Engineering:

There is a personal/societal motivation to go with mathematical equations, computer code and dense scientific theory!

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http://www.chemeprof.com/

OUTLINE

- Why did I become an engineer?
- Some reasons why you might wish to become an engineer
- Show some (simple) quantitative analysis which is foundational to engineering
- Explain the continuing need for engineers!

Why be an Engineer?

- Why am I an engineer?

http://www.chemeprof.com/

Why be an engineer?

When I taught a “Intro to Bioengineering course, I told the students that I could not figure out how dinosaurs could stay cool if they were very active. A student did some more calculations

In the end, our conclusions did not change. Dinosaurs almost certainly were not as active as shown in Jurassic Park

It took a few years but: We were right!

Do Dinosaurs Sweat?

Introduction:

Gigantism in dinosa
it is hard to understa
of stress that the ske
the creature's own r

T Rex could not have outrun a speedy human, scientists conclude

share

10

$C_6H_{12}O_6 + 6O_2 \rightarrow$

~30

$$\frac{\partial T(x,t}{\partial t}$$

JURASSIC WORLD DOMINION (2022) ♡

PURCHASE COMPLETED

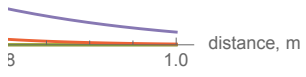
MONDAY, JUN 13 2022
6:30 PM

Cinemark Movies 14

910 W. Edison Rd, Mishawaka, IN 46545

View Order Details

$$T(x,t) =$$



t=.5s
t=1s
t=2s
t=5s
t=10s

A lot of humans could have outrun Tyrannosaurus Rex and certainly escaped in a car CREDIT: GETTY CREATIVE

Why am I an engineer?

- https://www.youtube.com/watch?v=1-JdqHxqkHA

JUMP TO TODAY

- Why be an engineer?
- Some contributions of engineering to mitigating the effects of the pandemic.

COVID 19

- It is easy to look back now and make the statement that no single field of expertise had the knowledge and quantitative tools to deal effectively with the spread of the virus or the resulting disease.

- What could a chemical engineer contribute?

COVID 19: VIEWED BY A CHEMICAL ENGINEER

A → UNIFECTED PEOPLE

B → INFECTED PEOPLE

DISEASE TRANSMISSION IS 2ND ORDER

$r = \beta C_A C_B$

$A + B \rightarrow 2B$

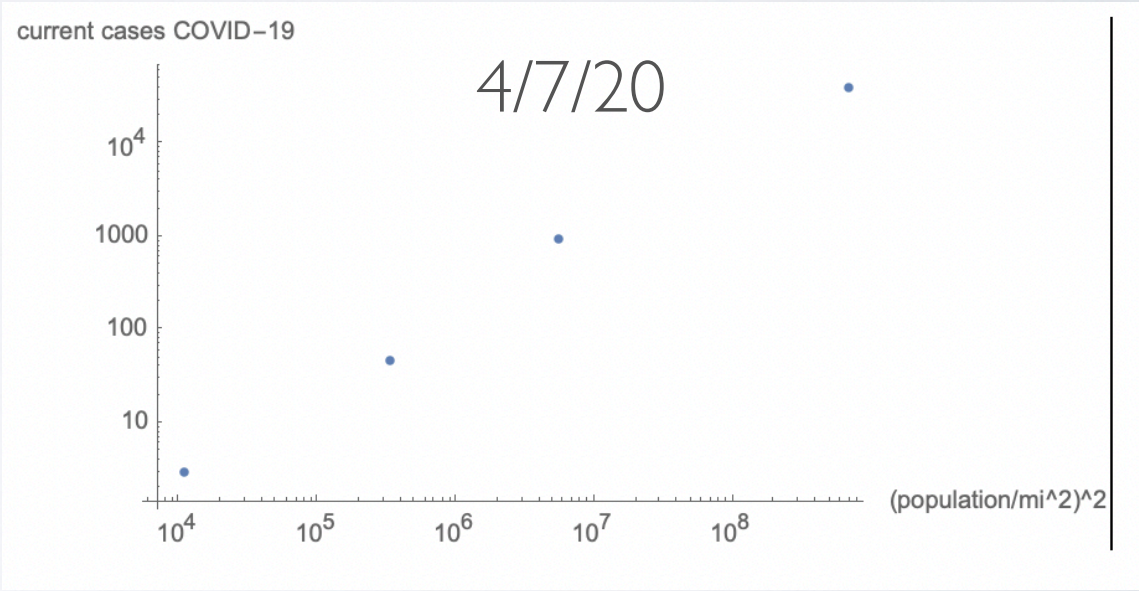
$\therefore \frac{dC_A}{dt} = -\beta C_A C_B$

