ASTT Annual Conference 2024
CFD Project
Gwion Clark

Photo: D. Thurlow.

Introduction

Computational Fluid Dynamics
- The basics
- Setting up a simulation

Turbulence Modelling
- Methodologies
- RANS Models

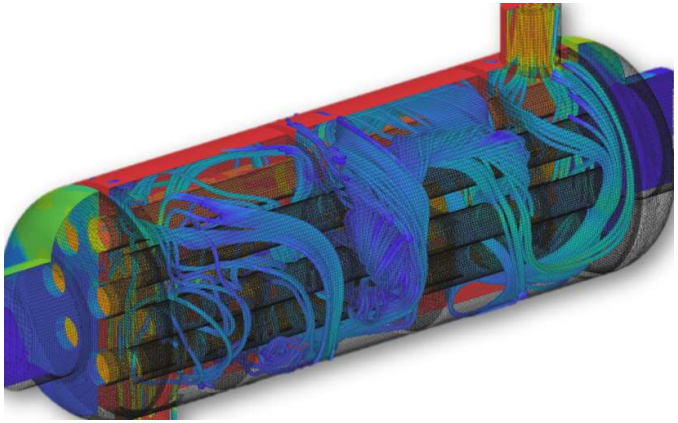
Third Year University Project –Exhaust System Model
- How it was done
- The results
- Possible improvements

Computational Fluid Dynamics

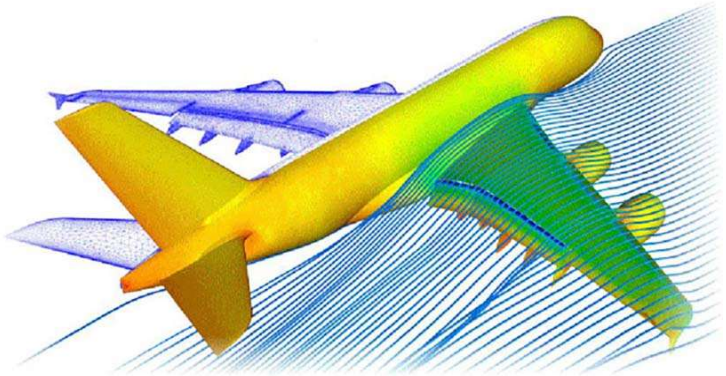
CFD: Applications

- Aerodynamics
- Heat transfer
- Weather prediction

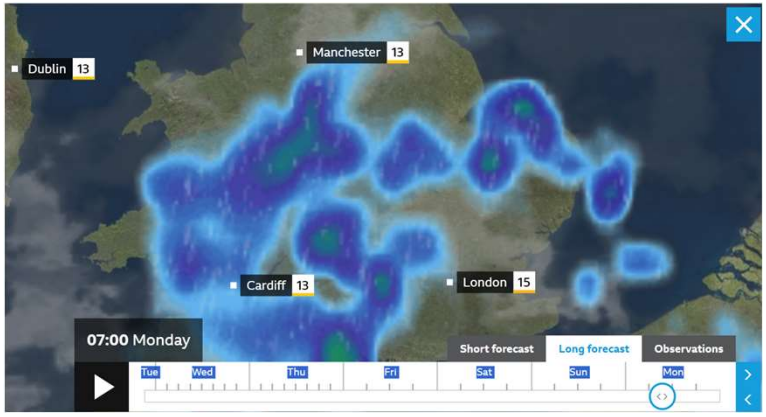
And much more!



ENGYS - Simulating heat transfer Multiphysics with HELYX.



KLM UK Engineering



BBC Weather

CFD: Navier-Stokes Equations

For incompressible Newtonian fluids:

x direction:

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

y direction:

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

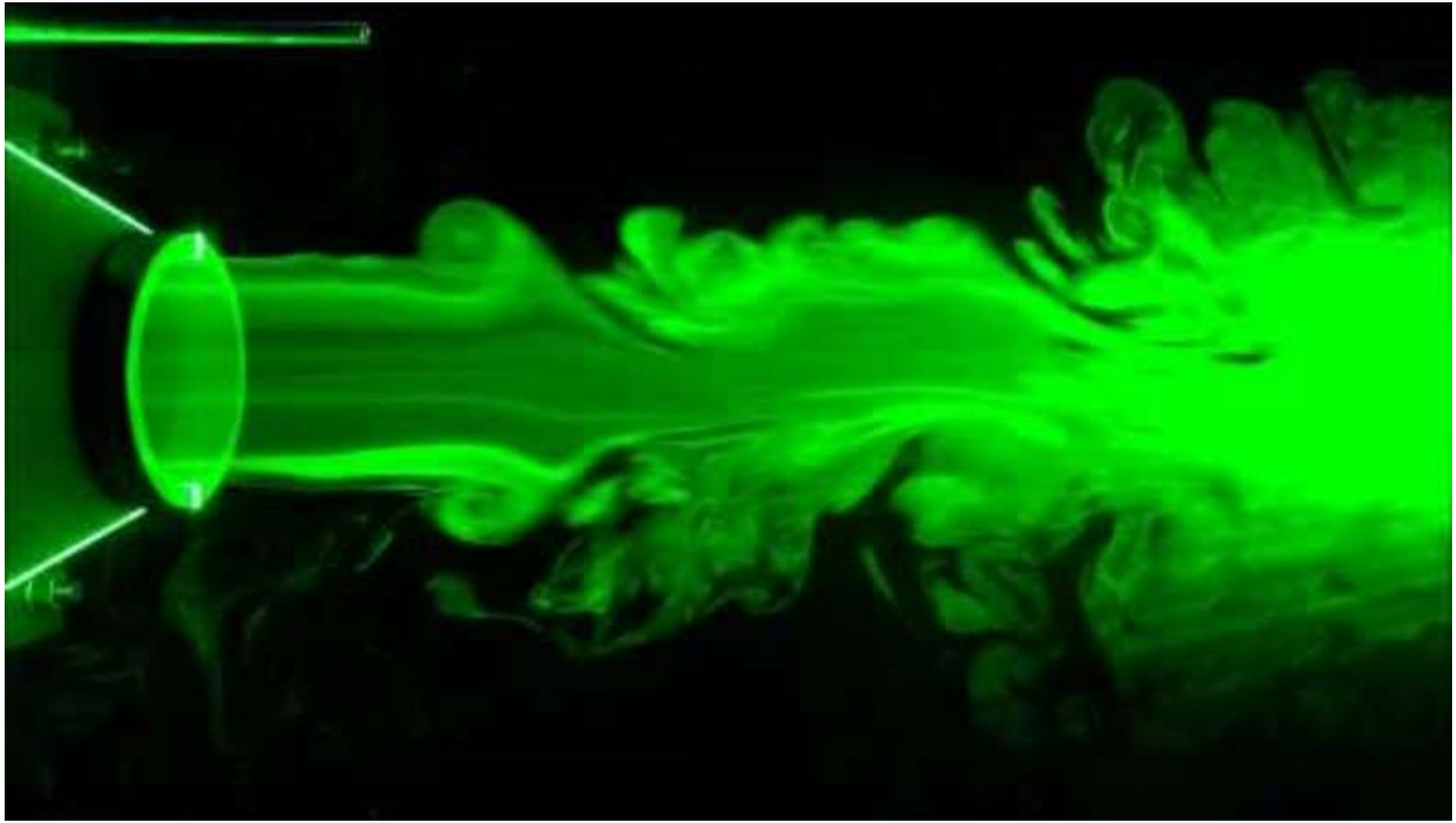
z direction:

$$\underbrace{\rho\left[\frac{\partial v}{\partial t}+\frac{\partial w}{\partial x}u+\frac{\partial w}{\partial y}v+\frac{\partial w}{\partial z}w\right]}_{\text{Mass}\times\text{acceleration}}=\underbrace{-\frac{\partial p}{\partial z}}_{\text{Pressure gradient}}+\underbrace{\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)}_{\text{Viscous effects}}+\underbrace{\rho g_z}_{\text{Body forces}}$$

