Astronomy 230

Section 1– MWF 1400-1450

106 B6 Eng Hall

This Class (Lecture 26):

Travel

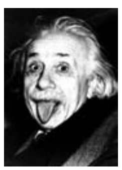
Research Papers are due on May 5th.

Next Class:

Travel

Outline

- Interstellar travel.
- What do we have now.
- What is a rocket and how do they work?
- Humans have never made a single rocket that can make it to space!
- What are the common fuels?
- Alternative Fuels
  - Nuclear Fission
  - Nuclear Fusion



Special Relativity Summary

All motion is relative, except for that of light. Light travels at the same speed in all frames of reference.

Objects moving close to the speed of light appear to shrink in the direction of travel.

Time appears to advance more slowly for objects moving close to the speed of light.

Mass of the moving object appears to rapidly increase as an objects moves close to the speed of light.

The future:

- May bring us closer to the speed of light
  - Right now we can travel through space at about c/25,000
  - Maybe fusion-powered crafts could in the near future reach 0.01c

Interstellar Travel

- The distances are huge!
- Nearest star is 4.3 ly away or around 4 x 10^{13} km!
- 40,000,000,000,000 km! 40 TRILLION km!!!
- But, what if all communication with ET fails?
  - Wrong frequencies.
  - Everyone is listening and no one is broadcasting.
  - We fail to recognize the signal.
- We can go visit them or the microbes. "To boldly go…"
- Human colonization of the Galaxy.

Energy into Propulsion

- For any type of space travel, we need an energy source to propel the vehicle.
- The basic idea is to convert some stored energy into *energy of motion* for the spacecraft
- Two ways basically:
  1. Process some sort of fuel
     - Carried onboard
     - Collected from space and processed
  2. Other, non-fuel-like energy source:
     - Solar (if near a star)
     - Gravity (using an astronomical body's gravity field to propel a ship)

Rocket Science

The Rocket Principle

- Conservation of momentum (mass x velocity):
  - Sit in a chair with wheels and throw a heavy ball.
  - You and the chair will recoil in the opposite direction
  - This is the famous "action-reaction" mechanism. Newton's 3rd law.
  - Your "rocket" chair would work by throwing a heavy ball
    - Achieving a high momentum with a large mass
  - Or, you could throw a light baseball, but very fast!
    - Achieving a high momentum with a large velocity
    - This is why a gun recoils when its fired.

Momentum and Rockets

- Rockets are propelled by the same principle (on Earth or in space):
  - Rocket fuel releases tremendous energy.
  - The by-product is directed out the back of the rocket.
  - The rocket is pushed forward just like the “rocket” chair.
  - The high momentum is created by high velocity and a large mass of fuel ejected.

http://bagocrap.1accesshost.com/drawings/rocketwheelchair.gif

Rocket Man: 4 Quantities

1. V_e : the exhaust velocity, usually in km/s.
2. Thrust : force exerted by the exhaust (Newtons or pounds).

$$Thrust = \frac{mass}{\sec} \times V_e = Force = mass \times acceleration$$

3. Mass Ratio :

$$R_M = \frac{M_{total}}{M_{payload}} = \frac{M_{fuel} + M_{payload}}{M_{payload}}$$

– This should be low. Depends on how fast you want to go & how efficient the fuel. But, the faster you want to go, the higher the R_m. Consequently, we need a fuel that produces more thrust per unit mass of fuel.

Rocket Man: 4 Quantities

4. Specific Impulse:

$$s.i. = \frac{thrust}{Fuel\ Rate} = \frac{\frac{mass}{s} \times V_e}{\frac{mass}{s}}$$

In metric

$$= \frac{Newtons}{\left(\frac{kg}{s}\right)}$$

In British Engineering System

$$= \frac{Pounds}{\left(\frac{Pounds}{s}\right)} = seconds$$

The units have traditionally been in seconds. But it is a little confusing, and has nothing to do with time.