$\frac{dC_B}{dt} = -\beta C_A C_B + 2\beta C_A C_B$

$\frac{dC_B}{dt} = \beta C_A C_B$

COUNTY	POPULATION DENSITY	(POPULATION DENSITY)^2	COVID 19 CASES
St. JOE	585 P/mi^2	3.4×10^5	44
MARSHALL	104	1.1×10^4	3
MARION	2369	5.6×10^6	964
NYC	26,400	7×10^8	41,000

Disease spread modeled as a "2nd order" chemical reaction:
Instead of A + B -> D
The disease is:
A + B-> 2B



This differs from the standard "SEIR" model since I use "concentration" (population density), not "number" of people

University of Notre Dame

chemeprof.com

COVID 19: VIEWED BY A CHEMICAL ENGINEER

Quantifying aerosol transmission

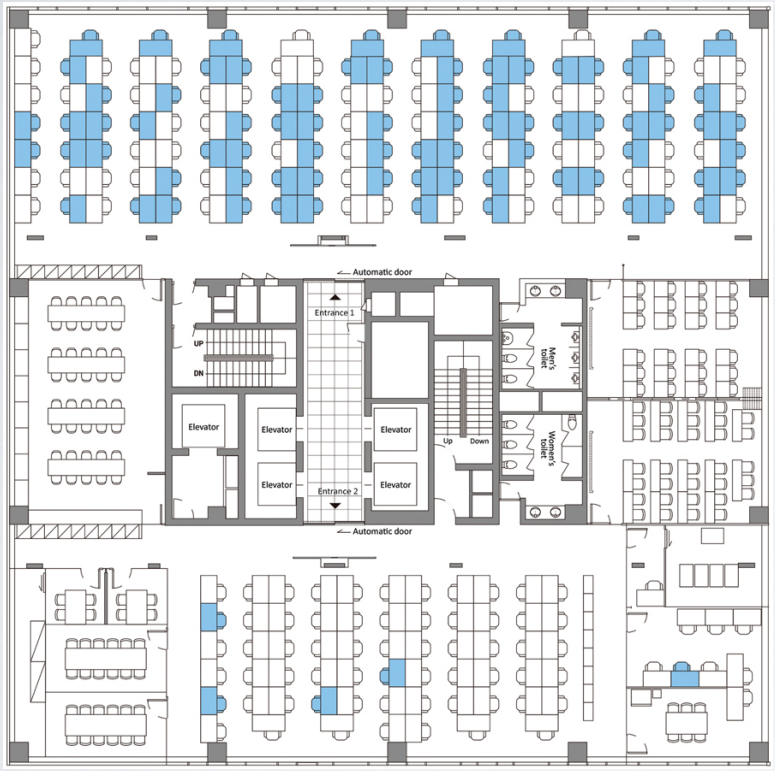
CBE 20255
Spring 2020
Final Exam
5/7/20

1. Potential for aerosol spread of SARS CoV 2 virus.

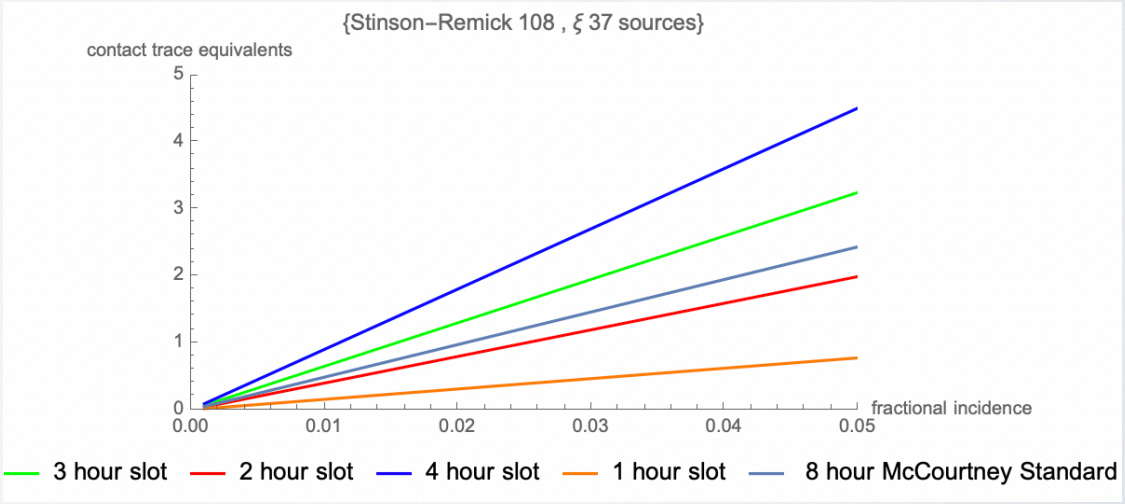
$$V\frac{dC_A}{dt} = q_{Af}C_{Af} - qC_A + S - D$$

$$C_A = \frac{S}{q}$$

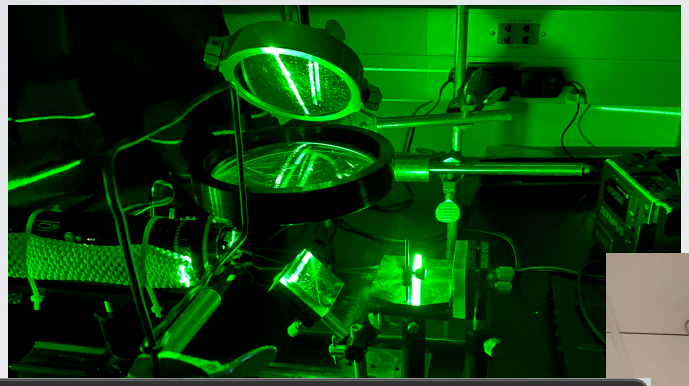
By April 2020, the following data were available. Blue seats were people who were infected during a 2 day period



We used this modeling to determine safe time limits for people working together in labs and offices



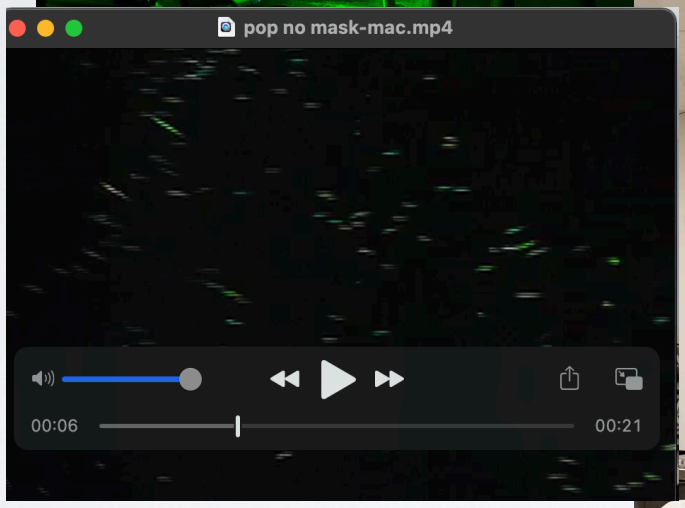
MASKS—CLASSROOM, FOOTBALL (WITH PROFESSOR LEIGHTON)