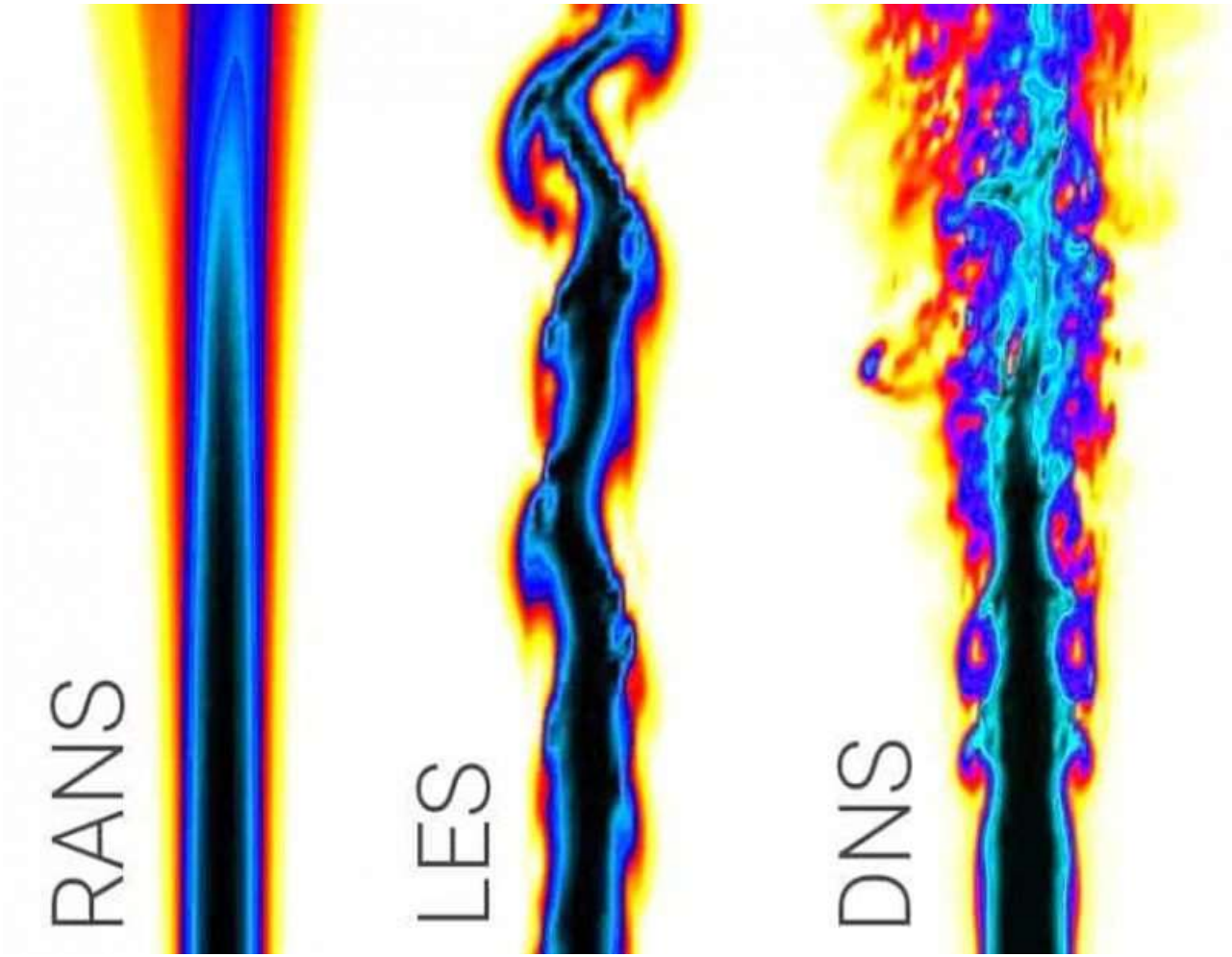
Continuity Equation:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0$$

Turbulence Modelling



Turbulence Modelling: Methodologies



idealsimulations.com - CFD modelling of a turbulent jet using different approaches.

Turbulence Modelling: Reynolds Averaged Navier-Stokes (RANS)

- Approximations must be made to close the RANS equations.
- Different models exist such as k-epsilon and k-omega SST.
- Two equation models solve a pair of transport equations.

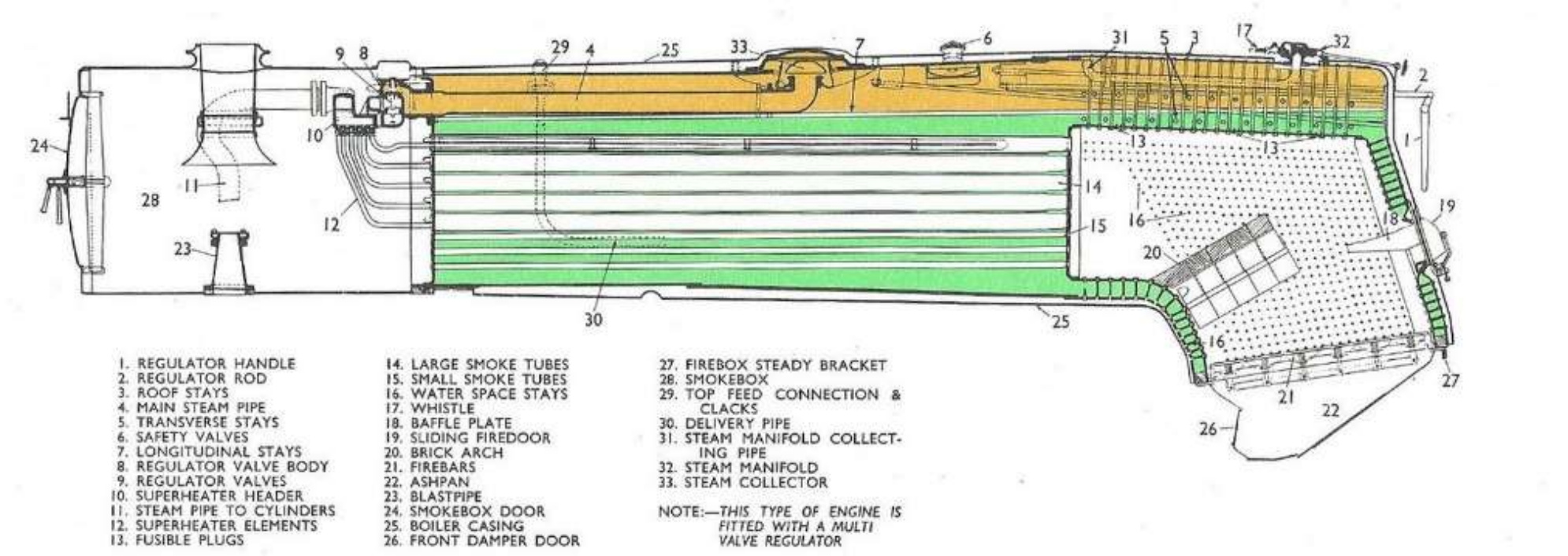
CFD Simulation: Setting Up

- Domain – 2D, 3D, axis-symmetric
- Meshing – structured, inflation layers
- Boundary Conditions – pressure outlet, velocity inlet
- Models – k-omega, k-epsilon
- Settings – compressibility effects, steady state, ideal gas, fluid properties such as temperature, number of iterations & convergence criteria.

The Project

British Railways - Performance and Efficiency Tests with Exhaust Steam Injector, Bulletin No.6.

The Project: Exhaust Systems Research



British Transport Commission - Handbook for Steam Locomotive Enginemen.

