Fluid Dynamics for Astrophysics

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Lecture - 01
Introduction to the course

Hello, my name is Prasad Subramanian. I am a professor of physics at the Indian Institute of Science Education and Research in Pune. And, I do astrophysics with an emphasis on high energy astrophysical phenomena, on plasma astrophysics with applications to phenomena like the solar corona, accretion around black holes and things like this.

So, this is my broad area of research. In much of what I do, I need to consider the dynamics of a fluids in astrophysical situations or as it might seem normally we think of you know astrophysics is having to do with planets and galaxies and black holes and discrete objects like this.

But nonetheless in fact, fluids the kinds of fluids that we encounter in everyday life; air, water, gases and things like this, the dynamics of such fluids are of central importance in understanding astrophysical phenomena. The fluids might not be the same, the character of the fluids might not be the same, but they are fluids nonetheless.

So, I figured I would give this course on the dynamics of fluids. This course provides a broad overview of fluid phenomena in astrophysics. And, the first few weeks we will cover the basics of fluid dynamics the kinds of which you will find in pretty much any fluid dynamics course be taught by someone doing lab fluid dynamics or engineering or so on so forth.

The basics are common to everything, there will be a little bit of tailoring towards astrophysics, but not that much. So, we will essentially cover conservation laws and things like this. So, this is what we will be doing in the first few weeks and the emphasis the slight emphasis will be on compressible phenomena. This is because this is what you know the basic emphasis, this is what astrophysics mostly deals with compressible fluids.

So, our coverage of the basics will be biased by that. So, these basic concepts of course, will be will then be applied in this roughly the second half of the course. These basic concepts will be applied to understanding astrophysical phenomena ranging from the solar wind to black hole accretion disks.

And, then we will talk a little bit about magnetic fields because magnetic fields although the bulk of the course will not consider magnetic fields, will simply talk about unmagnetized fluids. But, magnetic fields; however, are ubiquitous in astrophysics, in all kinds of astrophysical situations. And so, what really is important in astrophysics is the study of magnetized fluids and this is a branch of fluids called magneto hydrodynamics.

So, we will spend a little bit of time understanding the basics of the basic framework of magneto hydrodynamics. And, then we will applied to understand astrophysical phenomena such as dynamos; this is one of the phenomena this is one of the ways magnetic fields are generated in astrophysical situations and jets from black hole systems and so on so forth.

So, broadly this course will be talking about the basics of fluid dynamics, applications to astrophysical phenomena, a little bit about magnetic fields and the basics of magneto hydrodynamics. And, then go back to applications which use magneto hydrodynamics to understand phenomena, astrophysical phenomena.

So, upon completing this course, students will be well equipped to understand a broad range of research literature in astrophysics; specifically having to do with astrophysical fluid dynamics ok.

Hello welcome again. So, this is the point where we plunge right into the course and so, this is the course on Fluid Dynamics for Astrophysics, I am Prasad Subramanian. This is my email address and I work at the Indian Institute of Science Education and Research in Pune.

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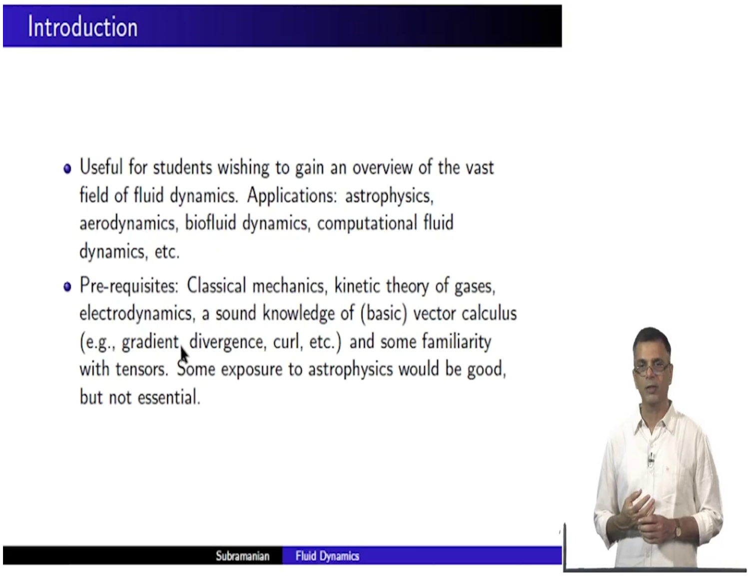

So, what this course is useful for, is useful for students who wish to gain an overview of the vast field of fluid dynamics. Fluid dynamics is really a vast subject studied by many many people, engineers, lab physicists to and all kinds of engineers for that matter. And, we here will be by some biologists and it is its really a very wide ranging field.