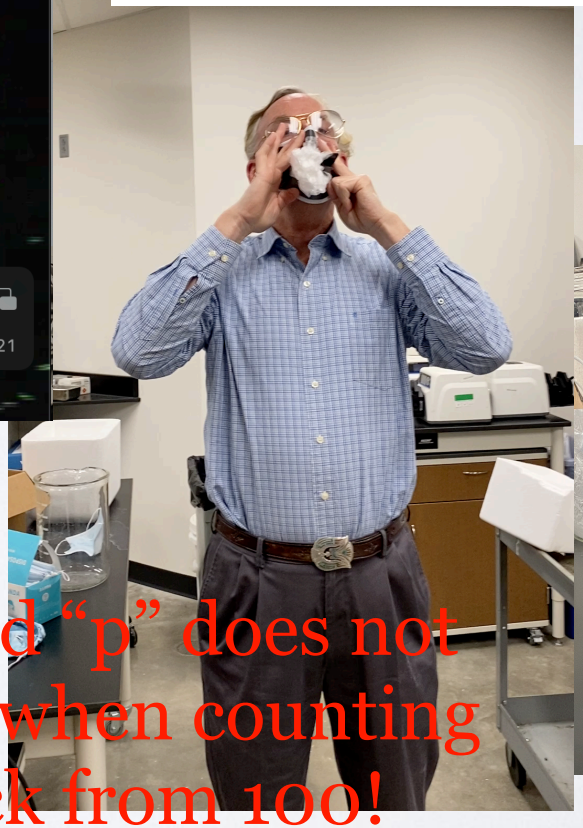


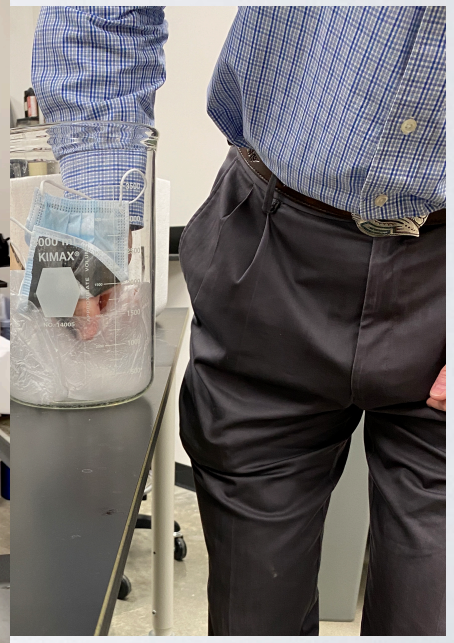
Strategies for Aerosol Mitigation in a Football Competition

David T. Leighton, Jr.
Mark J. McCready
Department of Chemical and Biomolecular Engineering
University of Notre Dame

Matthew Leiszler, MD
Health Services
University of Notre Dame







A hard "p" does not occur when counting back from 100!