The Project: Exhaust Systems Research

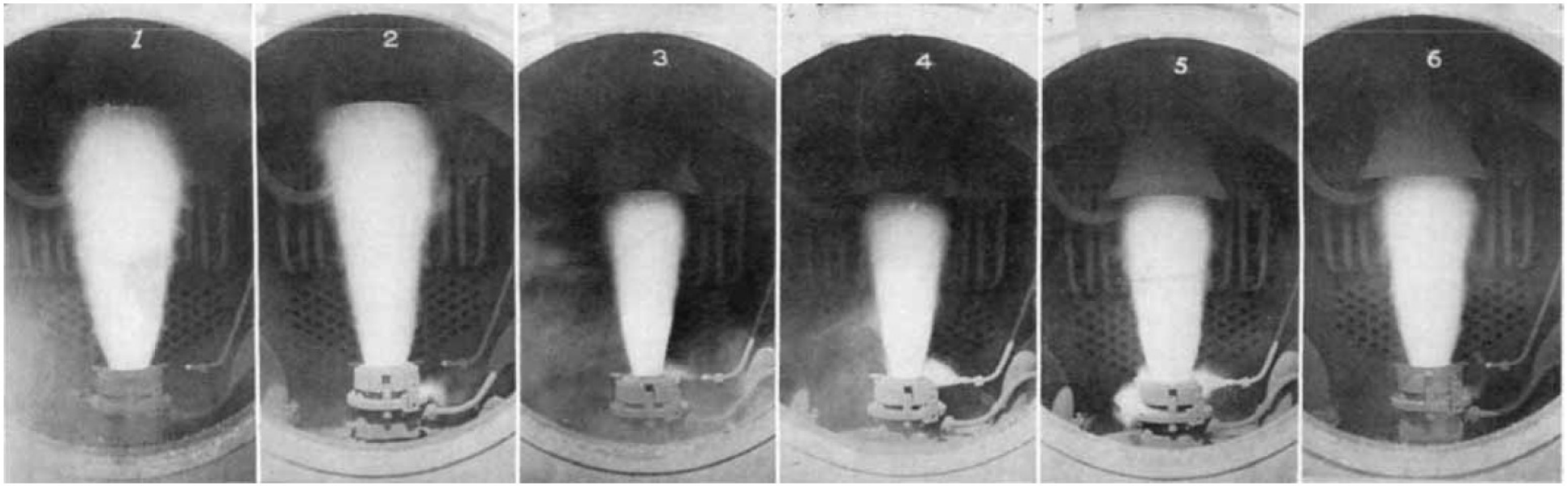


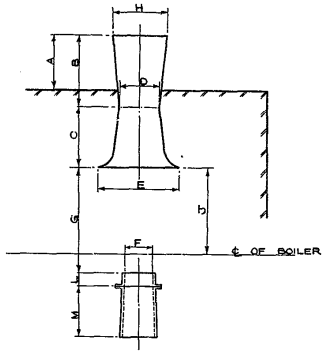
Fig. 1.	Fig. 2.	Fig. 3.	Fig. 4.	Fig. 5.	Fig. 6.
Without chimney extension. 10lb. pressure - jumper in operation.	Without chimney extension. 5lb. pressure - jumper in operation.	With chimney extension. 10lb. pressure - jumper wedged down.	With chimney extension. 5lb. pressure - jumper wedged down.	With chimney extension. 10lb. pressure - jumper wedged up.	With chimney extension. 5lb. pressure - jumper wedged up.

Fig. 16.

Gives Six Views of Exhaust Steam Under Varying Conditions, illustrating Mr. Dewhurst's Remarks.

M.M. Loubser, E.S. Cox - Locomotive Boiler Design: Theory and Practice.

The Project: Geometry



CLASS	TYPE	A	B	C	D	E	F	G	H	J	L	M	REMARKS
2	2-6-0	2'-3 3/8"	2'-10"	10"	1'-0"	1'-9 1/2"	4 1/8"	1'-7 1/2"	1'-2 1/2"	10 1/2"	3 1/2"	1'-0 7/8"	
2	2-6-2T	2'-3 3/8"	2'-10"	10"	1'-0"	1'-9 1/2"	4 1/8"	1'-7 1/2"	1'-2 1/2"	10 1/2"	3 1/2"	1'-0 7/8"	
3	2-6-0	1'-11 3/16"	2'-5"	10 3/8"	1'-0 3/8"	1'-11 3/8"	4 1/2"	1'-8 5/8"	1'-2 7/8"	1'-1 5/8"	6"	1'-1 7/16"	
3	2-6-2T	1'-11 3/16"	2'-5"	10 3/8"	1'-0 3/8"	1'-11 3/8"	4 1/2"	1'-8 5/8"	1'-2 7/8"	1'-1 5/8"	6"	1'-1 7/16"	
4	2-6-0	1'-6"	2'-7 1/4"	8 3/4"	1'-0 5/16"	2'-4"	4 3/8"	1'-11"	1'-2 59/64"	9"	6"	9 1/16"	
4	2-6-4T	1'-8"	2'-5"	9 1/4"	1'-1 1/2"	1'-11 3/4"	4 3/4"	1'-9 3/4"	1'-3 57/64"	1'-0 3/4"	6"	10"	
4	4-6-0	1'-8"	2'-5"	9 1/4"	1'-1 1/2"	1'-11 3/4"	4 5/8"	1'-9 3/4"	1'-3 57/64"	1'-0 3/4"	6"	10"	
5	4-6-0	1'-6 5/8"	2'-4 5/8"	1'-0 1/8"	1'-2 1/4"	2'-4 1/2"	4 7/8"	1'-9 1/2"	1'-4 3/32"	10 1/2"	4 1/2"	1'-3 15/16"	
6	4-6-2	1'-0"	2'-3 1/8"	10 3/4"	1'-2 1/4"	2'-0 1/2"	5 1/8"	1'-10 5/8"	1'-4"	8 5/8"	3 1/2"	1'-3"	
7	4-6-2	7 1/2"	2'-2 1/4"	1'-1"	1'-3 3/8"	2'-6 1/2"	5 3/8"	1'-9 3/4"	1'-5 31/64"	5 1/4"	3 1/2"	1'-3"	
9	2-10-0	7 5/8"	2'-4"	8"	1'-3 1/4"	2'-3"	5 3/8"	1'-8 7/8"	1'-5 1/4"	6 1/2"	3 1/2"	1'-3"	

A HEIGHT OF CHIMNEY FROM SMOKEBOX TOP

B DISTANCE FROM TOP OF CHIMNEY TO SMALLEST DIA. OF CHOKE

C DISTANCE FROM SMALLEST DIA. OF CHOKE TO BOTTOM OF COWL

D SMALLEST DIA. OF CHOKE

E DIA. INSIDE BOTTOM OF COWL

F INSIDE DIA. OF BLAST PIPE TOP

G DISTANCE FROM BOTTOM OF COWL TO TOP OF BLAST PIPE

H DIA. OF CHIMNEY TOP

J DISTANCE FROM BOTTOM OF COWL TO BOILER CENTRE

L HEIGHT OF BLAST PIPE TOP

M HEIGHT OF BLAST PIPE

THIS DRAWING APPLIES TO THE FOLLOWING CLASSES

CLASS	TYPE	FOR Nº PER ENGINE SEE	CLASS	TYPE	FOR Nº PER ENGINE SEE
2	2-6-0		5	4-6-0	
2	2-6-2T		6	4-6-2	
3	2-6-0		7	4-6-2	
3	2-6-2T		9	2-10-0	
4	2-6-0				
4	2-6-4T				
4	4-6-0				

NOTES:
MACHINE SURFACE ▽ GROUND SURFACE ▽▽
WELDING SYMBOLS TO BSS. 499, SECTION 7.
ALL SCREW THREADS TO BE TO B.S.S. 84 (MED.) UNLESS OTHERWISE STATED
DIMENSIONS OVER TO OR BETWEEN MACHINED SURFACES FOR WHICH NO LIMITS ARE GIVEN TO BE ±·010 INS.

SCALES:

ISSUE LETTER	DATE	DMANS INITIAL	ALTERATIONS

DATE	ORDER	FOR Nº PER ENGINE SEE	Nº OF ENGINES	ENGINE NUMBERS	CLASS

RELATIVE DIMENSIONS OF CHIMNEYS

LINERS AND BLAST PIPES

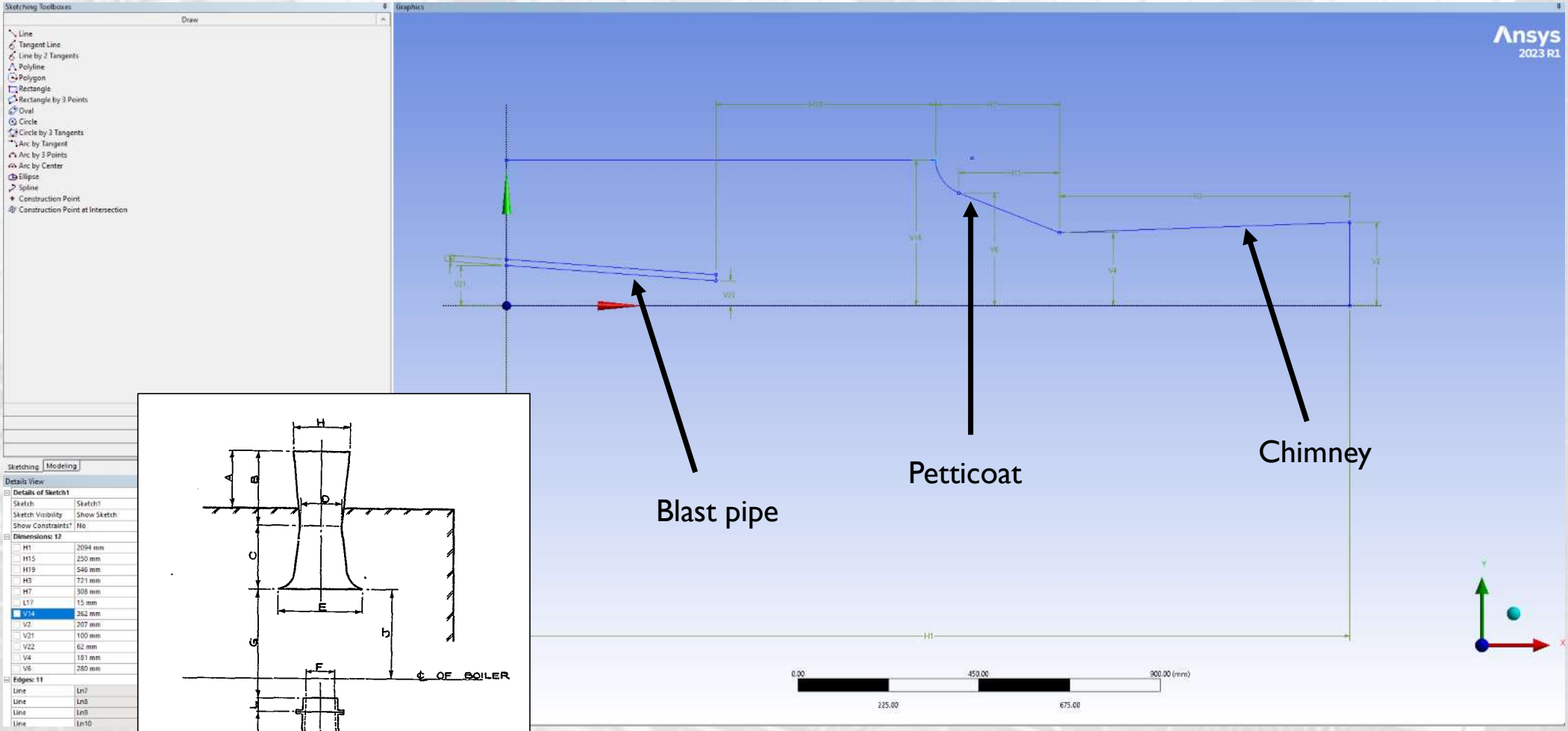
BRITISH RAILWAYS
LOCOMOTIVE DRAWING OFFICE
DONCASTER.

DRAWING Nº SL-DN-1-1128

DRAWN	TRACED	CHECKED	DATE
A.S.	J.A.	W.C.	5-4-55

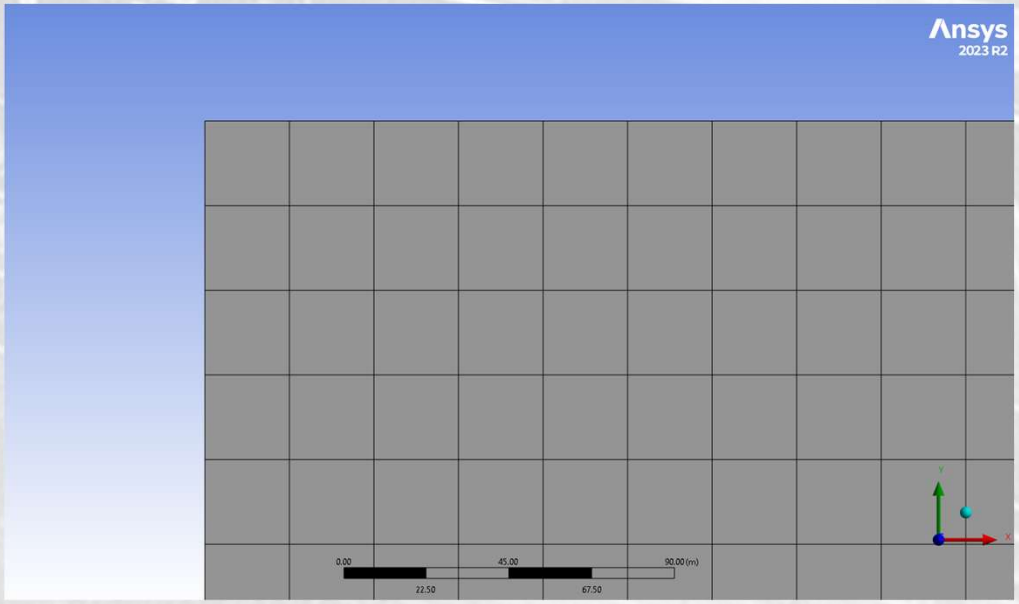
British Railways - Drawing No.SL-DN-1-1128

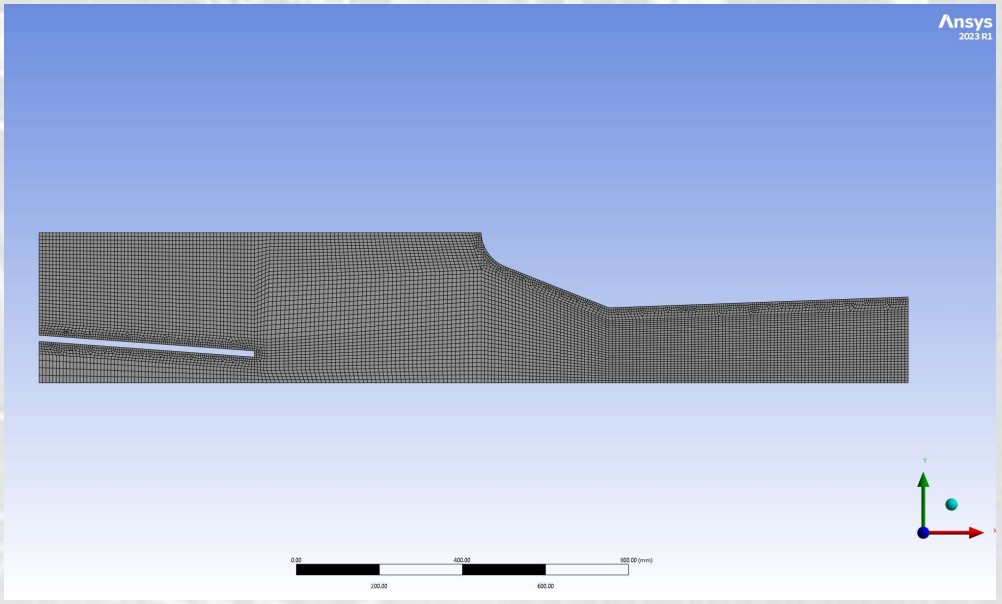
The Project: Geometry



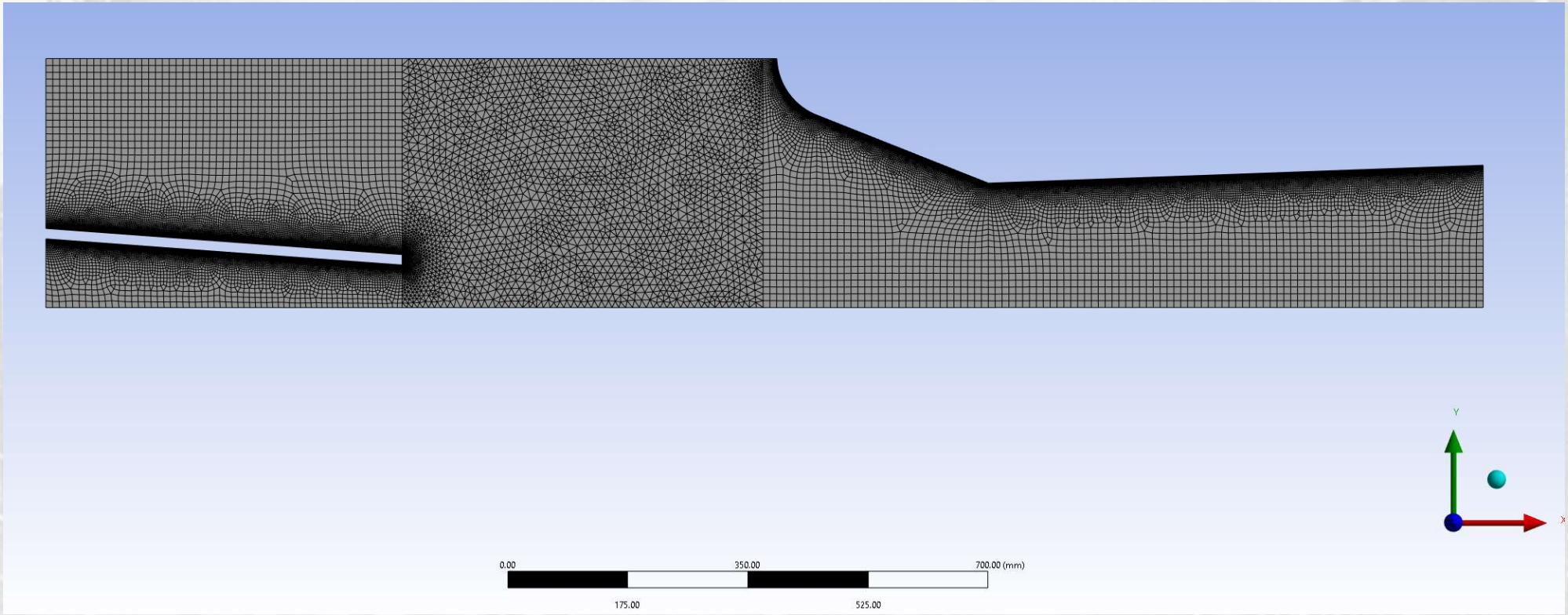
The Project: Meshing/Discretisation

- Required y+ value changes depending on turbulence model.
- Inflation layers used to create a finer mesh near the wall.
- Grid independence test performed to optimise mesh.

