AE2010 All the things I currently know about Thermodynamics

(at the end are questions)
###
What are fluid dynamics?

It encompasses a large range of topics which deal with the behavior of gasses and liquids.

###

Concept of continuum of gases for aircraft and balloons

-molecules move in air at T = above 0 kelvin
They bump into each other, move away, then bump again

The distance between the bum[s is called "free path."

The mean free path for air at sea level is 0.00001 mm. At 20 km, where a spy plane flies, it is 0.001m. At 50 km. where balloons go, it is 0.1 mm/

Airplanes are much larger than the mean free path, so you can model air as a continuum.

Lambda = mean free path
L = characteristic of the problem (i.,e, chord length)

lambda / L = Kn, knudsen number, which is the criterion for the concept of continuum

If Kn is less than 0.01, the continuum is valid

###

Pressure is the limit as the change in area goes to zero for the normal Force and the change in Area.
Pressure is a form of Energy!
Pressure in a fluid can be seen to be a measure of energy/ unit col
Static pressure + 1/2 rho*v^2 is the STAGNATION PRESSURE That second term is ENERGY

Stagnation pressure

-If you're not moving, stagnation pressure is 1atm. If you're moving it's whatever pressure you experience

###

DEFINITIONS
System - a restricted portion of space or a finite portion of matter upon which attention is focused
SURROUNDING - everything outside the systemw which has a direct bearing on its behavior
ENCOLSURE - a real or imaginary surface which separates the system from its surrounding
CLOSED SYSTEM - mass can't get in or out, energy can
OPEN SYSTEM - energy and mass can be exchanged with surroundings
ISOLATED SYSTEM - no energy or mass is exchanged

EQUILLIBRIUM
--Mechanical - there e is no unbalanced force in the interior of a system or between a system and its surroundings
--thermal -- exists when all parts of the system are a t the same temperature and this temperature is the same temp of the surroundings
--chemical - no tendency to undergo a spontaneous change in chemical composition, no matter how slow
--thermodynamic -- exists when the system is in mechnical, thermal, and chemical equilibrium

###

CLASSICAL THERMODYNAMICS EMPIRICAL LAWS
LAW! Bodies in thermical equilibrium onlin if they have the same "degree of hotness" (0th law)
LAW 2 - energy is conserved/ perpetual motion is impossible (1st law)
LAW 3 - Nothing can be reversed entirely (2nd Law)

Thermodynamic variables
-Extensive variables are additive. The value of a system is the sum of its constituent parts
-intensive variables are not additive
-they are locally specific at points in the system and may vary from point to point if not in equilibrium (pressure, rho, T)

###

INTENSIVE VARIABLES

For a pure substance (single phase), you need 2 intensive variables to determine any 3rd intenseive variable. These equations are "Equattions of State"

For a mixture of mols use mixture fractions

etc etc

##

Laws of THERMODYNAMICS

1st Law - Energy can neither be created nor destroyed

2nd Law - Tells us when processes are possible
-entropy must be conserved or increases
entropy cannot be decreased or destroyed
-tells us which way processes can proceed

Control Volume Analysis

We need to establish a boundary so that you can keep track of the fluid entering/exiting

Compressible Flow

-Density changs because of changes in velocity
occurs if $M > 0.3$ (this is an arbitrary limit for the purposes of modeling)

STATE POSTULATE

-How many intensive variables it takes to describe a system
-if you have ONE type of work that can be done, it is TWO variables
-It is the number of types of work tha can be done + 1
-So if you have mechanical, electrical, mechanic, it is 4
-The +1 must be an extensive property

THERMALLY PERFECT GASES

-A thermally perfect gas is
--there is so much space between the molecules and they don't interact with each other. The collide, but most of the time they don't interact). Therefore it's not a thermally perfect gas when the DENSITY is HIGH

COMPRESSIBILILITY

$Z = P / (\text{rho}*R*T)$

Perfect gas : $Z = 1$
IMperfect gas $Z<1$
Gases are not thermally perfect at higher pressures or densities

For a perfect gas it can also be shown that internal energy U = U because molecutres move from temperature only

Preoperties of a Gas

Let's say that u = u(T,v) (internal energy)