SAFETY: TIME AND DISTANCE

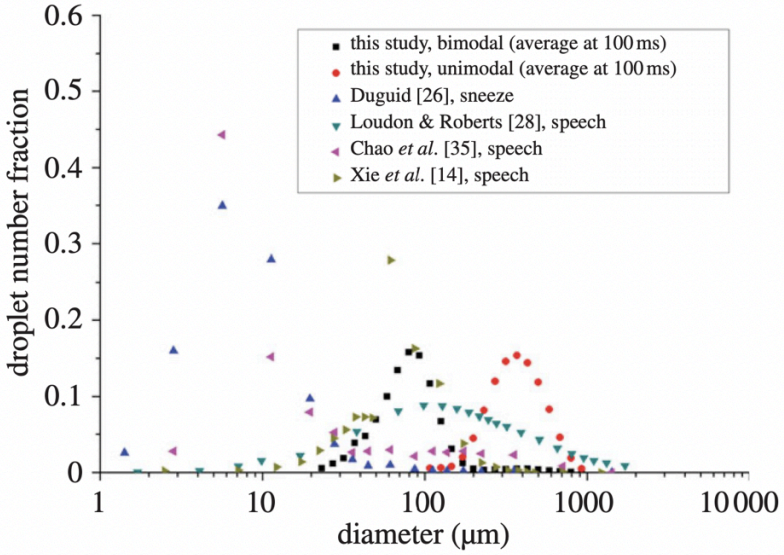
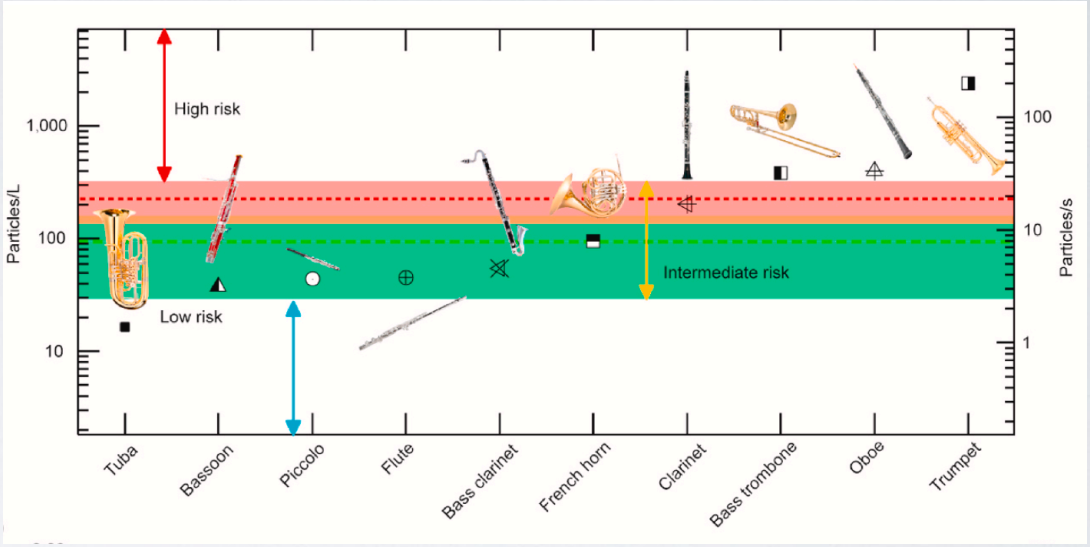
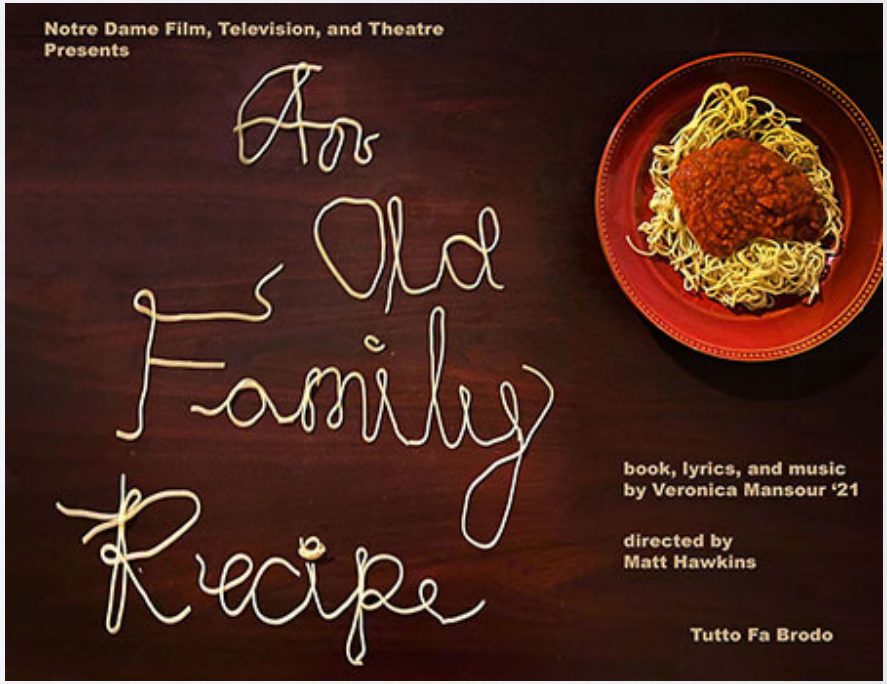


Figure 5. Comparison of the number size distribution of the droplets exhaled by sneeze and speech. (Online version in colour.)



$$F_d = \frac{1}{2}\rho u^2 c_d A$$

$$\frac{d\vec{P}}{dt} = \sum_i \vec{F}_i$$



Why be an engineer?

