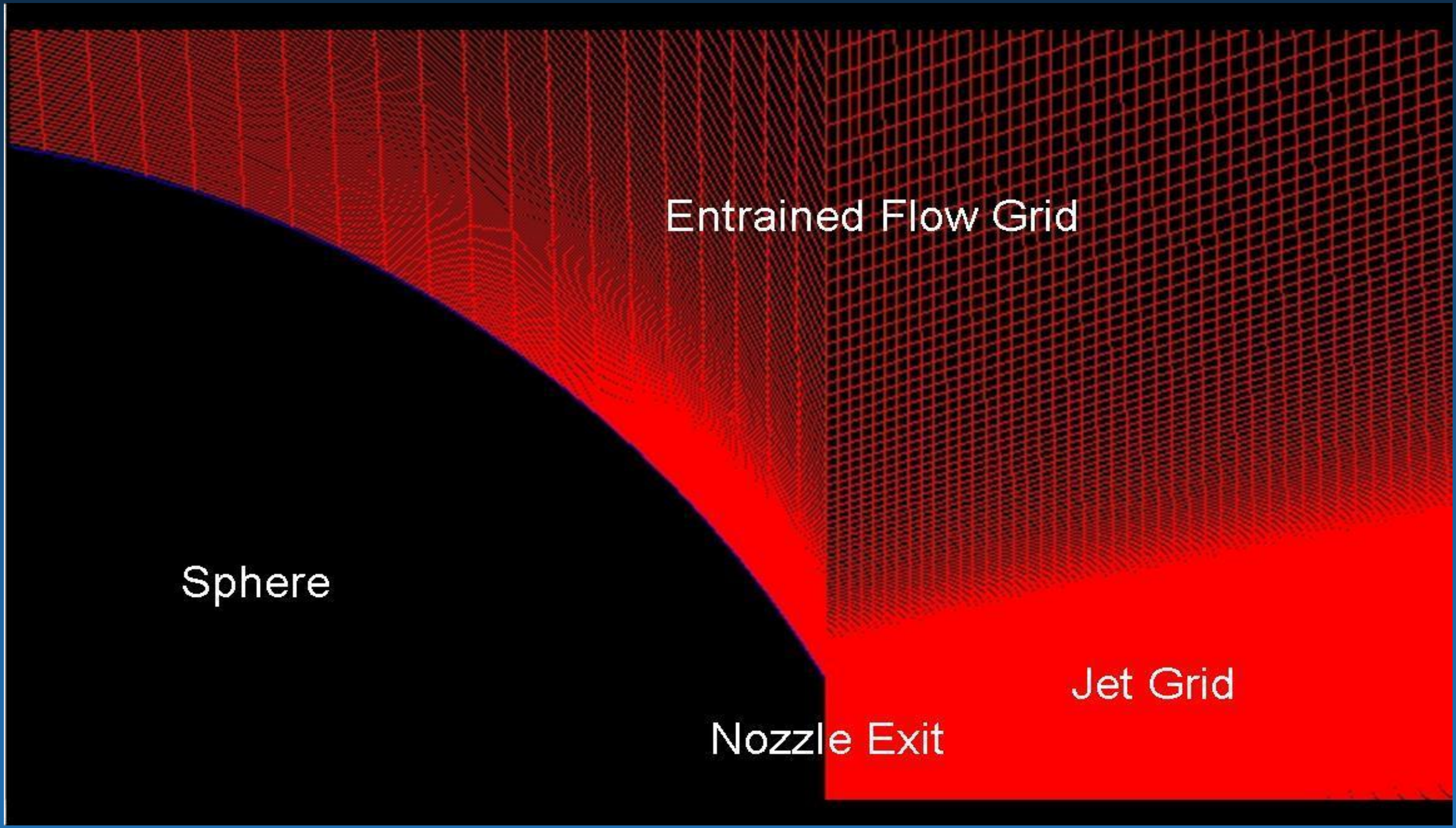
Exit Pressure Forced to Equal Atmospheric Pressure



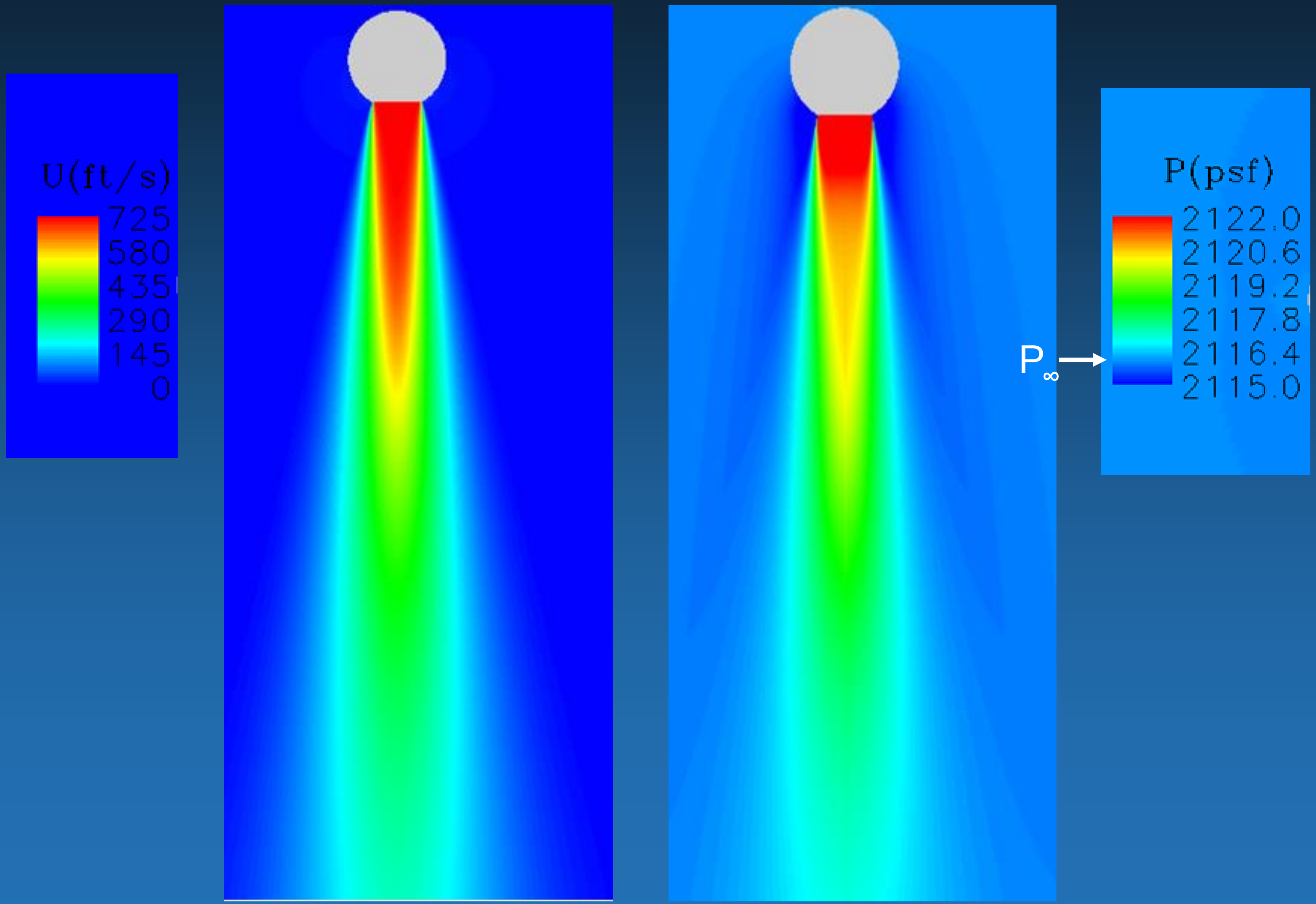
Computational Domain for a Jet From a Sphere