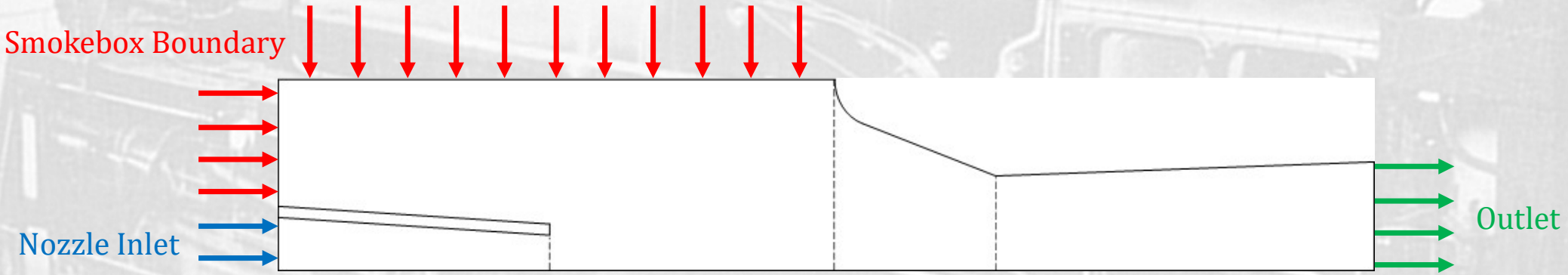




The Project: Meshing/Discretisation

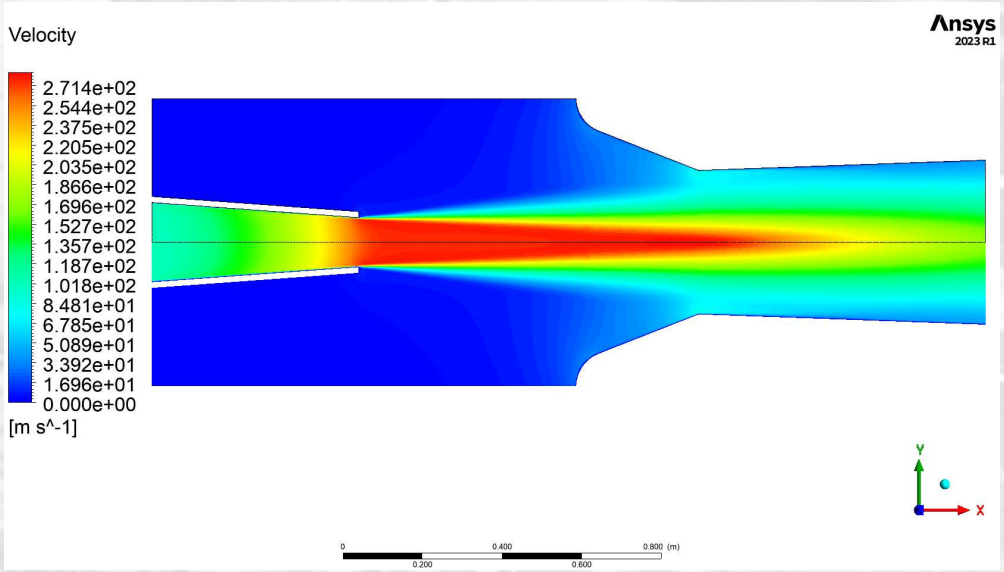


The Project: Boundary Conditions

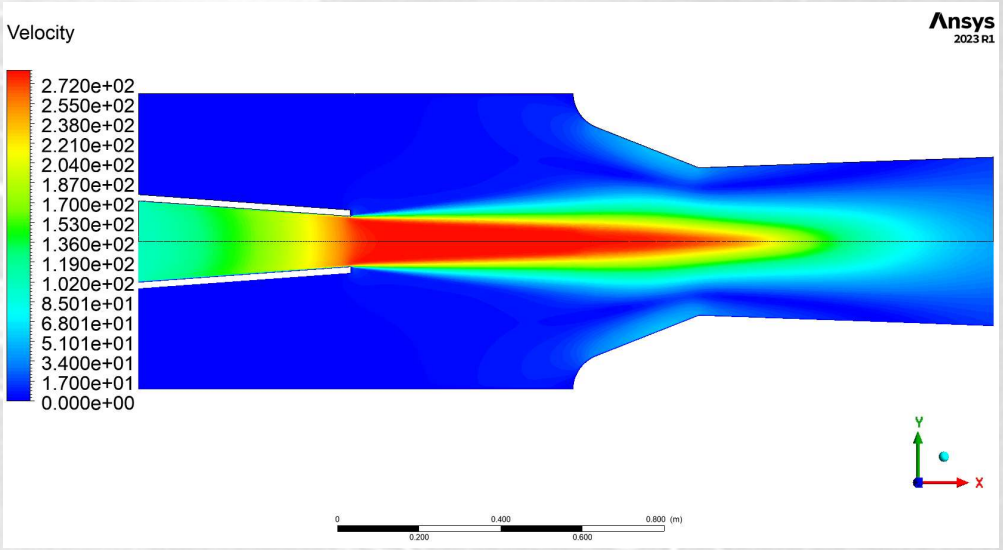


The Project: Boundary Conditions

Some initial simulations to investigate boundary conditions:



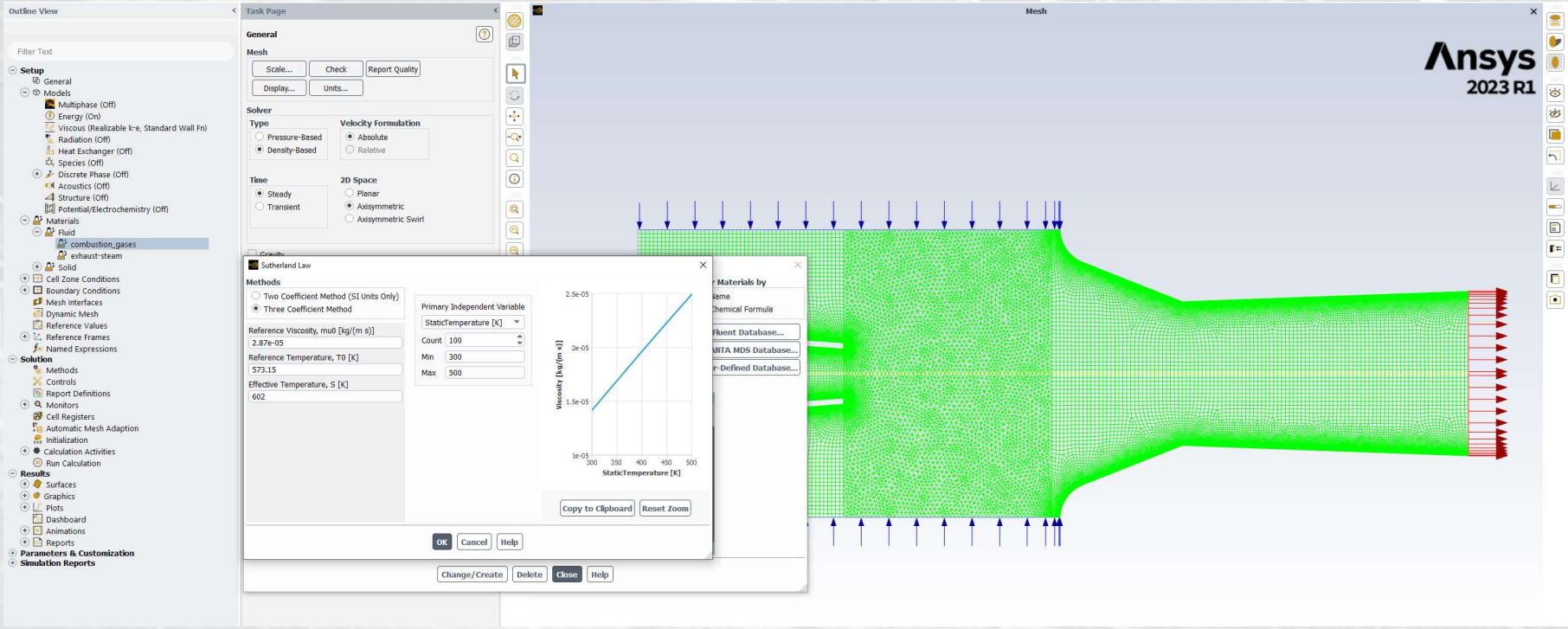
Velocity inlet, velocity outlet and pressure outlet.