- https://www.youtube.com/watch?v=JVKK4QxWSNo

Engineering combines knowledge of the basic physical (chemical, biological) laws with mathematical analysis.

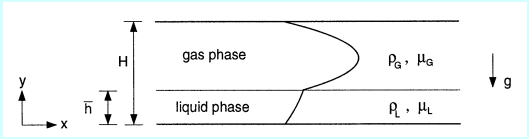
We endeavor to (and it is essential) that we use these calculations to predict how a device, system or phenomena will behave — before it is built!

There can be quite a bit of creativity in engineering — perhaps in deciding what "question" to ask or which problem to solve.

Many of these problems have a large impact on society!

Mathematical modeling can be complex

Geometry of interest



We will look at the linear stability problem for

- Steady flow
-
- Purely Oscillatory (Couette flow)

Gas-liquid flow interfacial stability problem

turbulence model: k-ε

Solve the base state with either a smooth or rough interface (try to match data).

then

Solve the differential stability problem the best we can

Liquid-phase: $0 \le y^* \le d_1$

$$\rho_1\left[\frac{\partial u_i^*}{\partial t^*} + u_j^*\frac{\partial u_i^*}{\partial x_j^*}\right] = -\frac{\partial p^*}{\partial x_i^*} + \rho_1 g^* \sin(\theta) + \frac{\partial}{\partial x_j^*}\left[(\mu_1 + \mu_t^*)(2s_{ij}^*)\right]$$

$$\rho_1\left[\frac{\partial k^*}{\partial t^*} + u_i^*\frac{\partial k^*}{\partial x_i^*}\right] = \frac{\partial}{\partial x_i^*}\left[\left(\mu_1 + \frac{\mu_t^*}{\sigma_{ke}}\right)\left(\frac{\partial k^*}{\partial x_i^*}\right)\right] + \mu_t^*(2s_{ij}^*)\frac{\partial u_i^*}{\partial x_j^*} - \rho_1\varepsilon^* - 2\mu_1\left(\frac{\partial\sqrt{k^*}}{\partial x_i^*}\right)^2$$

$$\rho_1\left[\frac{\partial \varepsilon^*}{\partial t^*} + u_i^*\frac{\partial \varepsilon^*}{\partial x_i^*}\right] = \frac{\partial}{\partial x_i^*}\left[\left(\mu_1 + \frac{\mu_t^*}{\sigma_\varepsilon}\right)\left(\frac{\partial \varepsilon^*}{\partial x_i^*}\right)\right] + c_1 f_1 \mu_t^*\frac{\varepsilon^*}{k^*}(2s_{ij}^*)\frac{\partial u_i^*}{\partial x_j^*} + 2\mu_1\mu_t^*\left(\frac{\partial^2 u_i^*}{\partial x_j^* \partial x_i^*}\right)^2 - \rho_1 c_1 f_1\frac{\varepsilon^{*2}}{k^*}$$