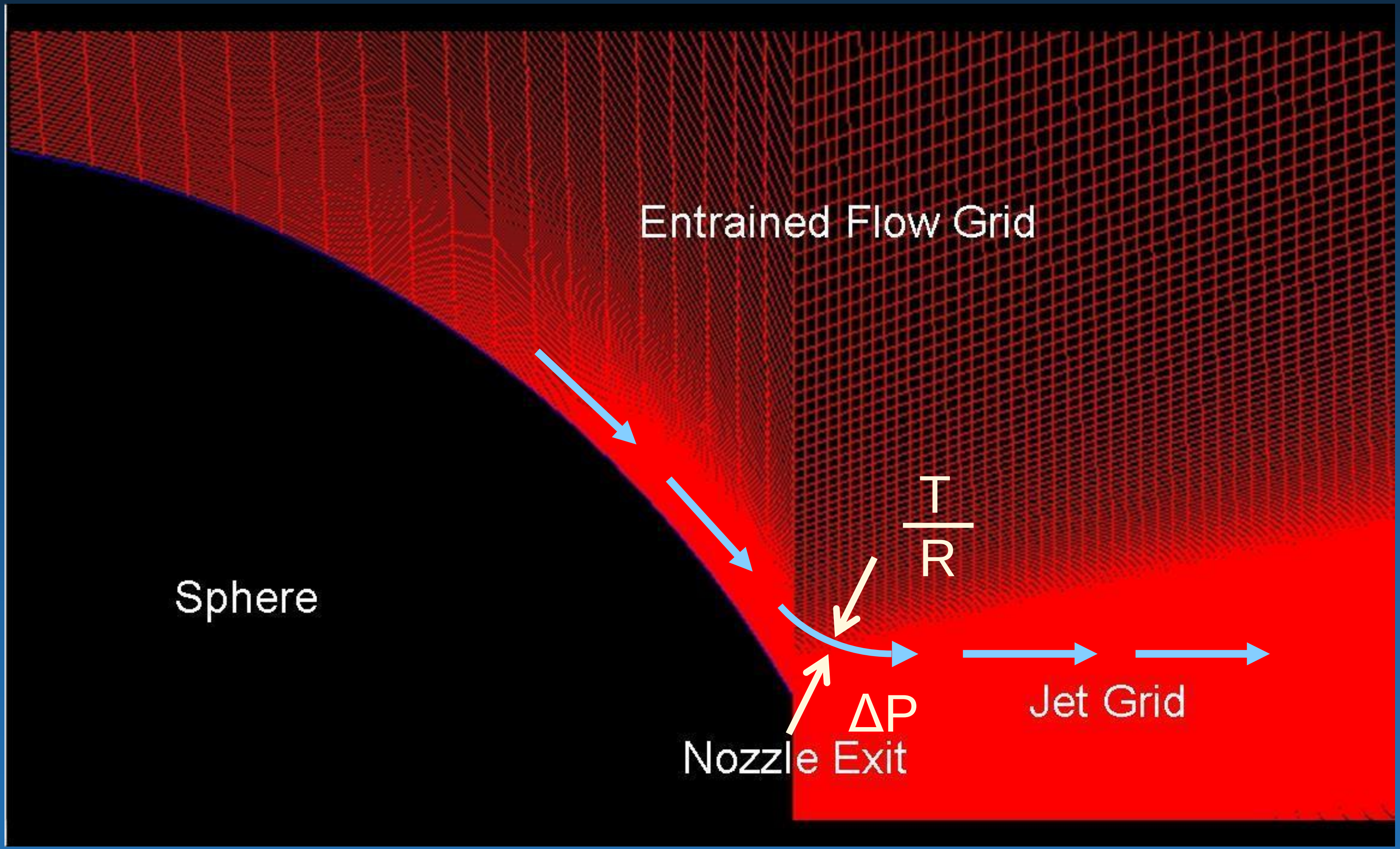
Computational Grid for a Jet From a Sphere