Velocity inlet, slip wall and pressure outlet.

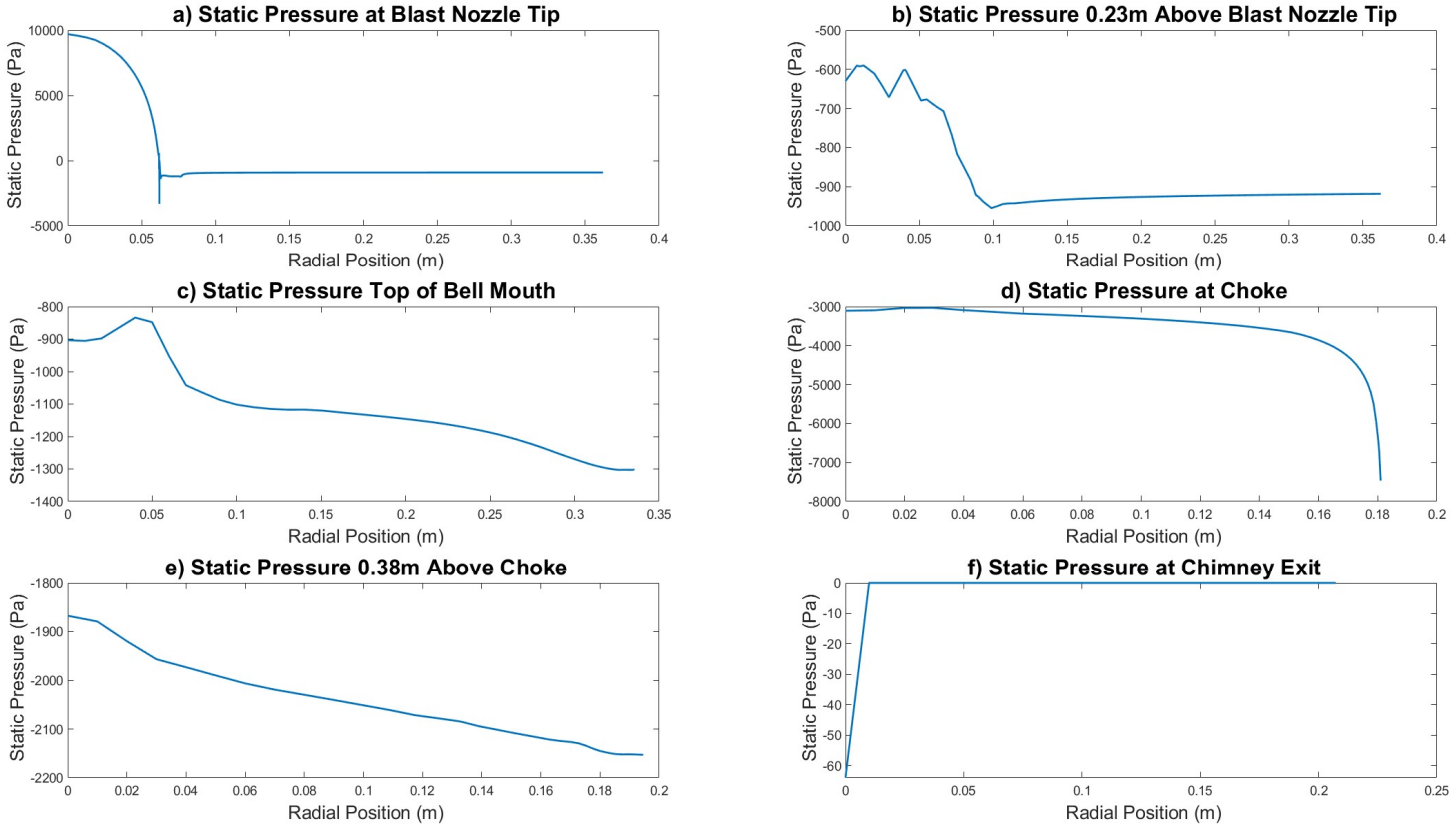
The Project: Set Up

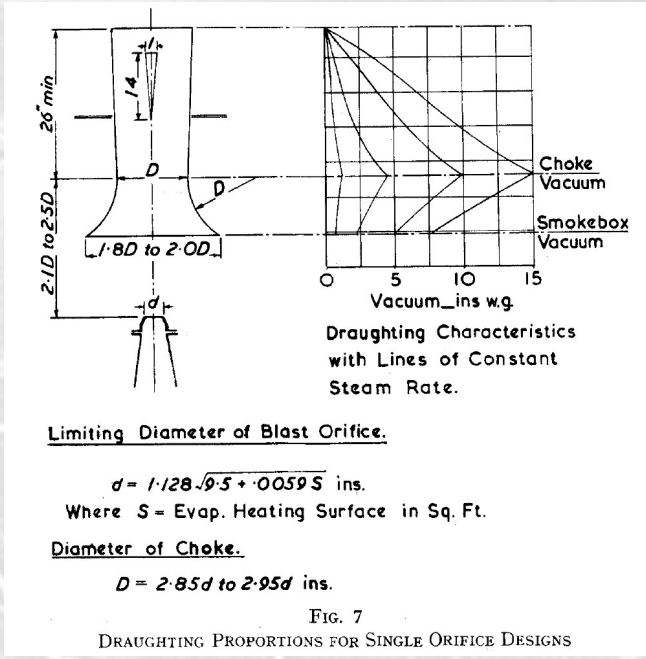
- Steady state
- Ideal gas – $pV = nRT$
- Sutherland Viscosity Law
- Compressible flow for Ma > 0.3.
- 10,000 iterations



Results

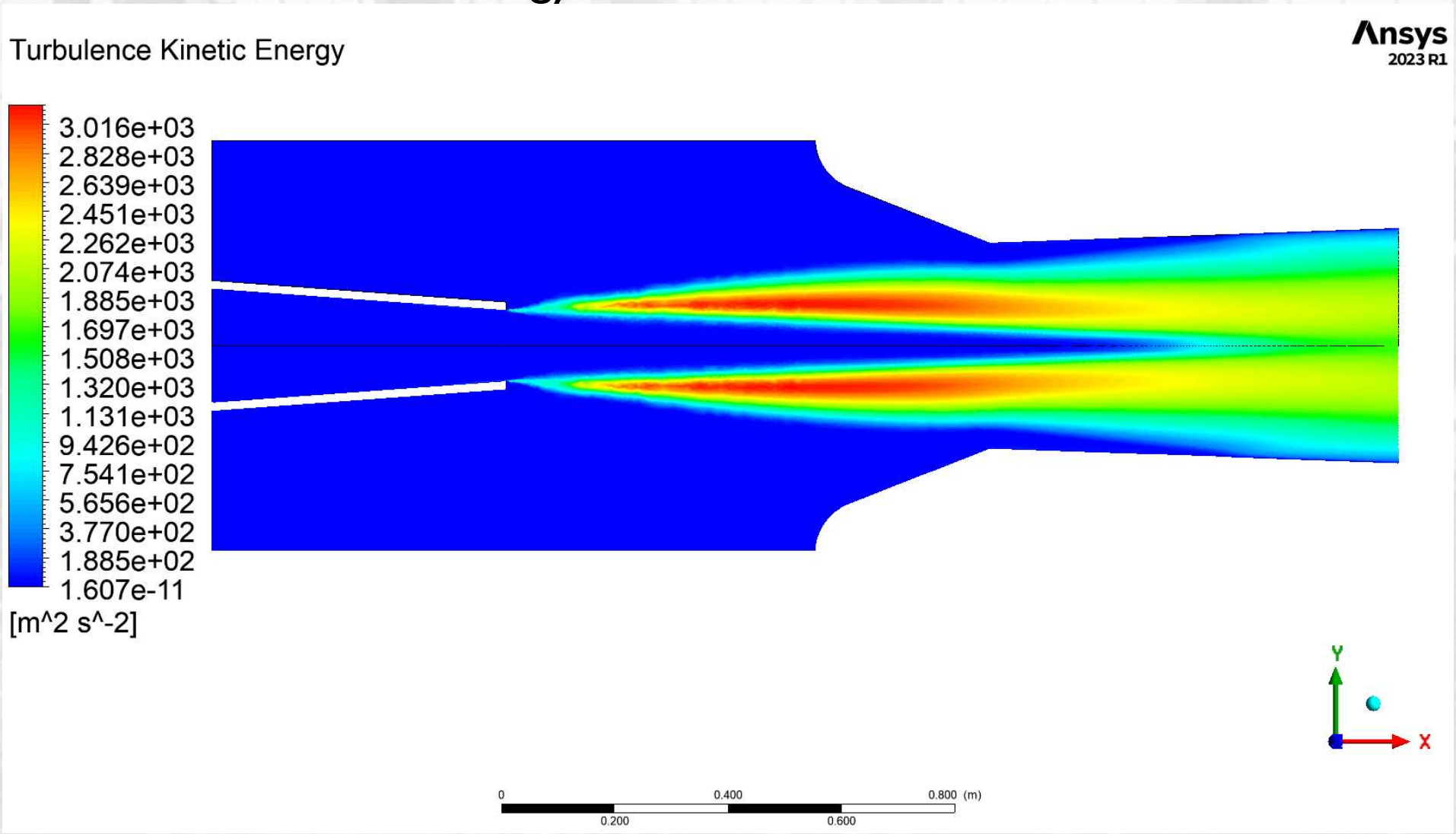
Results: Pressure at Different Points in the System



