FLUIDS
Examiner: Hultmark

Courses Covered

- MAE 551: Fluid Mechanics, taught by Prof. Smits
- MAE 553: Turbulence, taught by Prof. Smits

Note: I studies about 60/40 for Fluids/Turbulence, and my exam included both subjects approximately equally.

Preparation

- Textbooks: For fluids I used Lex’s various books/notes (I read all at least twice), with Anderson to supplement the sections on compressible flow. For turbulence, I would recommend reading Steve Pope’s book in addition to Lex’s notes. If you read both of those, I do not think it is necessary to read Bill George’s notes in addition.
  - A. Smits, *Class Notes for MAE 551*.
  - A. Smits, *Viscous Flows and Turbulence*. Chapters 6-13 cover turbulence; I did not look at the parts on viscous flows.
  - S. Pope, *Turbulent Flows*.
- Interview: I had my interview with Prof. Rowley about a month before my exam. I have done a separate write-up for the questions I received in that interview.
- Other: We had weekly group review sessions for fluids starting in October for general fluids topics.

Exam Content

- My exam was about evenly split between material from 551 and 553, but the exam bounced back and forth between the two subjects. I did not receive any questions on compressible flow, other than the first question.
- What do we mean by ‘compressible flow’?
  - I gave the definition that compressible flow is flow where the density following a fluid particle is not constant. I wrote the continuity equation in the form that includes the substantial derivative of density, and the flow is compressible if \( \frac{D\rho}{Dt} \) is not zero.
- Consider flow between two plates, each held at a different temperature. Is this a compressible flow?
I asked for several clarifications here and determined that Prof. Hultmark was referring to laminar, fully developed, pressure-driven flow and that the temperature difference was sufficient to cause significant density variations. In this case, even though there is a density gradient, the flow is incompressible because following a fluid particle the temperature/density is constant. (The temperature gradient is normal to the walls, fluid velocity is parallel to the walls).

- Write down the governing equations for the above situation, now assuming that the density is constant
  - I started with the Incompressible Navier-Stokes equations + Continuity and eliminated terms
- What if the flow is turbulent?
  - Instantaneous equations: unsteady and 3D terms required
  - RANS equations: like laminar equations but include unclosed Reynolds stress terms
- Consider again the flow shown above. If temperature variations are small such that temperature can be considered a passive scalar, what is the governing equation for temperature for laminar and turbulent flow? For turbulent flow, how can the turbulent diffusivity be modeled? For turbulent flow, does scalar transport depend on the properties of the fluid?
  - Laminar: \( \frac{d^2T}{dy^2} = 0 \) gives linear profile shown above
  - Turbulent: equations contain an unclosed scalar flux term \( <T'v'> \) which must be modeled, can be modeled using the gradient diffusion hypothesis. Turbulent transport is convective transport, so the turbulent diffusivity is largely unaffected by the fluid properties (diffusivity, thermal conductivity, etc).
- What is the Reynolds Number? Where does it come from?
  - Show by non-dimensionalizing the full N-S equations
- How does the friction in a pipe/channel scale? Draw a plot to show this? At low Reynolds number/laminar flows, what is the appropriate scaling for friction? What about at higher Reynolds number? Under what situation is \( \frac{1}{2} \rho u^2 \) the perfect scaling for friction?
  - I basically drew the Moody diagram. For laminar flows \( f = (\Delta p/L)D/(\frac{1}{2} \rho u^2) \) scales like \( 1/Re \). This indicates that a better scaling would be viscous rather than inertial scaling: \( \mu U/D \) instead of \( \frac{1}{2} \rho u^2 \) (for laminar flows the inertial terms don’t even show up in the governing equations, so scaling by \( \frac{1}{2} \rho u^2 \) doesn’t really make sense). For turbulent flow, the inertial terms do appear in the governing equations (via the Reynolds stresses) but the scaling is not perfect – for a perfect scaling \( f \) would be independent of \( Re \). When there is surface roughness, \( \frac{1}{2} \rho u^2 \) is the perfect scaling and \( f \) is independent of \( Re \). This is because the drag in this case is caused by form drag due to separation off of roughness elements, which scales like \( \frac{1}{2} \rho u^2 \).
For turbulent channel flow, discuss the velocity profile. What is the log-law? Where does it hold? Plot the velocity in the channel using both the inner and outer scalings, for 3 different Reynolds numbers (on both plots)?
  - Log law holds for $y^+ > 30$, $y/\delta < 0.1$.
  - In both scalings, the size of the log region increases with increasing Reynolds number
    - Inner scaling: near wall region remains constant as Re increases. Outer scaling: region near centerline remains constant as Re increases.

Is there also a log region for boundary layers? How does the velocity profile in a boundary layer differ from that in a channel? What is the constant stress region for a zero pressure gradient boundary layer?