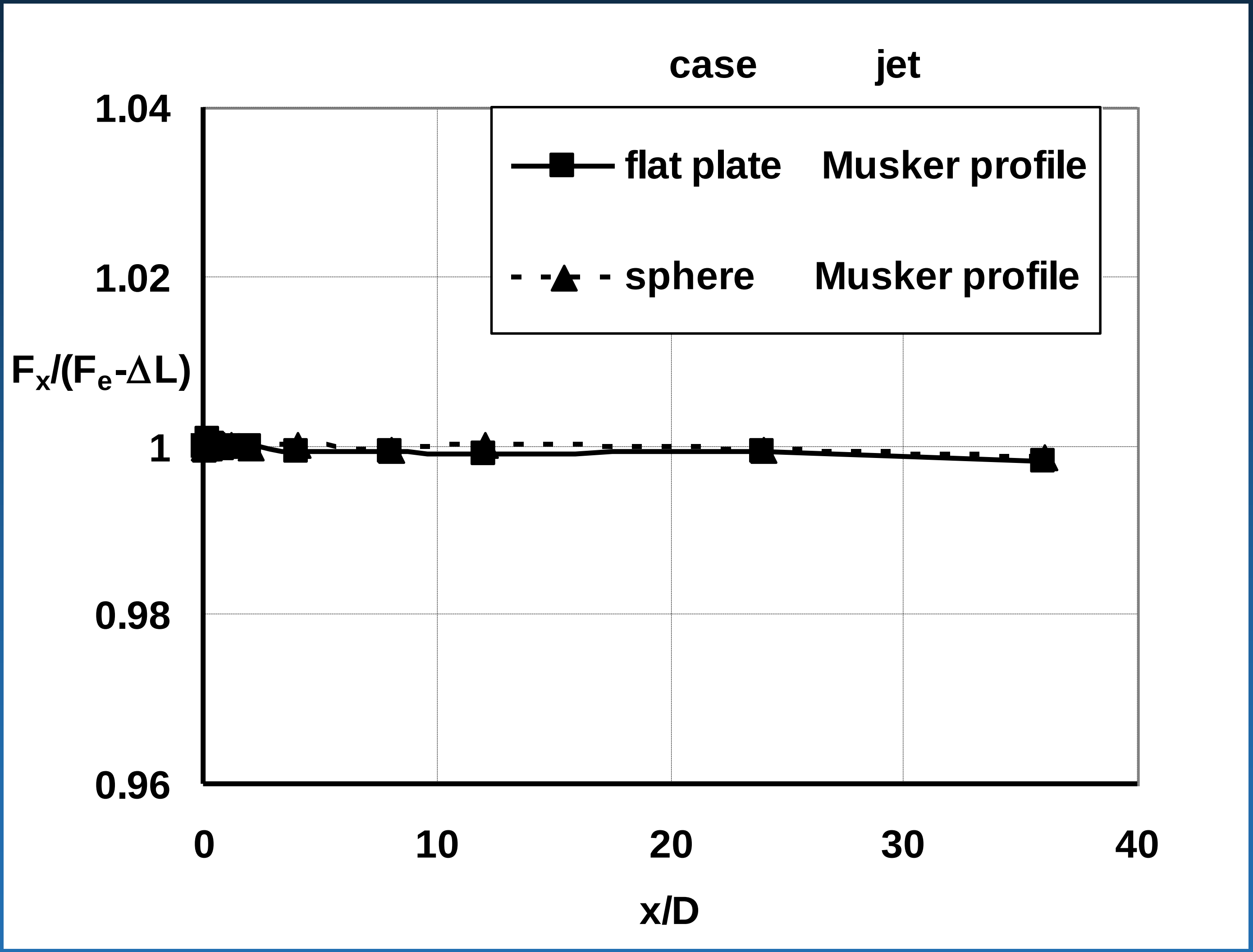
Jet From a Sphere



Centripetal Force Balance of an Entrained Streamtube

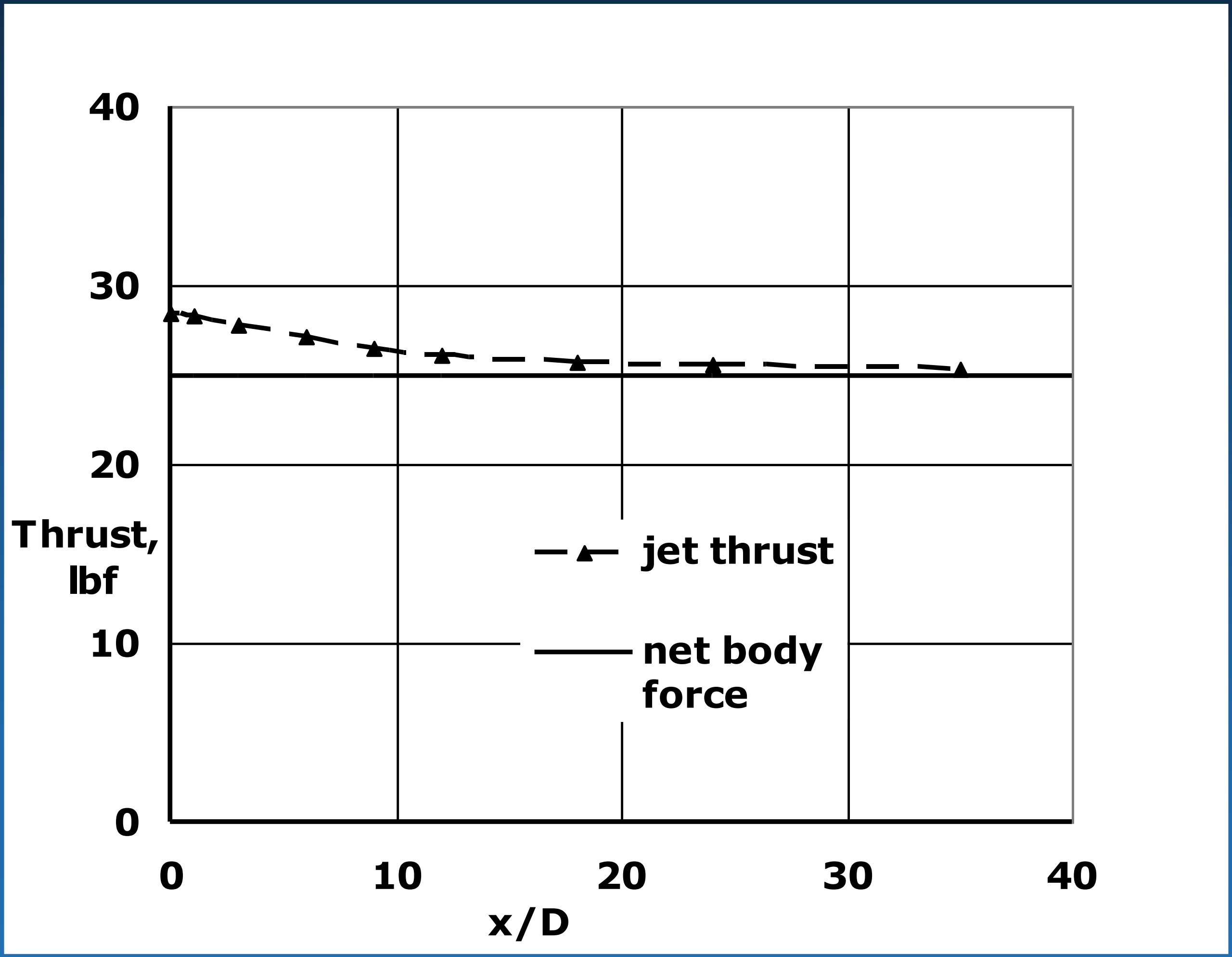


Conservation of the Net Body Force



Loss of Thrust by the Jet from a Flat Plate

Jet Velocity decreases as static pressure decreases, opposite of Bernoulli Equation