Here in this course we will be; we will be concentrating on applications to astrophysics. So, the prerequisites for this course are really a basic understanding of classical mechanics. You need to be very well versed with conservation laws such as you know momentum mass and energy conservation.

You a certain amount of familiarity with kinetic theory of gases would be good and especially for the latter half of the course, when we will be talking about magnetic fields you know knowing about electrodynamics, especially about electromagnetic waves that is essential. By way of mathematical preparation, I would expect the sound knowledge of basic vector calculus.

In other words, you should be comfortable with things like gradient divergence curl and things like this because, we will be using this extensively. Some familiarity with tensors is good ah, but not terribly essential; I will try to make this self contained you know tensor calculus is useful, but not totally crucial.

So, same with astrophysics, although we are talking about an applications of fluid dynamics to astrophysical phenomena; I really do not expect students of this course to be very familiar with astronomy; some exposure is good ah. But, if not that is alright, we will be trying to you know introduce these things in a self contained way.

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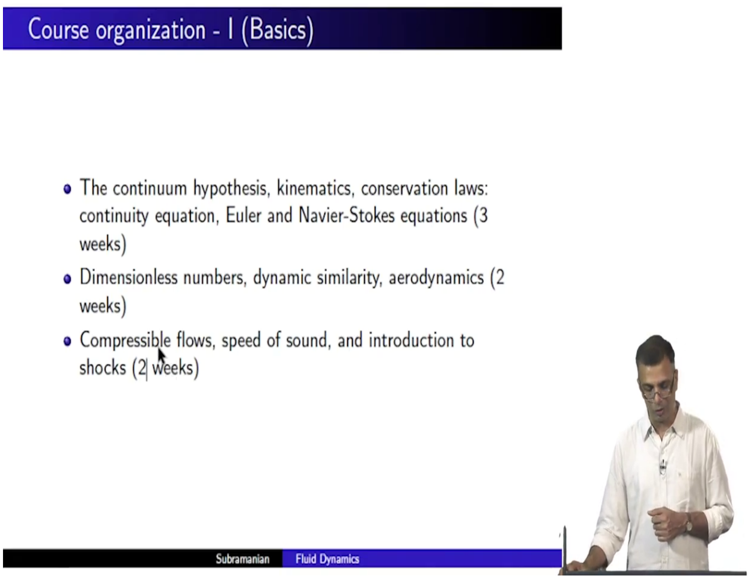

So, coming to the organization of the course, we will be proceeding in the following manner. The first half of the course, probably more than the first half will all be about basics, the basics of fluid dynamics. We will start with the continuum hypothesis by that I mean the manner in which the study of continua air, water so on so forth is different from the study of point particles yeah.

When you learn about Newton's laws F equals ma, it is generally applied to a point particle to a to you know say a stone idealized to be a point particle. Whereas, here we are not talking about point particles, we are talking about aggregates yeah; a gas for instance is an aggregate of several of several hundreds of thousands of molecules.

And so, how you apply these laws that we are these conservation laws that we are very familiar with to a continuum. So, this is what constitutes the continuum hypothesis. And, then we will talk about kinematics which roughly speaking is about how a fluid is responds to the forces that are acting upon it, without bothering too much about where the forces come from ok.

We will elaborate this in a minute when we come to it and all through we will be concerned about with the basic conservation laws that are central to pretty much all the physics. The continuity equation which is just another way of saying mass conservation, mass is neither created nor destroyed. And, then the momentum equation which in different guises is called the Euler equation or the Navier-Stokes equations right.

So, essentially we are talking mass conservation, momentum conservation; these are the two conservation laws we are talking about ah. So, we will spend roughly 3 weeks on this. And, after this we will go on to what are called dimensionless numbers and. This is one thing that is peculiar to fluid dynamics, plasma physics and things like this; you do not; you do not work with dimensional quantities such as energy, momentum and so on so forth.

You will you like to divide things with certain normalizing quantities. So, that you get dimensionless quantities and there were certain dimensionless numbers which are very very important and crucial to the study of fluids. And, we will talk about that for a bit and we will talk about what is called dynamic similarity which is to say for instance let me give you an example.

If you were to understand the dynamics of airflow over an airplane wing right. So, one way is to get a full size airplane wing, place it in a full size wind tunnel and study it study the dynamics. So, that is one way and that should be done at some point of course, you know, but you know even before that its useful to you know look at the dynamics in a scaled down version right, a miniature air airplane wing.