It is a property of the fuel and engine design. Sort of like octane rating in gasoline– a large s.i. is a good thing.

How’s it work?

- For rocket to take-off, its thrust must be greater than its weight (force up > force down).
- In addition, the rocket needs to escape the Earth’s pull.
- That means that the rocket velocity must exceed the Earth’s escape velocity (11.2 km/s or 7 miles/s).
- Humans have never built a rocket that can do this!!!

http://www.eos.ucar.edu/mopitt/instr/rocket.jpg

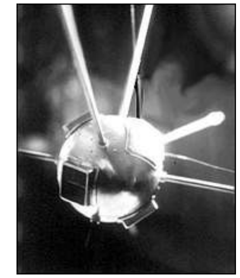
What you talking 'bout Willis?

- Humans have never built a rocket that can escape the pull of Earth?
- No, that's why we have to use multistage rockets.
- Once the fuel from the first stage is spent, it's dropped.
- Then, the next stage is higher up, so the escape speed is less than from ground level.
- To escape the Earth's gravity many stages are necessary.

http://www.utahredrocks.com/stardust/launch6.jpg

Not Good

- Multistage rockets are wasteful.
- The Mass Ratio can be huge!
- The first US satellite was the Vanguard launched on March 17, 1958.
- 6.4 inch diameter with 2 radio transmitters.
- Weighed 6.3 lbs = 13.9 kg.
- Rocket mass was 36,000 kg.
- $R_M = \frac{36000+13.9}{13.9} = 2590$
- Major ventures in space impossible with R_M this large.



http://www.bafsat.com/h3.html

Kiss and Make Better

- Can lower the mass ratio by increasing either the exhaust velocity or the specific impulse.
- Shuttle is state-of-the-art.
- Payload = 29.5 x 10^3 kg
- $M_{takeoff}$ = 2 x 10^6 kg
- $R_M = \frac{2\times10^6 + 2.95\times10^4}{2.95\times10^4} = 67.8$
- Shuttle thrust is 29 x 10^6 N with 80% from solid rocket boosters– they fall off at 40km.
- s.i. = 455 seconds
- Good, but not good enough for leaving Earth's orbit (orbits ~185 km)

Combustion Rocket Terminology

- A *fuel* is combusted, which means it 'burns', which means it reacts with oxygen.
- In space, there is no oxygen around, so the rocket must carry its own source of oxygen. Also known as an *oxidizer*.
- This forms a new waste compound called a *propellant* that is ejected out the back, thrusting the rocket forward by conservation of momentum.

Propellant-based

- Eject something backwards, you go forwards. Newton's da man!
  - Chemical : Burn fuel, exhaust is propellant
  - Nuclear : Reactor heats propellant
  - Electric/Ion : Ionize fuel atoms, push them out with electric fields
  - Anti-matter : Use energy from matter-antimatter annihilation to generate light thrust.

Fuels

- Look at the "octane" of various fuels available today.
- $H_2 + O_2 \rightarrow$ s.i. = 456 sec
- O_2 + hydrazine (N_2H_4) $\rightarrow$ s.i. = 368 sec
- H_2 + fluorine (F) $\rightarrow$ s.i. = 475 sec
  - But exhaust gas is hydrofluoric acid
- Note: No chemical fuel can achieve s.i. > 500 sec.