Loss of Thrust by the Jet from a Sphere

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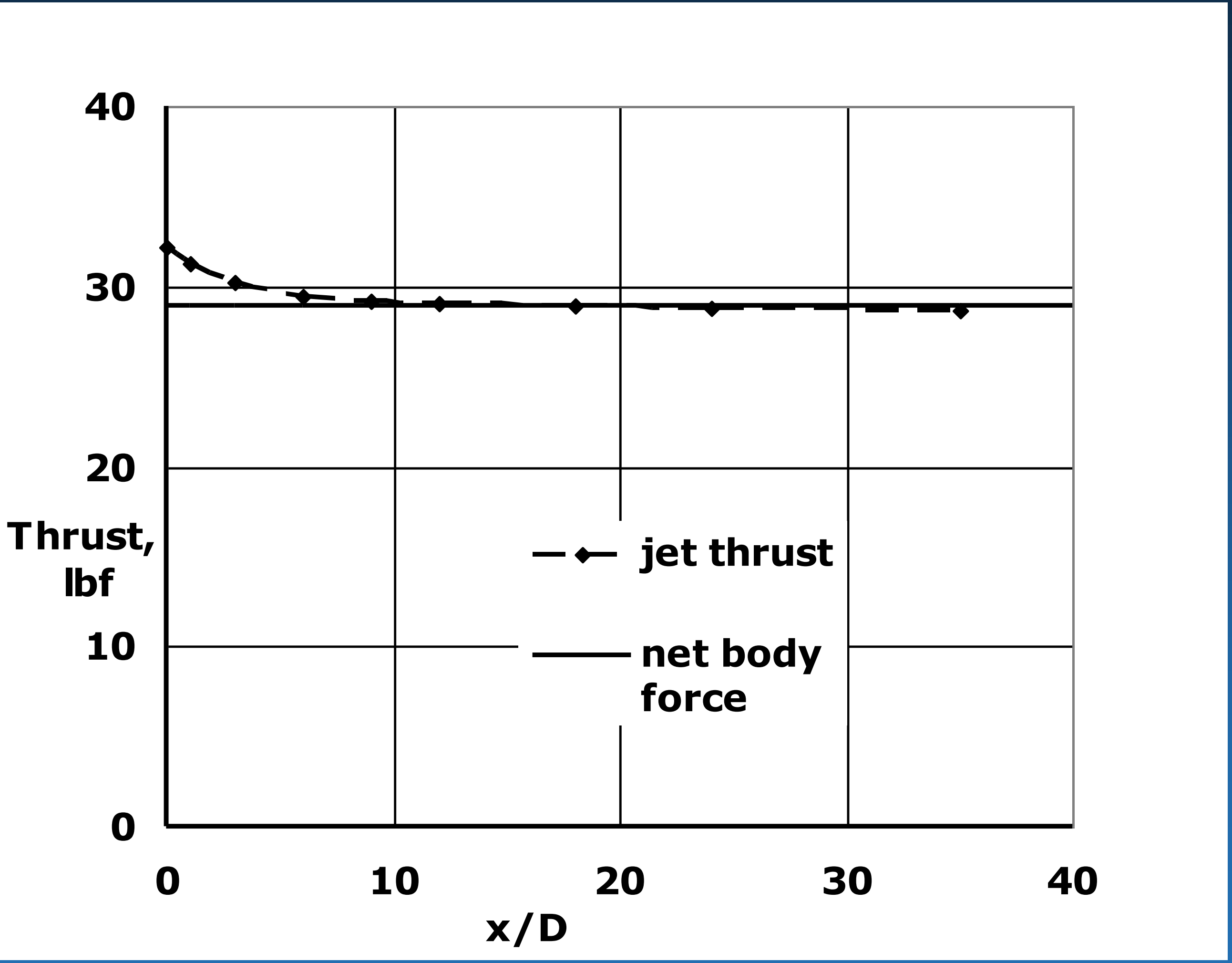
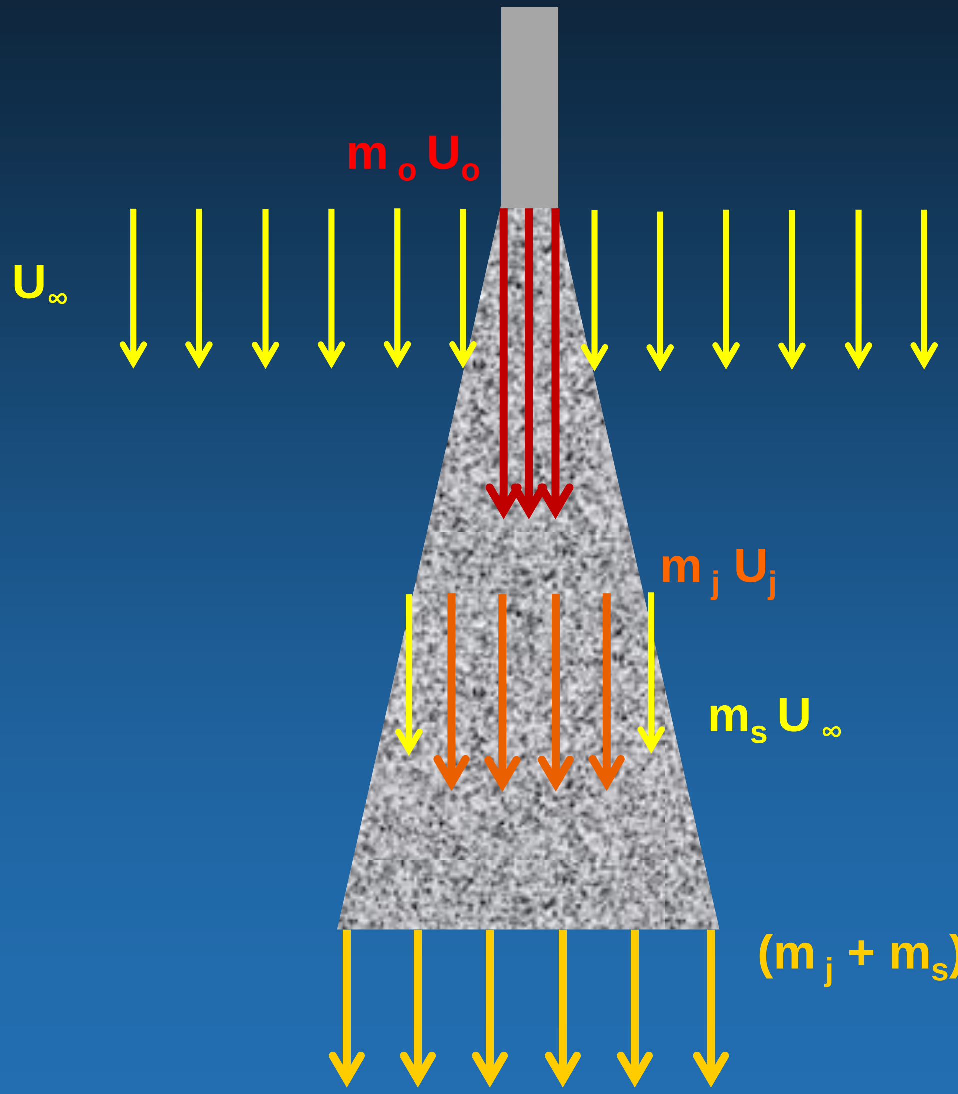


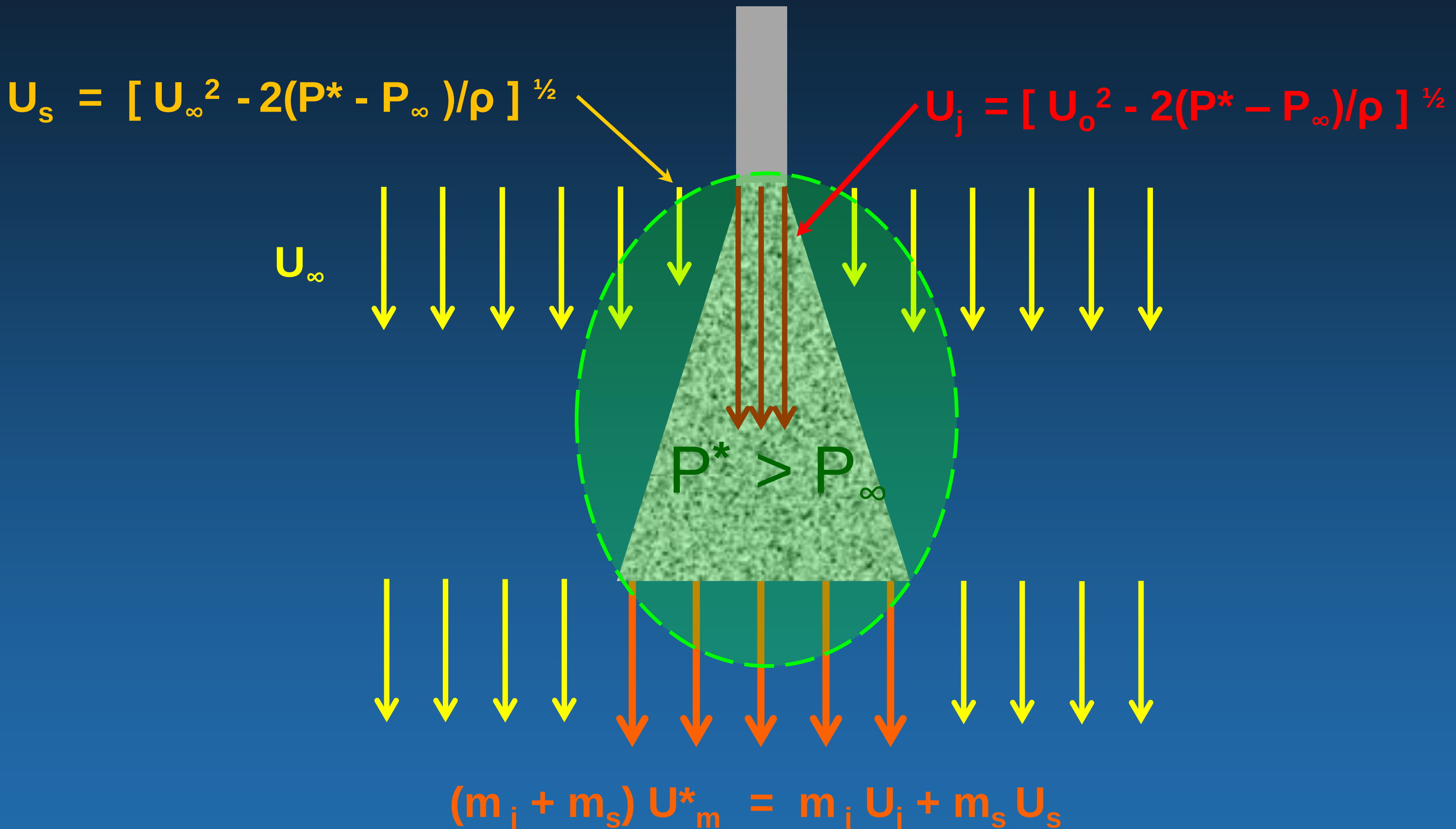
Thrust of a Jet in a Coflowing Stream is Conserved