Du = du/dT*dT + du/dv*dV

but for a TPG, du = du/dT*dT (v doesn't change, so it's only a function of T)

- For a *Thermally Perfect Gas*, u is a function of temperature
- Heat is not a state variable, must consider paths:
    - Heat change at constant pressure, c_P
    - Heat change at constant volume, c_V
- For a *Calorically Perfect Gas*, c_P & c_V are constant
- Two governing equations:

$$\Delta u = c_V(\Delta T)$$
$$\Delta h = c_P(\Delta T)$$

- Both are functions of temperature

SPECIFIC HEAT

The specific heat is the amt of heat required to raise T 1 degree
State variables P,T, rho, u

NOT state variables:
heat, work --- path must be SPECIFIED

For gasses, we use cv and cp for constant vol and constant pressure.

What happens if it's not constant vol or pressure? We'll see.

This is not valid for a phase change, or with work. If you add heat to raise temp, you also have to add heat/work to change the phase.

If you do work, you are not finding specific heatRELATIONSHIP between Cv and Cp

In general, du = cvdT + du/dv*dv

For perfect gas --- du = cvdT

If cv and cp are constant, gas is "calorically perfect"

If thermally and calorically perfect, gas i "ideal"

Thermally perfect gas = pV = nRT
calorically perfect = cv and cp constnat

ideal is both

ENTHALYPY

The expression u +P*V occurs frequently so, we c call it "h", enthalplpy

h = u + PV

Since for a perfect has, PV = RT

h = h(T)

PROPERTIES OF A GAS

In general, h = h(T,P)

for a perfect gas: dh = cpdT
cp - cv = R

Ratio of Specific Heats

THIS IS GAMMA

gamma = cp / cv

For a perfect gas: cv = R / gamma - 1

cp = gamma / gamma - 1 * R

v
###

1ST LAW OPEN SYSTEM

Reynold's Transport Theorum
-if what goes in is not the same as what goes out, then we have a delta-B

Extensive quantite: dB/d = d/dt*int(rho*beta*dV + int(rho*beta*vrel*n*dA (intensives)

Here: $B = E = V +1/2 m*v^2$ internal + kinetic motio

##

2nd LAW OF THERMODYNAMICS

-1st law - energy is conserved
-But is that enough?

-object drops - converts KE into heat
but we never see the opposite
-H_2 and O_2 react to form H_2O when ignited at room temp but not the reverse
-1st law would permit the reverse but 2nd Law does not.

IRREVERSIBILITY

-A flywheel is spinning in a fluid in an isolated box
-eventually the flywheel (and gas) slow down and stop - the fluid is now hotter
-KE of the flyqwhell has been converted to internal energy of the fluid.
Some energy is useful, some not so much.

KE can be used to generate power
-Organiezd motion goes to random motion
-Reverse does not happen by itself

##

ENTROPY

Mech. energy (organixed) generally more useful than heat(random). i.,e, it's more valid form of energy

-Entropy (s) is a measure of the disorder / randomness of a system
-systems naturally tend towards disorder

PREOPERTIES OF THE WNTROPY

-Entropy goes up with an increase in disorder, and useful energy is reduced
-Entropy can only be created but not destroyed (2nd law)

-Production: Ps = delta-s
The production of entropy is the change in entropy

In an isolated system, Ps = delta-s, which is greater than zero.

No heat. mas, work transfer

if delta-s is greater than zero, the process is irreverasbile

ISOLATED SYSTEM

Ps <0 --> impossible
Ps = 0 --> reversible process, energy flow between thermal, mechanical, etc, reversible
Ps > 0 irreversible - to reverse need S to decrease, not possible in an isolated system

NON-ISOLATED SYSTEM

-No insulation)

Two types of reversible flow possible
-internally reversible -- system alwayss processds through equilibrium states with no entrpoy production
-totall reversible - no entropy production in both system and surroundings
(reversible)

ENTROPY TRANSFER
-rigid walled cylinder containing H2O
at t = 0, mistly ice, at t2, mostly liquid
-liquid more RANDOM , therefore s2 > s1

molecules in liquid more around vs. oce, which is a crystal

-where does the netropy come from?
If you refreeze the ice, you go from higher entropy to lower entropy
-You freeze water by taking heat out
-heat transfer out == entropy transfer out

