Table 2 - File formats for importing into STAR-CCM+ (STAR-CCM+ user guide

8.04) Parasolid .x_t , .x_b
IGES .iges, .igs
STEP .stp, .step
Stereo lithography
file .stl PATRAN
shells .pat
NASTRAN shells
.nas
CATIA V4 .model, .exp, .session / CATIA V5 .catpart, .cadproduct
SolidWorks .sldprt, .sldasm
PRO/Engineer .prt, .asm
Autodesk Inventor .ipt, .iam

For turbulence models, various models that provide closure of the RANS equations, LES and DES model are also available (STAR-CCM+ user guide 8.04).

3. The selection of CFD code

Reviewing manuals, similarities and differences between FLUENT and STAR-CCM+ in their physics conditions such as turbulence types, grid discretization, and solving methods were obtained. Although FLUENT has difficulties in creating models and meshes from other tools such as GAMBIT. Moreover, the cost of its license ranges from $2,000 to $ 10,000 per year. In the case of STAR- CCM+, it provides a single environment in which users can perform CAD creation to post- processing and allows various types of file formats to be imported. In addition, free academic license is provided. Thus, STAR-CCM+ was employed for this present study.

Appendix F : The governing equations

Euler's Equations

- For Inviscid Flow, we put the viscous term in the N-S equations (attached to the 2nd order term) to 0 to get the Euler's eqns:

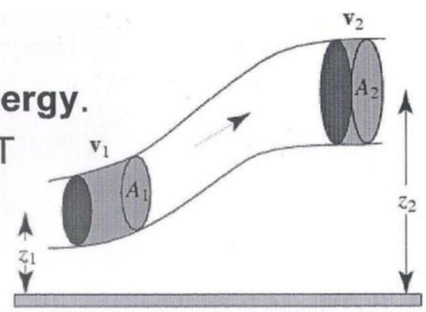
$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + X$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial y} + Y$$

$$\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial z} + Z$$

- Hence, Inviscid flow is also known as **Euler Flow**
- If you integrate along a Streamline, we obtain the Bernoulli's Energy Equation

Bernoulli's Energy Equation



- Bernoulli's equation deals with conservation of **Energy**.
- It is derived making 4 basic ASSUMPTIONS THAT MUST ALWAYS BE REMEMBERED when using Bernoulli's eqn :
  - Viscous effects are negligible (**INVISCID FLOW**)
  - Fluid Density is constant and low speed flow (**INCOMPRESSIBLE FLOW**)
  - Fluid properties at each point do not change w.r.t **time** (**STEADY FLOW**)
  - The equation is applicable along a particular streamline

$$pV + \frac{1}{2}mv^2 + mgz = C$$

Pressure Energy + Kinetic Energy + Potential Energy = Constant along a Streamline

where p = pressure, V = Volume, m = mass, v = velocity, g = acc. due to gravity, z = height

Dividing by V:

$$p_1 + \frac{1}{2}\rho v_1^2 + \rho g z_1 = p_2 + \boxed{\frac{1}{2}\rho v_2^2} + \rho g z_2$$

Static Pressure

Kinetic or "Dynamic" Pressure

Further dividing by ρg will give the equation in terms of respective 'Heads' in meters

Bernoulli and Euler Equations

For inviscid flows, the steady form of the momentum equation is the **Euler** equation,

$$\frac{dp}{\rho} + VdV = 0$$

Integrating along a streamline, we get the Bernoulli's equation for a compressible flow as