Turns out that there were certain things to be to keep in mind, it is not like you can keep the miniature airfoil in the same fluid as the larger as the full size airplane wing; in if you want to you know truly capture the dynamics. So, underlying this whole thing is a concept called dynamic similarity. So, we will talk about that a little bit, it is useful for astrophysics as well which is why we are talking about this. And so, we will spend about 2 weeks on dimensionless numbers and dynamic similarity.

We will then go on to talking about compressible flows because this is so important to astrophysics ah; flows that are essentially squishy yeah. And, and the concept of the speed of sound you are you are able to hear me because, you know pressure waves from my mouth are hitting the recording device and the recording devices converting them to electrical signals. And then recording it and then it finally, reaches you.

But, you know you know this phenomenon of the speed of sound is something that can be understood only after understanding you know the dynamics of a compressible medium because, you know sound is all about compressions and rare factions. So, we will devote some attention to compressible flows, partly because the speed of sound and some other characteristic speeds are central to understanding astrophysical phenomena.

And, this is where we make a little bit of a departure from the way fluid dynamics is studied for several other branches. For instance most engineering at least a lot of engineering applications do not concern themselves too much with compressibility, incompressible flows are just fine for them. And so, we will in studying this we will make some distinctions; we will.

Any given flow is neither fully compressible, nor fully incompressible, but nonetheless these you know these boundaries are useful. And so, when it comes to when we come to it we will understand these things. So, so suffices to say that we will devote sufficient attention to compressible flows and to the to how the speed of sound is derived.

And, we will make a brief introduction to the phenomena of shocks which are very central to astrophysics. We will spend about 2 weeks, maybe this a bit of an underestimate maybe we will spend about two and a half weeks on this thing.

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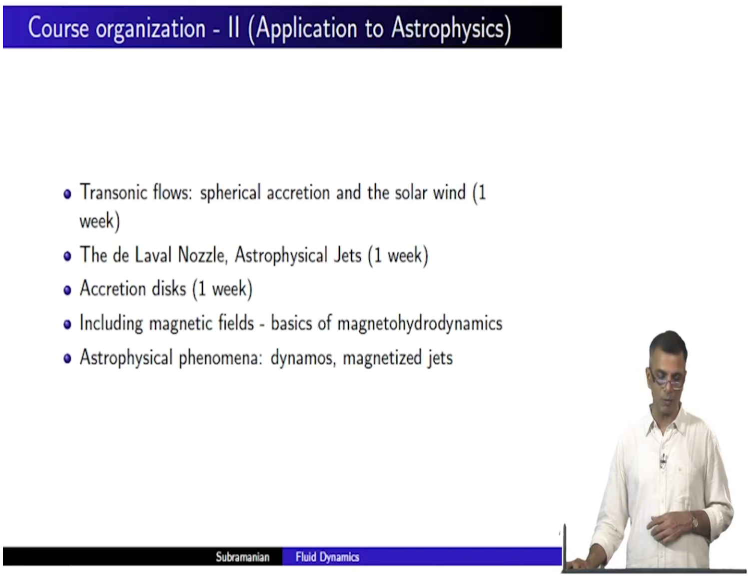

So, there is the next thing and the second half of the course we will concentrate mostly on applications to astrophysics. We will first of all start talking about transonic flows, by transonic I mean flows that sonic refers to the speed of sound.

So, by transonic we refer to flows that transition from being subsonic to supersonic. In other words, flows that transition from being below the sound speed to above the sound speed. And, there are some peculiar features that one has to be careful about and the reason we will pay attention to transonic flows is of course, because they are central to many many phenomena in astrophysics.

Specifically, these two kinds of phenomena, spherical accretion well these are two examples that we will study. Accretion refers to the manner in which an object attracts matter from around, it accretes matter. So, it turns out that you know an isolated massive object such as a black hole or other compact objects. They often attract matter from around it in a quasi spherical manner.

And, and in order to understand the manner in which matter or the gas around it is accreted onto the central object, one needs to understand how transonic flows work. And, another problem as we will see the math will work out that way which is pretty much is the mathematical formulation is almost exactly similar, except in this case the flow is not moving on to the central object, the flow is moving away.

And that is the solar wind ok, turn some of you might know that the sun is constantly blowing out part of its outer atmosphere which is the corona, it is constantly blowing out its corona out into space and so, this is called the solar wind. And, in order to understand the dynamics of the solar wind, you know the phenomena of transonic flows is a central importance.

So, after under after having understood the basics of transonic flows, we will consider these two applications and we will spend roughly a week on this. We will then with a view to studying astrophysical jets, we will introduce a concept called the de Laval nozzle. This you know the term de Laval nozzle originates in mechanical engineering as its as it turns out.