$$(m_j + m_s)\, U_m = m_j U_j + m_s U_\infty$$

$$= m_0 U_0$$

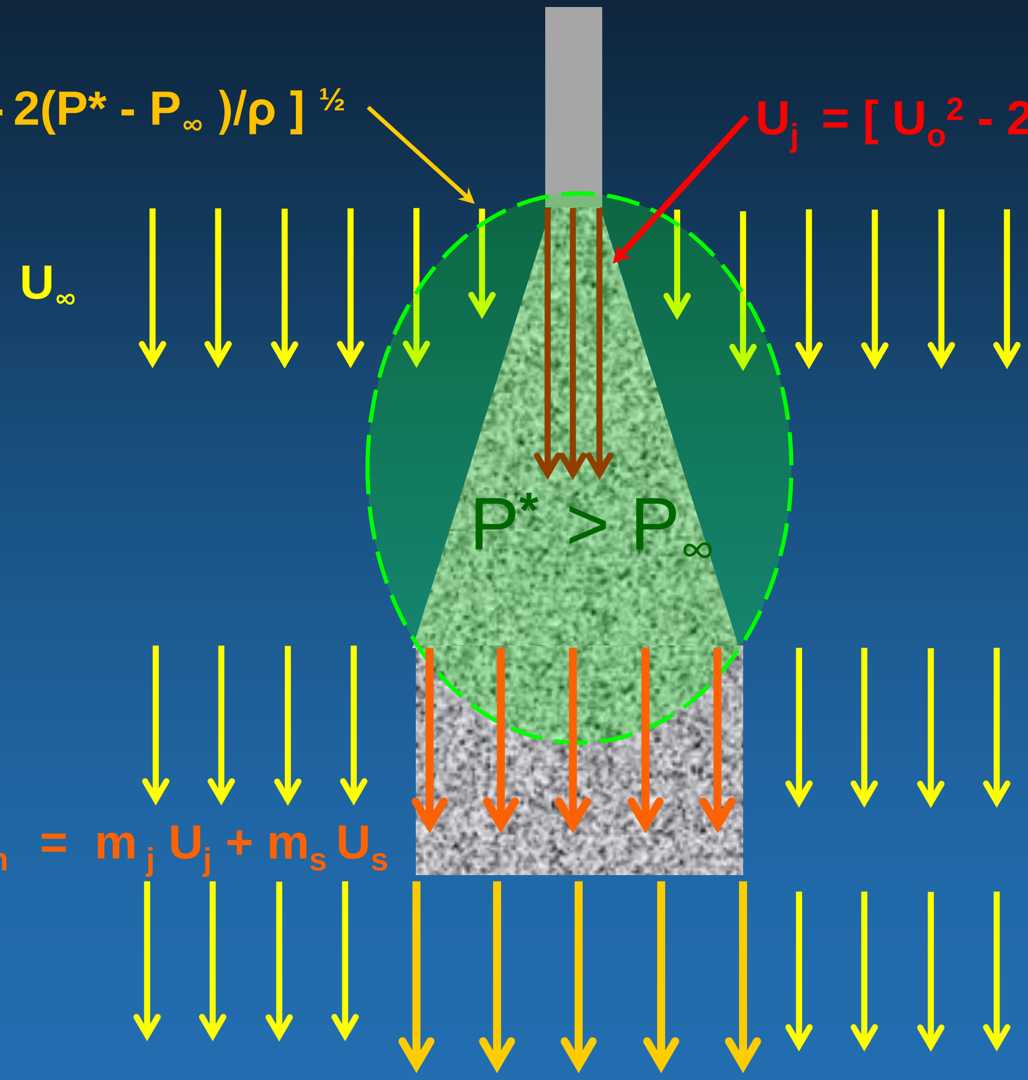
Jet Mixing within a High Pressure Region



An Inelastic Collision of a Jet with the Atmosphere

$$U_s = [\, U_\infty^2 - 2(P^* - P_\infty)/\rho \,]^{1/2}$$

$$U_j = [\, U_o^2 - 2(P^* - P_\infty)/\rho \,]^{1/2}$$



$$(m_j + m_s)\, U^*_m = m_j U_j + m_s U_s$$

$$(m_j + m_s) U_m = (m_j + m_s)\, [\, U^{*2}_m + 2(P^* - P_\infty)/\rho \,]^{1/2}$$

Thrust Comparison

$$R = \frac{(m_j + m_s)\, U_m - m_s U_\infty}{m_o U_o}$$

$$U_m = [\, U^{*}_m{}^2 + 2(P^* - P_\infty)/\rho \,]^{1/2}$$

$$(m_j + m_s)\, U^{*}_m = m_j\, U_j + m_s\, U_s$$

$$U_j = [U_o^2 - 2(P^* - P_\infty)/\rho]^{1/2} \quad \text{and} \quad U_s = [U_\infty^2 - 2(P^* - P_\infty)/\rho]^{1/2}$$

$$R = [((1 - P)^{1/2} + M\,(U - P))^2 + (1 + M)^2\, P]^{1/2} - MU$$

$$M = m_s / m_o, \qquad U = U_\infty / U_o, \qquad P = 2(P^* - P_\infty) / \rho U_o^2$$

Free Jet Mixing at Constant Pressure

If there is no pressure change, then P = 0

$$R = \left[\left((1 - 0)^{½} + M\,(U - 0)\right)^2 + (1 + M)^2\, 0\right]^{½} - MU$$

$$R = \left[\left(1^{½} + MU\right)^2\right]^{½} - MU$$

$$R = \left[1 + MU\right] - MU$$

$$R = 1$$

Thrust is conserved, so the solution reduces to that for free jet mixing

Flow in a Streamtube without Mixing

If there is no mixing, then M = 0

$$R = [\ ((1 - P)^{1/2} + 0\,(U - P))^2 + (1 + 0)^2 P\ ]^{1/2} - 0U$$

$$R = [\ ((1 - P)^{1/2})^2 + 1^2 P\ ]^{1/2}$$

$$R = (1 - P) + P$$

$$R = 1$$

Thrust is conserved, so the solution reduces to the flow in a streamtube

Lift Jet of an Aircraft Hovering in Still Air

For the special case of a hovering VSTOL airplane,

$$U = U_\infty / U_o = 0,$$

and the equation for the thrust ratio may be approximated by the expression:

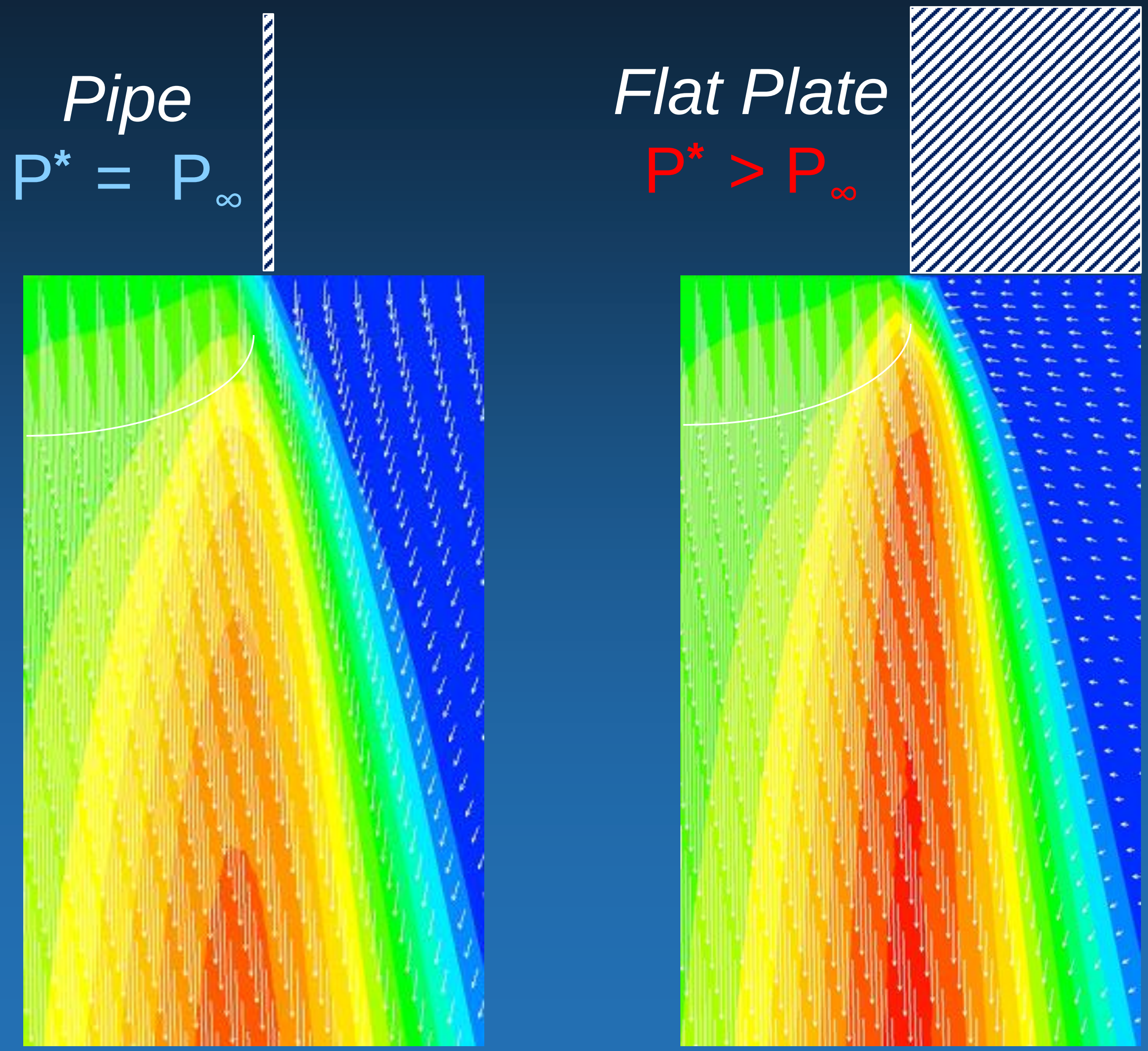
$$R = [((1 - P)^{½} + M (0 - P))^2 + (1 + M)^2 P]^{½} - M0$$

$$R = [(1 - P) - 2M P(1 - P)^{½} + M^2P^2 + (1 + M)^2 P]^{½}$$

$$R \sim 1 - 2MP$$

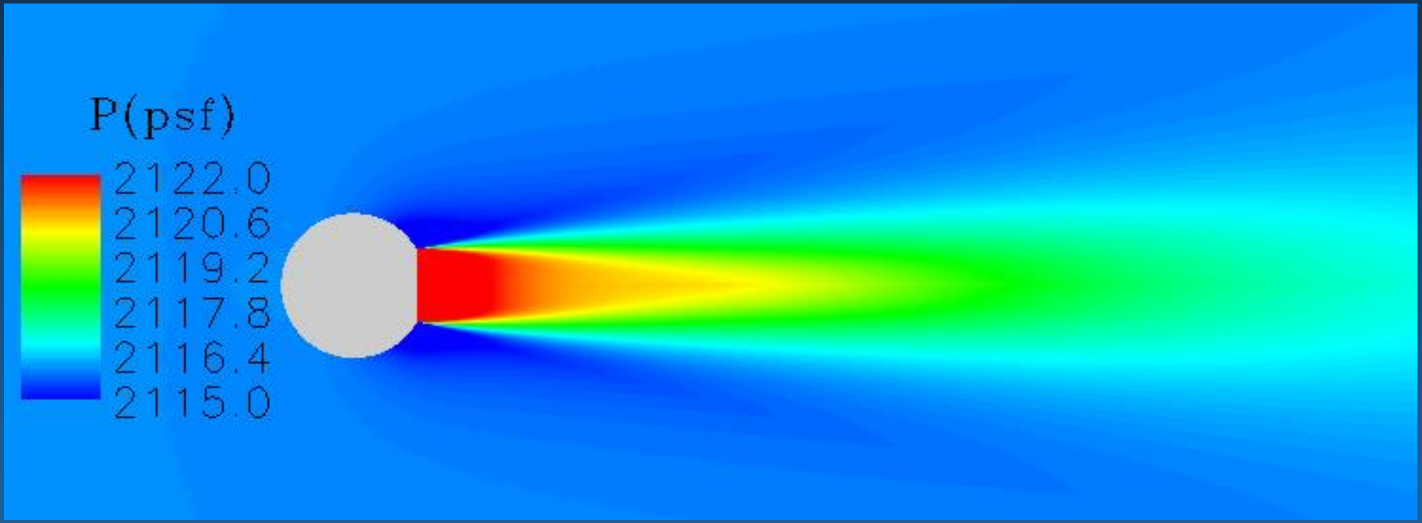
so thrust decreases as entrainment and static pressure increase