$$\int \frac{dp}{\rho} + \frac{V^2}{2} = \text{constant}$$

By assuming, ρ = constant and along a streamline above equation is

$$\frac{p}{\rho} + \frac{V^2}{2} = \text{constant}$$

Conservation of momentum

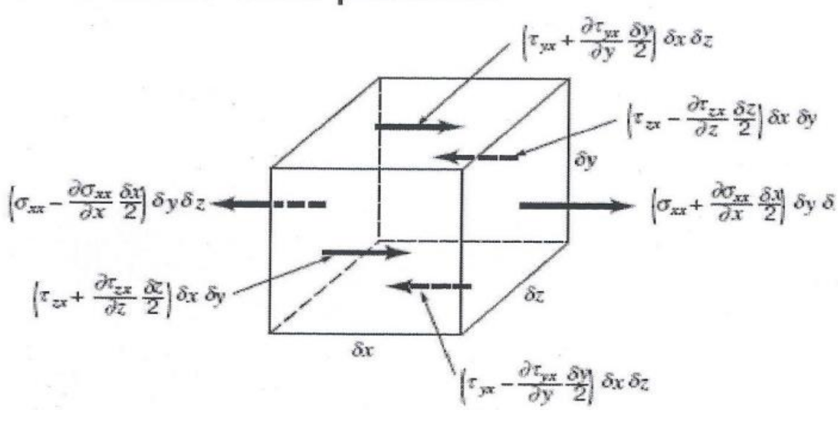
Conservation of Momentum: The resultant force acting on a system equals the rate of momentum change of the system.

Momentum G = mv and F = dG/dt = ma

In component form for a cubic fluid particle:

- $\delta F_x = \delta m a_x$
- $\delta F_y = \delta m a_y$
- $\delta F_z = \delta m a_z$

Surface Forces



Navier – Stockes Equations

The Differential form of the Momentum equation derived from Eqns of Motion is known as the Navier-Stokes (N-S) Equations:

(x direction)

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial p}{\partial x}+\rho g_x+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)$$

(y direction)

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=-\frac{\partial p}{\partial y}+\rho g_y+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)$$

(z direction)

$$\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=-\frac{\partial p}{\partial z}+\rho g_z+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)$$

LHS: **Inertial** force acting on the fluid element, i.e. the product of density and velocity derivatives w.r.t. ***time*** and **space**

RHS: (a) **Pressure forces** acting normally +
(b) **Gravitational** force acting on fluid element+
(c) **Surface** forces which depend on ***viscosity***

Mach Number — Ratio of Inertia and elastic forces

$$M=\frac{V}{a}$$

V is object or flow velocity

Speed of sound, a, in a perfect gas depends only on temperature of gas

$$a=\sqrt{\gamma RT}$$

M <1 Subsonic flow

M =1 Sonic flow

M >1 Supersonic flow

M >4 Hypersonic flow

Incompressible Flow – Fluid density is constant or change in density is negligible in the flow. (M <0.3)

Compressible Flow – Fluid density will vary throughout the flow field. (M>0.3)

Ideal Gas Law

Pressure, density and temperature of a gas are related through an equation of state. Under ordinary conditions for air,

$$P = \rho R T$$

Compressible Bernoulli equation (simplified energy equation)

$$h_1 + \frac{V_1{}^2}{2} = h_2 + \frac{V_2{}^2}{2} = h_o$$

$$c_p T_1 + \frac{1}{2} V_1^2 = c_p T_2 + \frac{1}{2} V_2^2 = c_p T_0$$

Isentropic relation

It's derived from the energy equation.

It gives relation between total, static temperature and Mach Number.

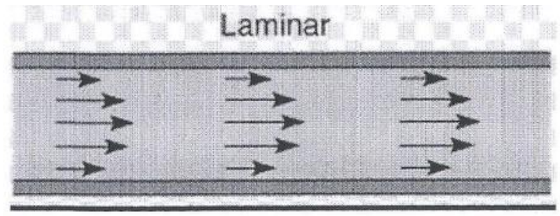
$$\frac{T_o}{T} = \left(1 + \frac{\gamma - 1}{2} M^2\right)$$

$$\frac{p_o}{p} = \left(1 + \frac{\gamma - 1}{2} M^2\right)^{\frac{\gamma}{\gamma - 1}}$$

$$\frac{p_1}{p_2} = \left(\frac{\rho_1}{\rho_2}\right)^{\gamma} = \left(\frac{T_1}{T_2}\right)^{\gamma/(\gamma-1)}$$

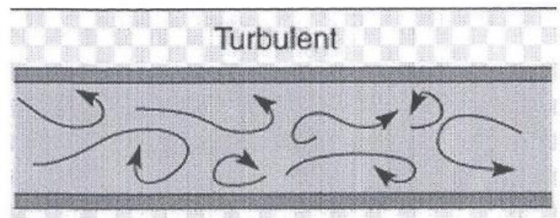
Laminar Flow

Fluid particles move in smooth, layered fashion.



Turbulent Flow

Fluid particles move in a chaotic, "tangled" fashion



Reynolds No = Inertia force / Viscous Force