Rocket Combustion Fuels

- Petroleum : Refined kerosene with LOX (liquid oxygen) oxidizer. *(Saturn V first stage)*
- Cryogenic : Ultra cold hydrogen fuel with LOX oxidizer. Propellant is…water! *(Space Shuttle Main Engines)*
- Hypergolic: A fuel and oxidizer which combust with no need for ignition. Fuel can be "monomethyl hydrazine" (MMH) and the oxidizer is "nitrogen tetroxide" (N_2O_4). *(Space Shuttle Orbital Maneuvering Subsystem)*
- Solid: Oldest form (like in model rockets), exists in solid form, hard to stop burning, with oxidizer mixed together with fuel. *(Space Shuttle Boosters– SRBs)*

http://www-pao.ksc.nasa.gov/kscpao/nasafact/count2.htm

Petroleum rocket fuel in action

The mighty Saturn V 1st stage (launched Apollo 11) used petroleum fuel.

http://vesuvius.jsc.nasa.gov/er/seh/movies.html#Saturn

http://www.hq.nasa.gov/office/pao/History/alsj/a16/ap16-KSC-72PC-184.jpg

Cryo fuel in action

The Shuttle's main engines!

http://www.slivka.com/Trips/ShuttleLaunch/pics/LOX_tank_750,000_gallons_at_launch_complex_39A_T.jpg

http://engineering.newport.ac.uk/StaffPer/StaffEngPer/DevansPer/Space-Shuttle.JPG

http://www.physicscurriculum.com/Photos/Space3.JPG

Hypergolic

Space shuttle orbital maneuvering system uses hypergolic fuel

Solid fuels:

Space shuttle launch uses solid fuel (like model rocket).

1.3 Mlbs at launch. The fuel for each solid rocket motor weighs approximately 1.1 Mlbs. The inert weight of each SRB is approximately 192,000 pounds.

- Ammonium perchlorate (oxider)
- Aluminum (fuel)
- Iron Oxide (catalyst)
- Polymer (binder)

Fuel Efficiency

- To really think about interstellar travel or even going to Mars, we need the most <u>bounce for the ounce:</u>
  - Need to carry (probably MUCH) fuel
  - Must be very thrifty about efficiency
  - In other words, if we are going to carry fuel mass on a ship, we had better get as much energy from it as possible!

$E=mc^2$

- Another consequence of special relativity is that mass has energy wrapped up in it
  - In fact, physicists often use units of energy to quantify mass
  - A useful unit of energy in particle physics is the "***electron volt***" or "eV"
    - This is a unit of energy
    - It is used to measure mass as well since mass is really just wrapped-up energy
- A proton "weighs" about 1billion electron volts: 1GeV
- An electron "weighs" only about 511,000 electron volts: 511keV
- Most of the mass of an atom is in its nucleus, clearly!

Fuel Efficiency

- Burning chemical fuel (like burning wood or rocket fuel) one only gets a few eV of energy from each atom or molecule
  - In other words, only about 1 billionth of the total mass of the chemical agents gets converted into energy!
- Nuclear fission gives off a few hundred MeV for each nucleus which fissions:
  - So, about one thousandth of the total mass gets converted into energy!
  - Better than chemical by a factor of a million!
- Nuclear fusion reaction can produce about 10MeV from a light nucleus
  - So, the efficiency is about one hundredth!
  - Getting better!

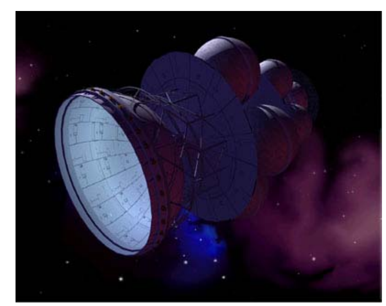
Project Orion

- A spacecraft powered by nuclear bombs– nuclear fission
- Idea was sponsored by USAF in 1958
- Los Alamos group.
- You dropped hydrogen bombs wrapped in a hydrogen rich jacket out the rear of a massive plate.
- 0.1 kton bomb every second for take off, eventually tapering to 1 20 kton bomb every 10 sec.
- s.i. theoretically around 10,000 to one million seconds
- Limited to about 0.01c.
- But, it is a "dirty" propulsion system.
- A 1963 treaty banned nuclear tests in the atmosphere, spelled the end of "Orion".
- Still argued to be the best rocket we could build today.