“Lost” Thrust Increases the Turbulence Kinetic Energy



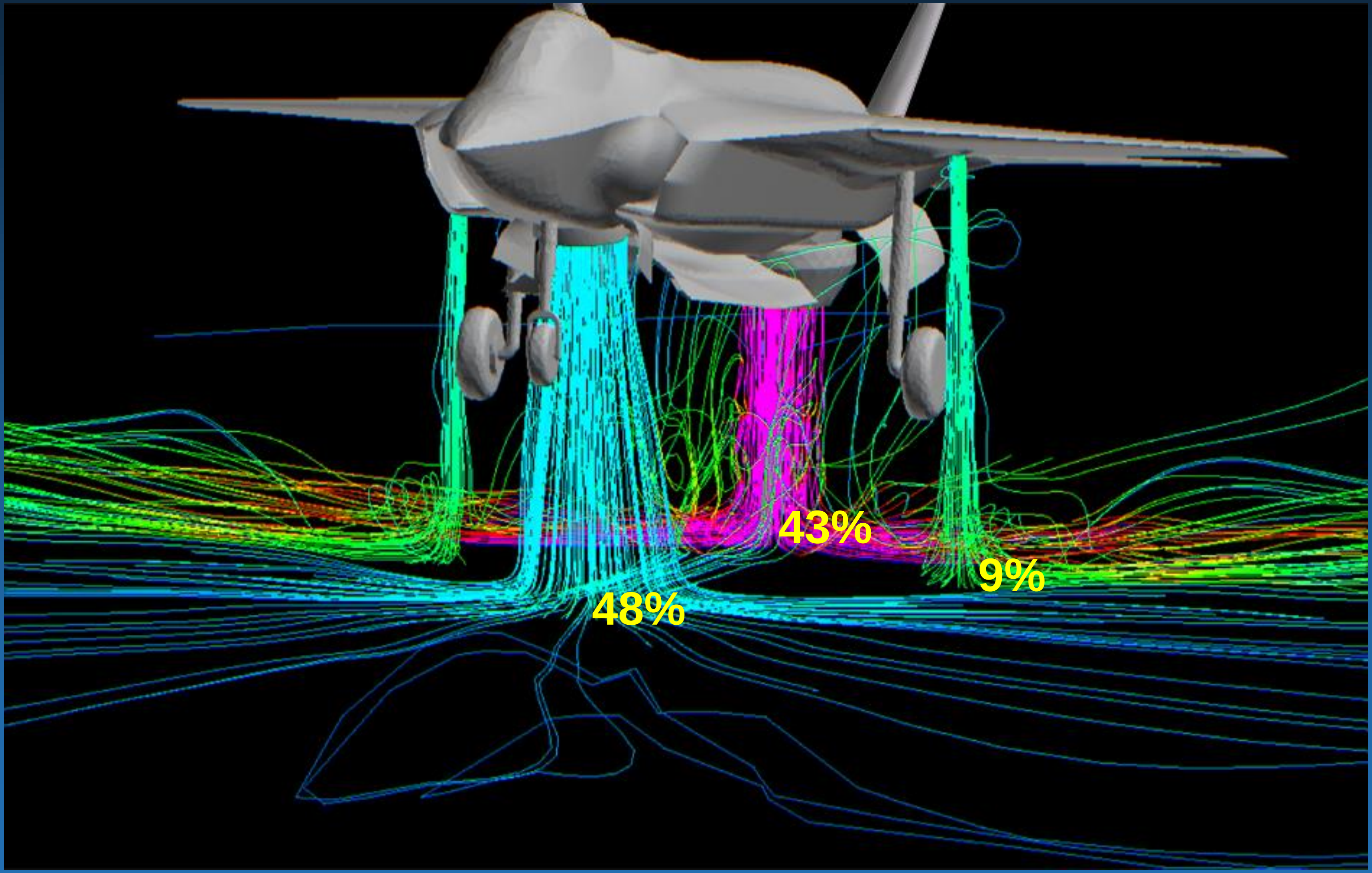
Summary

Jet entrainment induces drag on the body and an equal but opposite loss of jet thrust



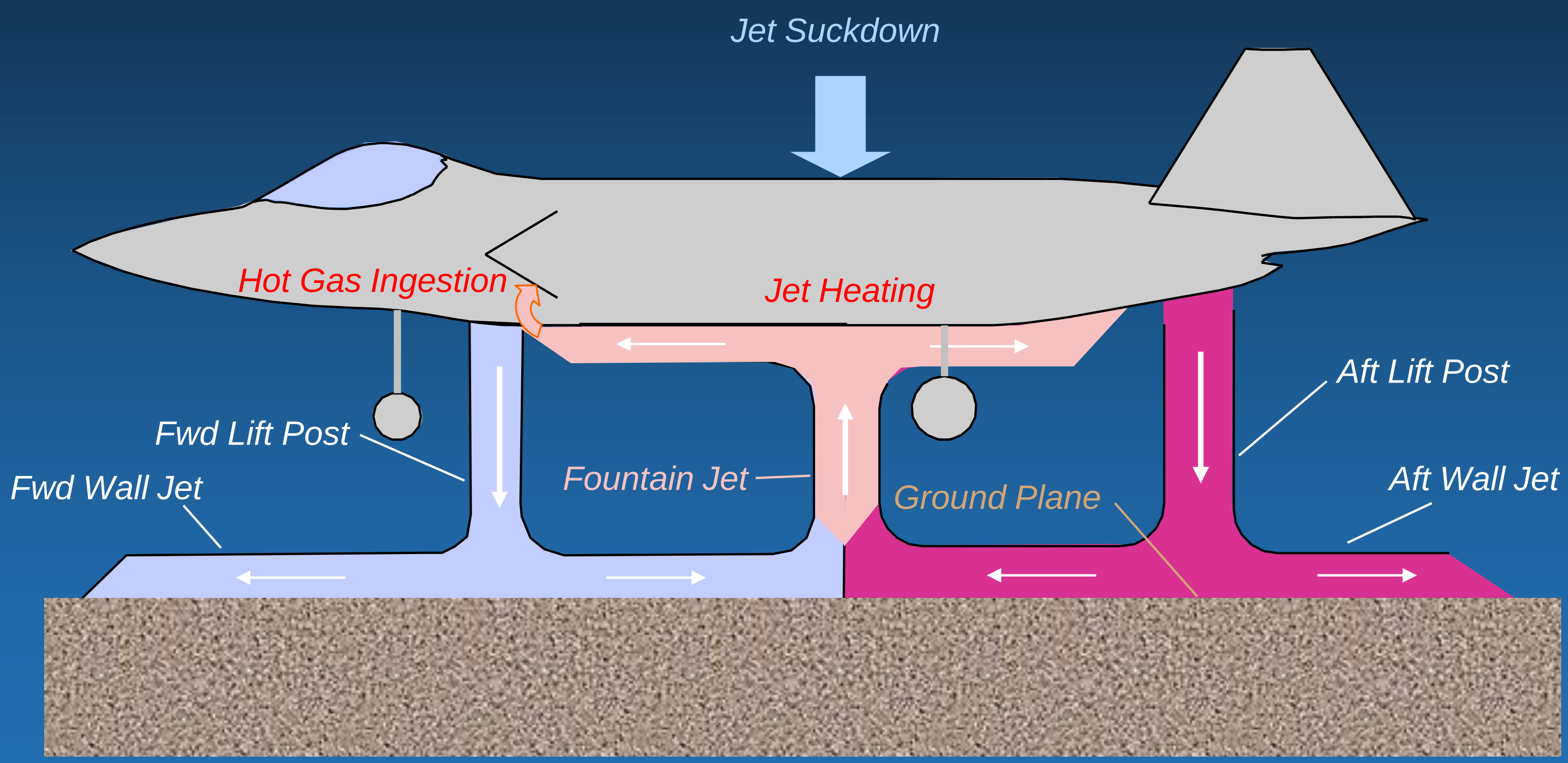
- Turning of the entrained flow causes the static pressure within the jet to rise
- Mixing within the high pressure region reduces the kinetic energy of the jet
- The lost jet kinetic energy appears as an increase in the turbulence kinetic energy
- The loss of jet kinetic energy reduces the thrust of the jet

