Imperial College London

Advanced Hydrodynamics

Module Code	PHYS97001	FHEQ Level	Level 7
Pre-requisites	Fluid Dynamics	Co-requisites	None
Primary Department	Physics		
Module Leader	Professor Jeremy Chittenden		
Additional Teaching Departments	None		
Teaching Staff	Professor Jeremy Chittenden + Course Associates		

Programmes on which the Module is delivered	Core/Elective
All UG Physics programmes (F300, F303, F309, F325, F390, F3W3)	Elective

Learning Outcomes	The course is designed to extend beyond the third year fluid dynamics course which deals with subsonic incompressible flows to cover supersonic compressible flows, shock physics and associated research topics including inertial confinement fusion and high energy density physics. Most material will be presented using detailed PowerPoint slides with additional material written on the blackboard. You don't need to buy a text book. All material required for exams should be in the lectures.
Description of Content	We use supersonic flight as a way to introduce the fundamental concepts of shocks, with hypersonics used to illustrate the importance of heat dissipation and the changes induced in material properties. The treatment of shocks in solids then illustrates how the equation of state influences the properties of the shock. Mathematical models of shocks are then introduced which include the Rankine-Hugoniot conditions, Hugoniot curves and the concept of isentropic compression. The behaviour of shocks in solids is contrasted with that of shocks in gases and plasmas, where heat dissipation and energy transport through X-ray emission and absorption can become the dominant process. Methods of compression in planar and convergent geometries are described along with applications to materials science, planetary science and fusion research. The theory of surface waves in fluids is then used to introduce the concept of fluid instabilities and to derive the growth rates for Rayleigh-Taylor and Kelvin-Helmholtz instabilities. We then examine how the interplay between these instabilities provides a mechanism for the generation of turbulence. A detailed description of spherical implosions used in inertial confinement fusion illustrates how fluid instabilities ultimately limit how fast a fluid can be compressed. The facilities designed to achieve the high pressures required for inertial confinement fusion are described and the theory of dimensionless scaling of compressible hydrodynamics is used to demonstrate how these facilities can be used for laboratory astrophysics studies of stellar evolution.

Assessment		Assessment Type	Weighting
Written Exam		Exam	100%

Learning & Teaching Hours	Independent Study Hours	Placement Hours	Total Hours
23.5	51.5	0	75
ECTS Credit	3	CATS Credit	6
Date of introduction	October 2016	Date of Last Revision	April 2020

Advanced Hydrodynamics – Course Outline

Introductory Lecture

1. Reminder of Fluid Dynamics

1.1 The Navier Stokes equation

1.2 Bernoulli's principle

1.3 Compressible flow

1.4 Streamlines & flow lines

2. Aerodynamics

2.1 Lift

2.2 Types of aircraft drag

2.3 Streamlining

2.4 Stall

3. Supersonic and Hypersonic Flight

3.1 Transonic flight & wave drag

3.2 Supersonic flight (Mach's construction, oblique shocks, aircraft design, Lavall nozzles)

3.3 Hypersonic flight & detached shocks

4. Shocks in Solids

4.1 Shocks formation from a steepening non-linear sound wave

4.2 Shocks due to impact (particle model)

4.3 The Rankine-Hugoniot, or shock 'jump' conditions

4.4 The Hugoniot curve, the adiabat & the Rayleigh line

4.5 Equation of States based on the Lennard-Jones and Mie-Gruniesen potentials

4.6 Shocks as a method of determining the Equation of State or other material properties

4.7 Isentropic compression

5. Shocks in Plasmas

5.1 Strong shocks conditions, Noh's problem, driven implosions (snowploughs & slugs)

5.2 Blast waves & Sedov-Taylor scaling

5.3 Radiation cooling, radiation transport and radiative precursors

6. Waves

6.1 Linear or Airy wave theory, shallow and deep water waves

6.2 Shoaling & breaking, Tsunamis

6.3 Generalised dispersion relation for surface waves

7. Instabilities

7.1 The Rayleigh-Taylor instability

7.2 The Kelvin-Helmholtz instability

7.3 Turbulence

8. Inertial Confinement Fusion

8.1 Ablation

8.2 Implosion

8.3 Ignition

8.4 Burn

8.5 Current limits on performance

9. Laboratory Astrophysics

9.1 Dynamic similitude (wind tunnels)

9.2 Dimensionless parameters and Buckingham π theory

9.3 Proto-stellar jets – propagation, acceleration & rotation

9.4 Magnetised shocks

9.5 Radiative accretion shocks