Unit 301 The analysis of compressible fluid flow

Unit summary

This unit is about the analysis of compressible fluid flow. It includes one, two and three-dimensional flow for subsonic and supersonic situations.

Aim

To provide the candidate with advanced knowledge and understanding of the behaviour of compressible fluid motion.

Prerequisites

It is anticipated that candidates will have successfully completed units in Applied thermodynamics and The analysis of the mechanics of fluids at the Certificate and Graduate Diploma level or equivalent.

Learning outcomes

There are **four** outcomes to this unit. The candidate will be able to:

- Understand and apply the working relationships involved in one-dimensional flow
- Understand and apply the working relationships involved in two and three-dimensional flow
- Understand and apply the working relationships involved in unsteady one-dimensional flow
- Understand and apply the working relationships involved in real gas flow in the presence of heat transfer and viscosity

Guided learning hours

It is recommended that 300 hours should be allocated for this unit. 120 of those hours are actual taught hours. This may be on a full time or part time basis.

Key Skills

No Key Skills were identified for this unit.

Occupational Standards
This unit has been mapped to the following National Occupational Standards:

1.1.1 Identify the requirements of clients for engineering products or processes
1.1.2 Produce specifications for engineering products or processes
1.2.1 Identify and define areas of research
1.3.2 Evaluate the results of research
1.4.4 Evaluate designs for engineering products or processes
2.1.1 Determine the production requirements of engineering products and processes
2.2.2 Solve production problems with engineering solutions
2.3.2 Evaluate the production process
3.2.2 Solve installation problems with engineering solutions
4.1.1 Determine the operational requirements of engineering products or processes
4.1.2 Specify operational methods and procedures to achieve operational requirements
4.2.2 Solve operational problems with engineering solutions
6.1.1 Analyse the risks arising from engineering products and processes
6.2.1 Assure the quality of engineering products or processes
7.2.3 Evaluate projects
8.1.1 Maintain and develop own engineering expertise

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Outcome 1 Understand and apply the working relationships involved in one-dimensional flow

Knowledge requirements
The candidate knows how to:

1 recognise the general features and applications of isentropic flow for a perfect gas

2 analyse nozzle flows with and without choking for varying pressure ratios and low Mach number flows

3 recognise the general features of adiabatic flow of a perfect gas

4 identify deviations from the perfect gas laws and flows in real nozzles

5 recognise the features and governing relations of a normal shock, shock wave formation, thickness and movement

6 determine the features and governing relationships of a normal shock in ducts, converging-diverging nozzle characteristics, supersonic diffusers and supersonicpitot tubes

7 recognise adiabatic flow of a perfect gas in a constant area duct

8 analyse isothermal flow in long ducts and flow at various pressure ratios

9 apply friction coefficients to gas flow situations

10 recognise stagnation pressure and temperature and the change of stagnation temperature with heat transfer

11 solve problems involving recovery factor, coefficient of heat transfer and shock waves with changes of stagnation temperature

12 solve problems involving flow with

- a combined friction and area change
- b combined friction and heat transfer

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Outcome 2 Understand and apply the working relationships involved in two and three-dimensional flow

Knowledge requirements
The candidate knows how to:

1 use the equations of motion for irrotational flow

2 recognise the links between continuity, rotation, thermodynamic properties of a fluid and the laws of thermodynamics

3 recognise the interrelationship between velocity potential and stream function

4 solve problems involving two-dimensional subsonic flow with small perturbations including

- a linearisation of the pressure coefficient and the potential equation
- b flow inside two-dimensional passages and wind tunnel corrections
- c the effects of compressibility

5 solve problems involving three-dimensional subsonic flow with small perturbations including

- a flow past bodies of revolution, spheres and ellipsoids
- b flow past
  - i wings of finite span
  - ii swept-back wings
  - iii swept-back wings of finite span

6 solve problems involving two-dimensional supersonic flow with small perturbations including

- a linearisation of the equations of motion
- b flow past
  - i wave-shaped walls
  - ii supersonic aerofoils

7 solve problems involving the reflection and intersection of waves

8 apply the method of characteristics to

- a two-dimensional supersonic flow
- b the design of supersonic wind tunnel nozzles

9 analyse adiabatic, non-viscous flow with rotation

10 derive the oblique shock equations

11 analyse the geometry and special features of oblique shocks applied to
   a reflection and interaction of shocks
   b curved shocks
   c two-dimensional flow profiles
   d interaction of shocks with boundary layers
12 describe axially-symmetric supersonic flow and flow over wings of finite span
13 describe and develop the features of hypersonic flow using
   a the similarity laws
   b oblique-shock and simple-wave relations
14 determine the performance of two-dimensional profiles and bodies of revolution
15 describe and develop the features of transonic flow using the similarity laws
16 analyse transonic flow
   a in the throat of converging-diverging nozzles
   b over walls and wedges
17 describe the characteristics of transonic flow
   a over wings
   b in terms of drag on bodies of revolution
18 describe detached shocks and their interaction with boundary layers

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Outcome 3 Understand and apply the working relationships involved in unsteady one-dimensional flow

Knowledge requirements
The candidate knows how to:

1 extend linearised theory and the method of characteristics to simple waves of small amplitude in the presence of a pressure pulse

2 determine the effects of gradual changes in duct area and boundary conditions

3 analyse moving shocks, weak shocks and the shock tube

4 analyse the interaction between shocks and end conditions

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Outcome 4 Understand and apply the working relationships involved in real gas flow in the presence of heat transfer and viscosity

Knowledge requirements
The candidate knows how to:

1 analyse the laminar boundary layer using differential and integral equations

2 determine laminar flow conditions when using

- a gases with a Prandtl number of unity
- b gases with arbitrary Prandtl number values

3 explain comparisons between theoretical and experimental results for laminar boundary layer flows

4 determine the stability of a laminar boundary layer

5 analyse the turbulent boundary layer using differential and integral equations

6 determine the effects of turbulent boundary-layer flow over a flat plate in terms of

- a skin friction
- b recovery factor
- c heat transfer

for gases with a Prandtl number of unity

7 determine turbulent boundary layers on bodies of revolution

8 explain comparisons between theoretical and experimental results for turbulent boundary-layer flows

9 analyse real gas flow in ducts involving

- a shock-boundary layer interactions in supersonic and transonic flows
- b normal shocks
- c boundary layer separation produced by shocks

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Recommended reading list

Core texts	Author(s)	Publisher	ISBN
Fundamentals of Gas Dynamics	Zucker	John Wiley & Sons Inc.	0471059676
Gas Dynamics	Aksel	Prentice Hall	0134977289
Gas Dynamics, theory and applications	George	American Institute of Aeronautics & Astronautics	0930403126
Rarefied Gas Dynamics from basic concepts to actual calculations	Cercignani	Cambridge Uni Press	0521659922
Other useful texts			
The Dynamics and Thermodynamics of Compressable Fluid Flow Vol 1&2	A H Shapiro	Renold Press Company	