ENTROPY TRANSFER CTD
-Heat transfer --> entropy transfer
-As T increasese in colder system, its randomness increases and vice versea

-work represents "organized" energy
-work does not "transfer" entropy unless it is done ireeversibly

ENERGY EQUATION
1ST LAW OF THERMODYNAMICS

-Energy cannot be created or destroyed
-It can, however, chane from one type to another or transfer from one system to another
-Energy concservation is a postulate
---experience based -- no proof or disproof

CLOSED SYSTEM

-No mass transfer
-However, energy transfer is possible: Heat (Q) (random motion)
-Work (W) (organized motion)

1st LAW FOR A CLOSED SYSTEM

dE(controlled mass) = dQ - dW

if you add heat, it's positive
if you take away heat, it's negative
-if work is being done by the system, it's positive

OTHER FORMS OF 1ST LAW

-In rate form:

dE/dt = Q-dot - W-dot   (that is the d/dtof Q and the d/dt of W

first law for a constant vol......
PdV = 0, no work done
therefore U = Q and dU/dt = Q-dot = mcvdT/dt

SOME MORE ENTROPY
-there's such a thing as measure of not-so-useful energy --- s is a measure of energy that's not in its most useful state
-liquid has mrore entropy than solid

###

STAGNATION CONDITIONS

-conditions that exist when a flow is slowed down reversibly and without loss or gain of energy

If the flow of a system is isentrpoic Po is constant --> staticp resssure changes
Po is always larger than static P. BERNOULLI ---- Po = P + 1/2*rho*v^2

Po is the sum of the energies of pressure

P/Po depends on how fast you are going.

Through the duct, you are changing kinetic energy into potential enerrgy
P changes quicker than T so P/Po > T/To

If it's NOT isentropic, Po can chamge (i.e., iwth friction) but To doesn't really change that much

To can change if you add energy to the system.

MORE STAGNATION CONDITIONS

To is how much TOTAL energy there is
Po is how much USEFUL energy there is
##

ENEOUGH OF THERMODYNAMICS -- NOW ONTO COMPRESSIBLE FLOW

##

SPEED OF SOUND

Duct --- piston in duct, no heat transfer, no shaft work, no friction -- therefore isentropic.
-incompressible flow
- a chunk of wood
-compressible flow -- finite time for message to travel

-Layer of air on piston face vp, p+ delta p, rho + delta-rho

Piston stopped, pulse of air continues

##

MACH WAVES

Point source of sound along a line normal to the screen...
-flow v > c (

VELOCITY-AREA RELATIONSHIP
-flow model --reversible, adiabatic, no work, steady, 1-D flow

-Governing equations
-energy eq --- $ho = h + V^2/2$
Euler equation $cdc + 1/\rho * dp = 0$

Continuity -- m-dot is constant

second law

-thermal equation of state.... $pv^\gamma = 0$

VELOCITY-AREA RELATIONSHIP:

$dv/v = -1/(1-M^2) * dA/A$

-physical significant for $M < 1$, if A goes up, then v goes down.

For $M > 1$, if A increases, then Vel increases

no throat, no supersnc flow

If you want to go back, you need another throat
ALSO
The speed of sound changes as you go down a duct with changing area!!

###

CONVERGING NOZZLE FLOW

Nozzle gets choked when $Pe/Po = 0.528$, $Me = 1$. Lowering Pb no longer changes conditions in nozzle. Pb is no longer equal to Pe. If you want a higher mass flow rate, you need a higher Po instead of a lower Pb.

###

ENTROPY CHANGE ACROSS SHOCK

ForYuou cannot have a lower pressure after a shock. A shock is a compression wave. Weak shocks are almost isentropic.
Shocks make the front pressure and the back pressure compatible.