So, just to you know demonstrate the close correspondence between different branches of fluid mechanics, we will first introduce de Laval nozzle and this concept was applied to understanding astrophysical jets. So, this is what we will do for the next week. And, we will then spend about a week talking about accretion disks.

We already talked here about accretion, the manner in which matter from around a compact object is attracted towards the central object. Turns out that it is not always the case that matter is accreted in a quasi spherical manner, it turns out that in certain circumstances where there is a companion to the central object, there is a companion from which the central object is attracting matter.

There are certain circumstances in which the matter is accreted not in a spherical manner, but in the manner of a disk ok. We will talk about the details when we come to it. So, the accretion takes place in the form of a disk; so, hence the word accretion disks. So, we will spend about 1 week talking about accretion disks. Finally, we will as I indicated earlier magnetic fields are central to much of astrophysics; they in many many situations they control the dynamics fairly profoundly, for instance in the solar corona yeah.

So, far we have not touched magnetic fields at all, we have mostly been talking about neutral fluids. And, from now on we will try to we will do a very quick job of including magnetic fields; I it turns out that it needs to be included mostly in the in the momentum equation via what is called the Lorentz force; certain modifications that need to be made in the overall mathematical framework.

And, these modifications are part of the field called magneto hydrodynamics which as the name implies is hydrodynamics combined with magnetic fields. So, we will introduce the basics of magneto hydrodynamics as a prelude to applying it to astrophysical situations such as dynamos which is as you would have guessed from the name, the phenomena by which you know magnetic fields are generated in astrophysical bodies.

And, we will also consider magnetized jets; these astrophysical jets that I lured it to a little earlier; they are often magnetized, they often entrain magnetic fields and they are often confined by large scale magnetic fields. So, in order to understand this, you would have to understand magneto hydrodynamics first. So, these are the astrophysical applications of magneto hydrodynamics and.

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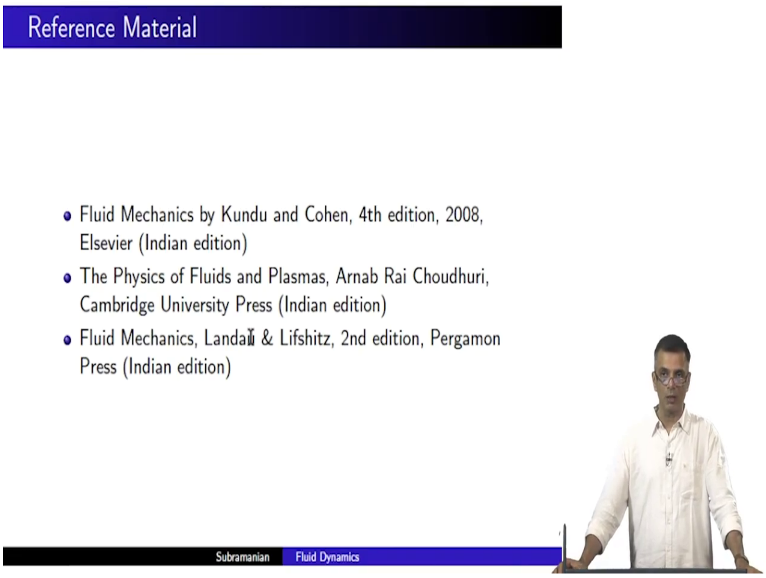

So, that pretty much brings us to the end of the overall outline of the course and the books, the reference material that I will be using for this course are Fluid Mechanics by Kundu and Cohen, I have simply said 4th edition here. But, there might well be a later edition, I want to emphasize that there is an Indian edition available at a reasonable price.

The other book I will be using fairly extensively is The Physics of Fluids and Plasmas by Arnab Rai Choudhuri, also an Indian edition is available, I highly recommend this book. It talks about fluid dynamics as well as magneto hydrodynamics and even a little bit about plasma physics with a specific aim towards connecting to astrophysics. And of course, there is a classic book on Fluid Dynamics by Landau and Lifshitz, one cannot go wrong with this kind of a book.

So, I will be in the course of what I am doing I will be borrowing some from Landau and Lifshitz also. So, before I end this, I just want to emphasize that you know what I will be talking about in this course is simply you must simply regard it as a guide to reading the material in these books; really I mean there is really no substitute for reading the book and for solving the problems in the book. What I will be telling you in this course is merely you know the is merely snippets from these books.

And so, just merely a guide to reading these books concentrate on this, concentrate on that. This is this is a good way of understanding what this book is what this particular chapter in the book is saying, things like this.

So, the real repository are these books and needless to say there is plenty of other materials, there is plenty of other good books. And, I will be putting up certain other reference material such as review papers and so on so forth and you will have access to that too.