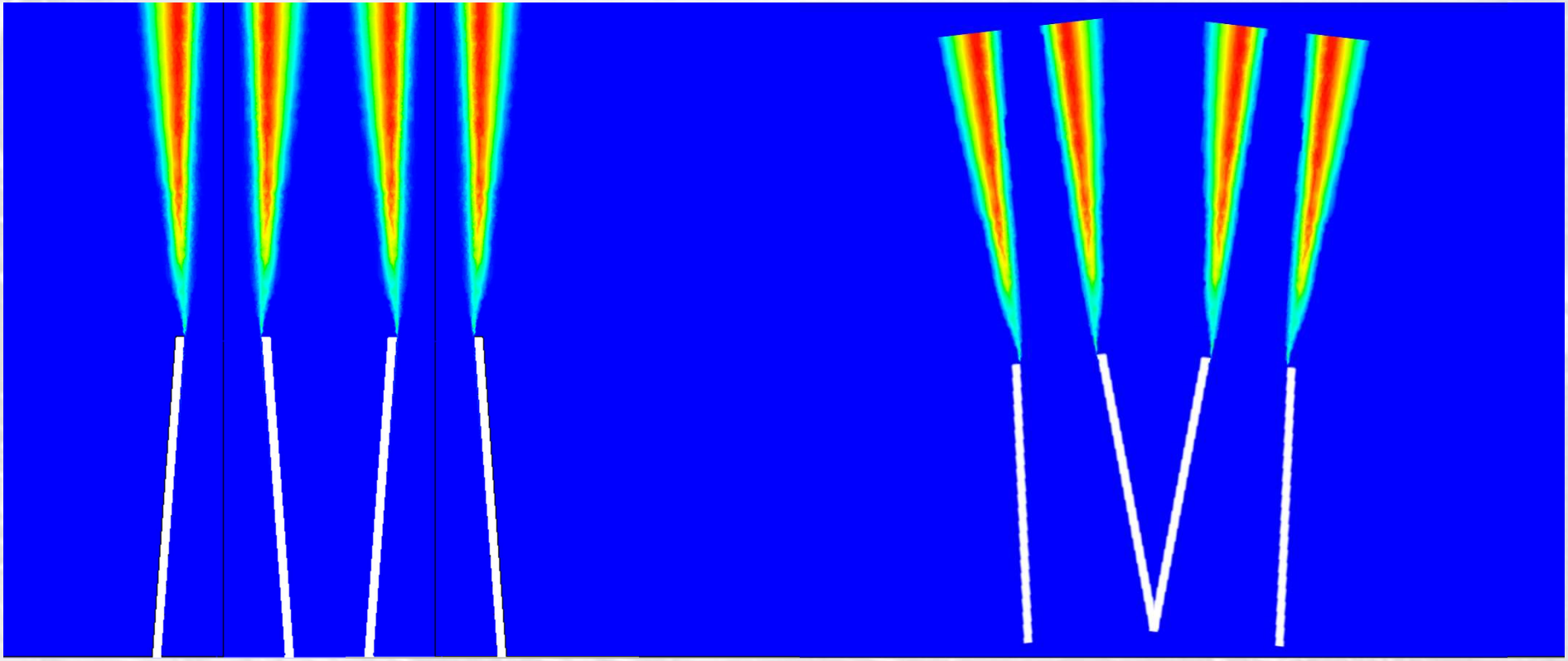


S.O. Ell - Developments in Locomotive Testing

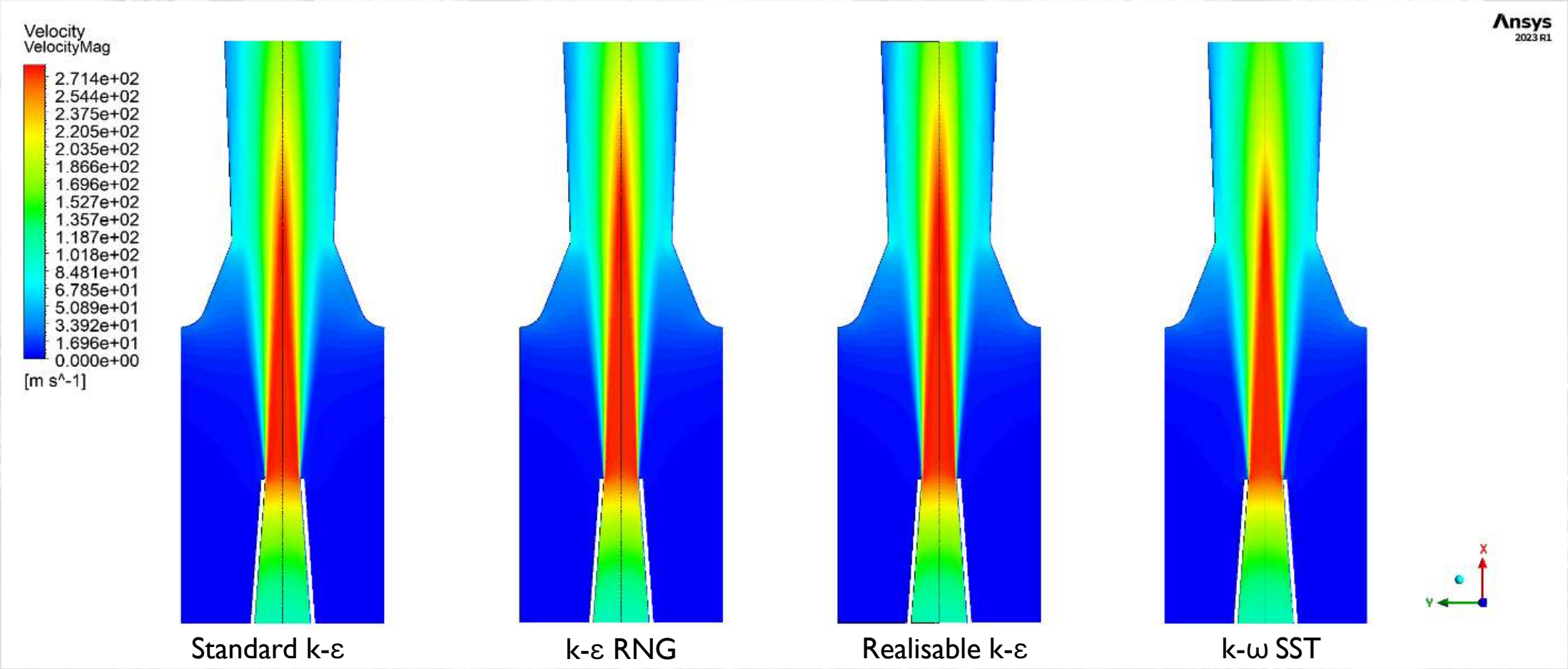
Results: Turbulence Kinetic Energy



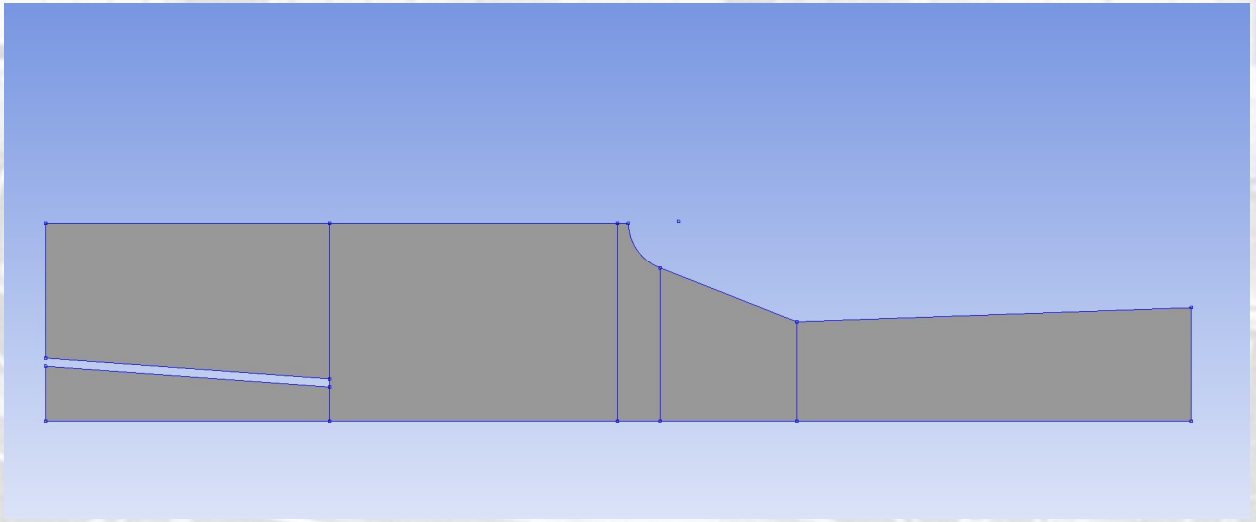
Results: Turbulence Kinetic Energy

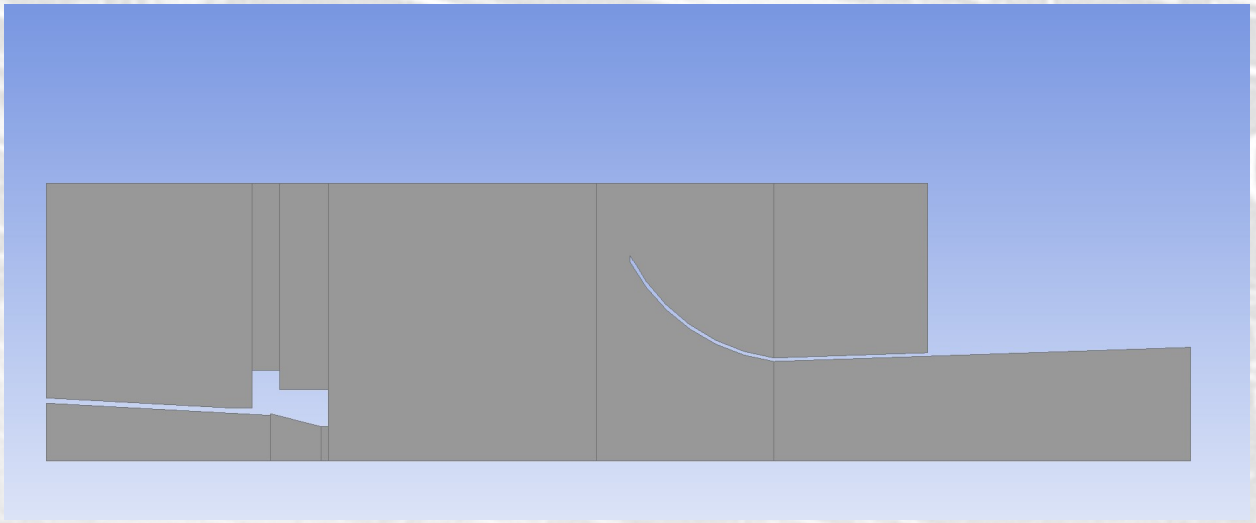


Results: Turbulence Models



The Project: Possible Improvements





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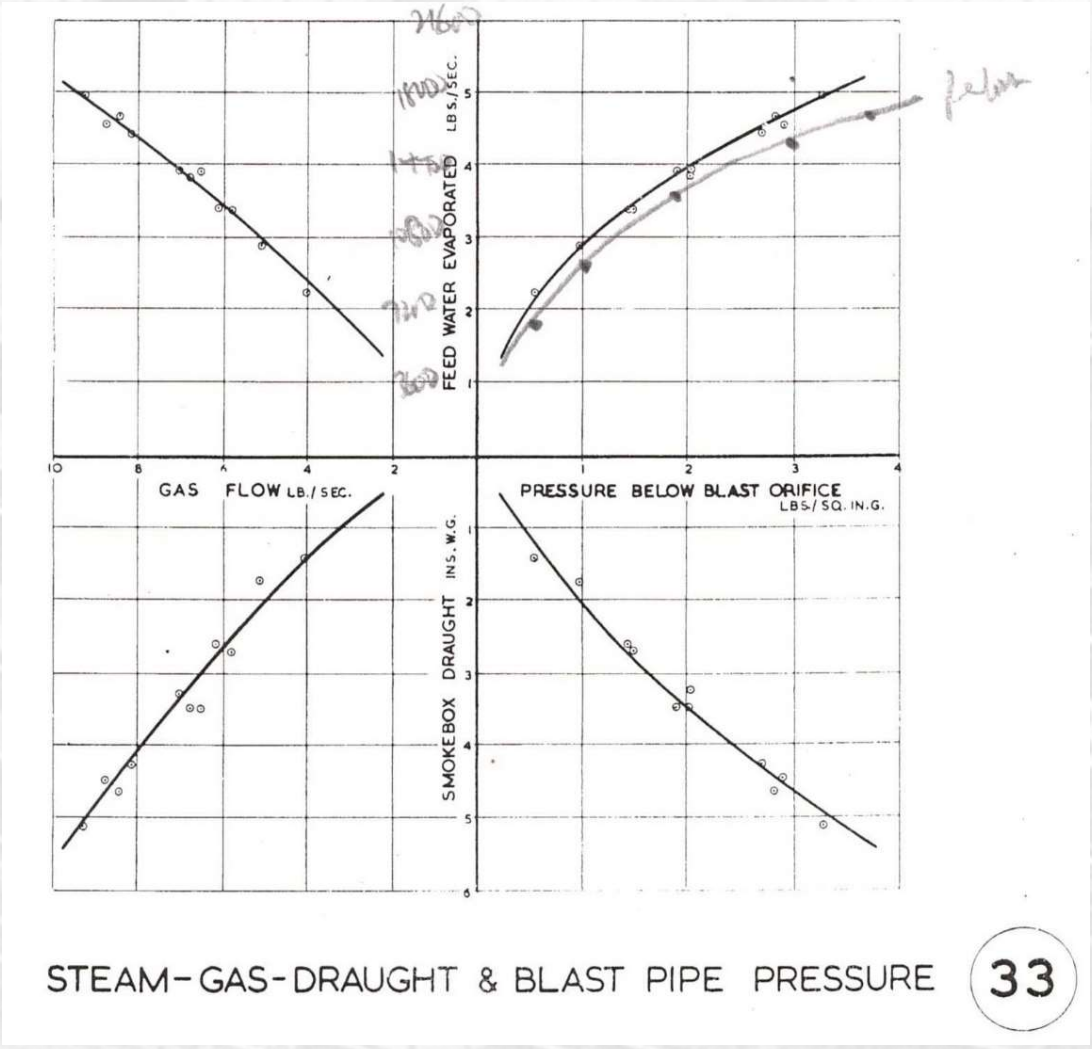

Conclusion

- CFD can be used to provide results for relatively low cost.
- Computational Fluid Dynamics is hard!
- Turbulent flows are chaotic in nature and turbulent models can be used to simulate their behaviour.
- Third year project - successfully modelled a locomotive exhaust using CFD!
- Future plans? - More research on exhaust systems!

Any questions?