The flow after a shock is ALWAYS subsonic (normal shock)

###

Moving Normal shocks
When the shock is moving, you should convert the moving shock to a stationary shock.
-Galilean transform
-switch directions
-Now the shock problem looks like a problem we've already solved :D :D
Static properties are unaffected by transofrming the reference frame
-Stagnation properties
-depend on velocity so they are not the same after trnsform
-find using static properties and Mi, MgREFLECTED NORMAL SHOCKS

What happens when a shock hits a boundary?
-closed wall
-open end of a pipe
-change in coundary conditions must be transmitted back to flow
-reflected waves
-compressions or expansions

-while (incident) shock is heading towards a wall, there is a flow behind it
-but if there is a closed coundary,, so no flow can go through a wall

-Must generate a reflected wave that stops oncoming flow
-flow is slowed down
P, rho increase
-compression __> reflected shock

-InIn lab reference frame, v= 0 behind a reflected wave.

In shock reference frame, Vrs = V2 . Use this and known Vg and shock relationships to find Vrs.
"Reflected is a bad name for it --> Vrs is a newly formed shock such that Vg __> V =0

##

OPEN TUBE

-Now the boundary condition is a constant pressure at open end
---same as initial pressure P1

Put P1 is less than P2 behind the shock

---> refelection is an expansion wave. No shock! But we don't really cover that

##

NORMAL SHOCKS IN CD NOZZLES

If you have a reservoir and a CD Nozzle coming out of it, as back pressure is reduced, the nozzle becomes choked. The flow starts to go supersonic after the throat and then shocks happen
--you end up having a standing shock in the nozzle. Over what range of back pressures will there be a shock in the nozzle?
---until the shock occus at the exit plane of the nozzle.

So, the quwestion becomes -- what is the exit pressrure when a normal shock sits at the ext?

--The answ is found by combining isentropic and shock solutions.

###

OVER AND UNDEREXPANDED NOZLES
-What happens if back pressure goes below value when the shock is at the exit?

STARTING PROBLEMS

-Why do we care about what the shock would be?

-for supersonic wind tunnels, closed circuit tunnel requires less power to operate than open tunnels
--do not have to accelerate flow as much

SWALLOWING SHOCK

So to have a shock "disappear", it must pass thorugh a 2nd throat.
-At2 = A2* at M2 after shock at Mtest
-Increase Po/Pb slightly about previous

-For lowest Po loss, shock has to be at smalest area
-loesr power requirements
-operates with weakest shock possible

-Variable diffuser throat area
-Lowesrt Po loss is for no shock. If shock stands exactly at the throat, there is danger of shock standing at the test area)

Can you make a wind tunnel work with no shock at all?
Yes -- if you have a variable diffuser throat area, but that is very expensive!

OBLIQUE SHOCKS

Supersonic flow turning

-For normal shocks, flow is perpendicular for shock
-no change in flow direction
-How does supersonic flow change direction, i make a turn
-ingine slows to subsonic ahead of turn
(can make a gradual turn --> bow shock)

You can get two shocks from oblique shocks...D: if it's open airfoil, you get a weaker shock most of the time. But if it's in a ipie or wind tunnel, you get a strong or weak shock. It depends on pressure probably

Depends on upstream versus downstream pressure. e.g., back pressure

WARNING
You can't have too many oblique shocks, because....you'd need a really big engine inlet, and that means the engine is heavier
-if you have a pressure increase, flow can separate and you get like...a vortex

##

EXPANSION
Supersonic flow turning
-previously, we examined supersonic flow over concave corners, but what if the turn is convex?
Expansion "shock" is impossible because that would destroy entropy
Turns out you get these things that are expansion turns and it's like a fan of different mach waves, kinda
Mach goes up after turning a corner. It's isentropic. and uniform

What does it mean for a flow to be chocked ?

What is a thermally perfect a calorically perfect gas ?

A thermally perfect gas has its molecules far enough apart that the extra energy from them bumping into each other doesn't really matter so much

For a choked flow with fixed geometry, how will decreasing the back-pressure affect the flow rate ?

What is the 'quality' in Thermodynamics ?

Consider a frictionless flow in a straight pipe with heat addition. If the flow is choked, where in the pipe is the (a) stagnation pressure a maximum, (b) static enthalpy a minimum ??

What is the dimension of the friction coefficient ?

In an irreversible flow the entropy can only go up ? Yes or no and why ?