CFD Study of Hot Gas Ingestion

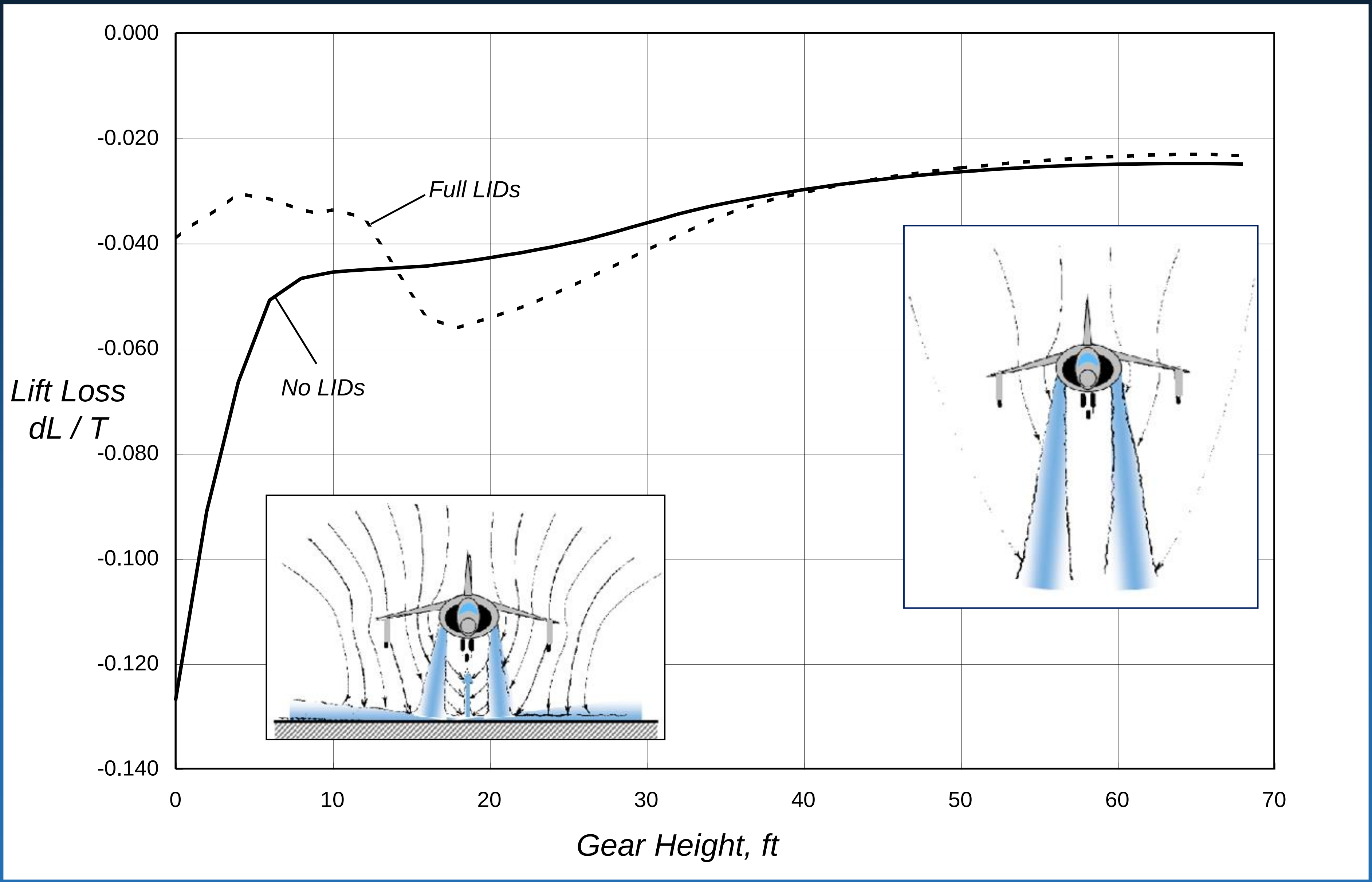


Some Backup Charts

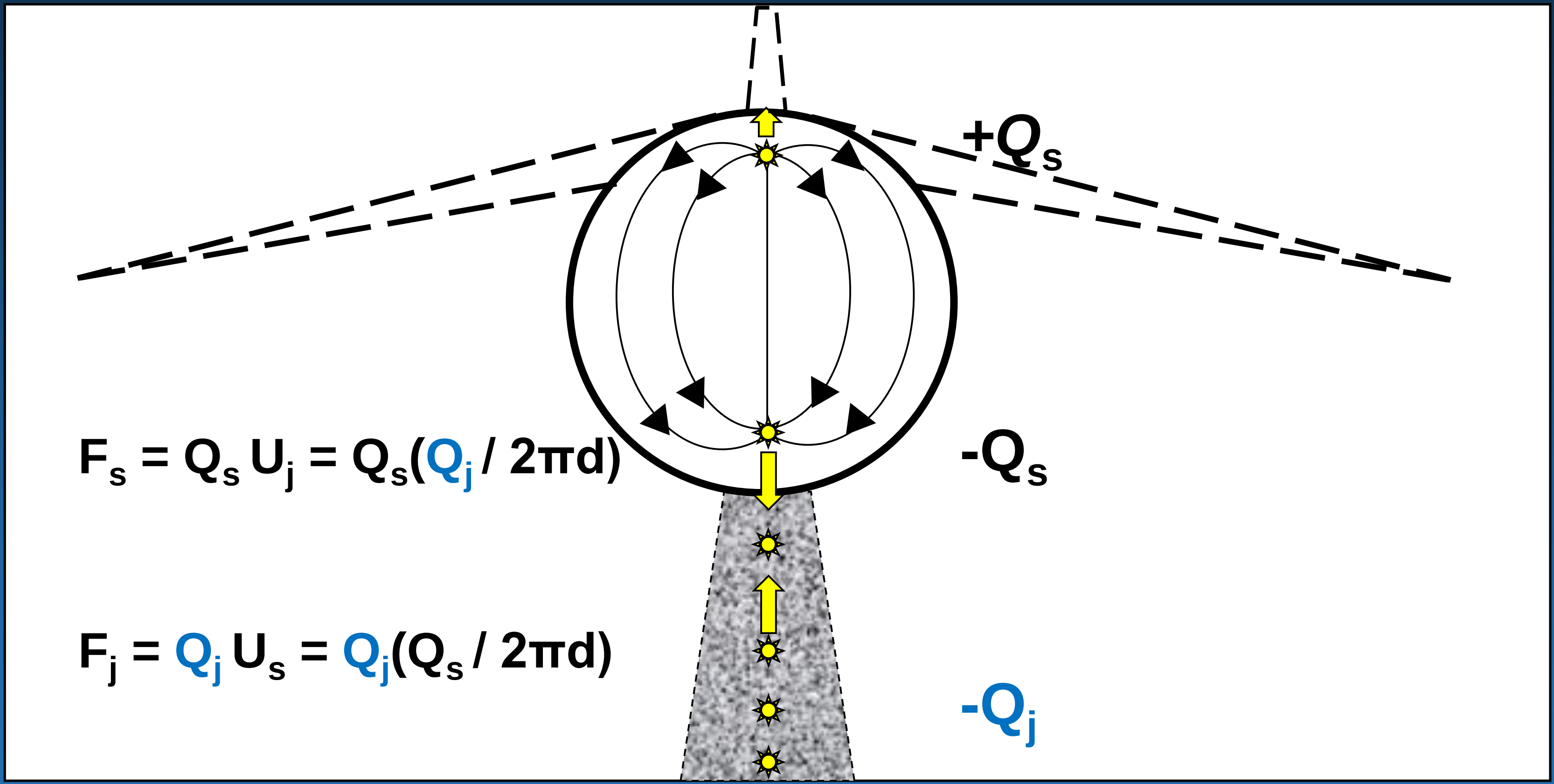
Typical Aircraft /Jet Interactions in Ground Effect



Typical Suckdown and Lift Improvement Device Effectiveness



Equal and Opposite Forces on the Body and Jet



$$F_s = Q_s U_j = Q_s(Q_j / 2\pi d)$$

$$F_j = Q_j U_s = Q_j(Q_s / 2\pi d)$$

Static Pressure

For the special case of a hovering VSTOL airplane,

$U = U_\infty / U_0 = 0$,

and the equation for the thrust ratio may be approximated by the expression:

$$R = [1 + 2M[(1 + P)^{1/2} (U^2 + P)^{1/2} - P] + M^2U^2]^{1/2} - MU$$

$$R = [1 + 2M[(1 + P)^{1/2} (P)^{1/2} - P]]^{1/2}$$

$$R \sim [1 - 2MP^{1/2}]^{1/2} \qquad (P \ll P^{1/2})$$

$$R \sim 1 - MP^{1/2} \qquad .001 \ll .032)$$

so thrust decreases as entrainment and pressure increase