http://www.daviddarling.info/encyclopedia/O/OrionProj.html

Project Daedalus

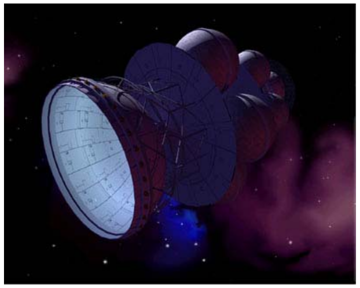
- Continuation/extension of Orion
- British Interplanetary Society project (1973-1978)
- A robotic fly-by probe to Barnard's Star
  - 2^{nd} closest star system to Earth, 6 lyr away
  - In human lifetime scale (chose 50 yrs)
  - Needs to reach 12% c.
- Idea was to use nuclear pulsed power, but fusion.



http://www.daviddarling.info/encyclopedia/D/Daedalus.html

Project Daedalus

- Good example of interstellar travel with foreseeable technology.
- Use fusion, like the stars.
- But, we have to use the more energy efficient part of hydrogen → helium.
- But there's a problem.



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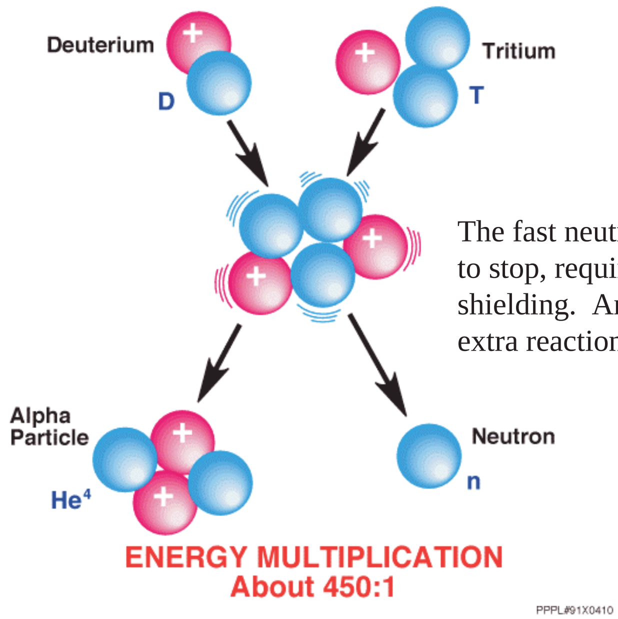
Deuterium–Tritium Fusion Reaction



The fast neutrons are hard to stop, requires too much shielding. And can create extra reactions.

Project Daedalus

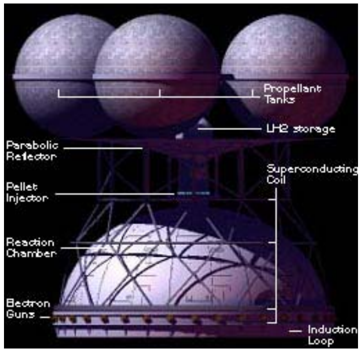
- Instead Daedalus would use:

$$d + {}^3He \rightarrow {}^4He + p$$

- The by-products are normal helium and a proton.
- Both are positively charges and can be deflected with magnetic fields into an exhaust.
- Reasonably efficient, converting 4 x 10^{-3} mass into energy.
- 1 MINOR problem. ^{3}He is very rare on Earth.
- Could be collected from Jupiter's atmosphere.

Project Daedalus

- Daedalus would accelerate for 4 years, then coast for 50 years to reach Barnard's star.
- At blastoff the mass would be 54,000 tons, of which 50,000 would be fuel.
- That's an R_M = 12.
- The fuel would be in pellets that enter the reaction chamber 250/sec.
- Sophisticated robots for repair.
- For dust erosion at 0.12c, requires a beryllium erosion shield 7mm thick and 55 meters in diameter.
- Once it reached Barnard's star, it would disperse science payload that would study the system.
- Would transmit back to Earth for 6-9 years.



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