Stability equations continued

Gas-phase: $d_1 \le y^* \le d_1 + d_2$

$$\rho_2\left[\frac{\partial u_i^*}{\partial t^*} + u_j^*\frac{\partial u_i^*}{\partial x_j^*}\right] = -\frac{\partial p^*}{\partial x_i^*} + \rho_2 g^* \sin(\theta) + \frac{\partial}{\partial x_j^*}\left[(\mu_2 + \mu_t^*)(2s_{ij}^*)\right]$$

$$\rho_2\left[\frac{\partial k^*}{\partial t^*} + u_i^*\frac{\partial k^*}{\partial x_i^*}\right] = \frac{\partial}{\partial x_i^*}\left[\left(\mu_2 + \frac{\mu_t^*}{\sigma_{ke}}\right)\left(\frac{\partial k^*}{\partial x_i^*}\right)\right] + \mu_t^*(2s_{ij}^*)\frac{\partial u_i^*}{\partial x_j^*} - \rho_2\varepsilon^* - 2\mu_2\left(\frac{\partial\sqrt{k^*}}{\partial x_i^*}\right)^2$$

$$\rho_2\left[\frac{\partial \varepsilon^*}{\partial t^*} + u_i^*\frac{\partial \varepsilon^*}{\partial x_i^*}\right] = \frac{\partial}{\partial x_i^*}\left[\left(\mu_2 + \frac{\mu_t^*}{\sigma_\varepsilon}\right)\left(\frac{\partial \varepsilon^*}{\partial x_i^*}\right)\right] + c_1 f_1 \mu_t^*\frac{\varepsilon^*}{k^*}(2s_{ij}^*)\frac{\partial u_i^*}{\partial x_j^*} + 2\mu_2\mu_t^*\left(\frac{\partial^2 u_i^*}{\partial x_j^* \partial x_i^*}\right)^2 - \rho_2 c_1 f_1\frac{\varepsilon^{*2}}{k^*}$$

Stability equations continued

k=1 (liquid-phase) $0 \le y \le 1$

k=2 (gas-phase) $1 \le y \le n_2 + 1$

$$\frac{(\hat{\rho}_k u'_{b,k})'}{m_k} + \left(\Gamma_{b,k}\hat{\phi}'_k\right)' - 2\alpha^2\left(\Gamma_{b,k}\hat{\phi}_k\right)' + \alpha^4\Gamma_{b,k}\phi_k = i\alpha R\frac{\rho_k}{m_k}\left\{\left(u_{b,k} - c\right)\left(\hat{\phi}''_k - \alpha^2\hat{\phi}_k\right) - u''_{b,k}\hat{\phi}_k\right\}$$

$$\frac{(\hat{\rho}_k k'_{b,k})'}{m_k} + \frac{\hat{\rho}_k u''_{b,k}}{m_k} + \Gamma_{b,k}\left(\hat{k}'_k - \alpha^2\hat{k}_k\right) + \Gamma_{b,k}\hat{k}_k + 2\frac{\hat{\rho}_{b,k}u'_{b,k}}{m_k}\left(\hat{\phi}'_k + \alpha^2\hat{\phi}_k\right) + \frac{k'_{b,k}}{k_{b,k}}\left(\frac{k'_{b,k}}{2k_{b,k}}\hat{k}_k - \hat{k}'_k\right)$$
$$= i\alpha R\frac{\Gamma_k}{m_k}\left\{\left(u_{b,k} - c\right)\hat{k}_k - k_{b,k}\hat{\phi}_k\right\}$$

$$\frac{(\hat{\rho}_k\varepsilon'_{b,k})'}{m_k} + \Gamma_{b,k}\Gamma_{b,k}\left(\hat{\varepsilon}'_k - \alpha^2\hat{\varepsilon}_k\right) + \Gamma'_{b,k}\hat{\varepsilon}_k + 2c_{1,k}f_k\frac{\hat{\rho}_{b,k}u'_{b,k}}{m_k}\left(\hat{\phi}''_k + \alpha^2\hat{\phi}'_k\right) + r_k Re_{2,k}f_k\frac{\varepsilon_{b,k}}{k_{b,k}}\left(\frac{\varepsilon_{b,k}}{k_{b,k}}\hat{k}_k - 2\hat{\varepsilon}_k\right)$$
$$+ \frac{\left(u'_{b,k}\right)^2}{m_k}\left[c_{1,k}f_k\frac{\varepsilon_{b,k}}{k_{b,k}}\left(\hat{\rho}_k + \hat{\varepsilon}_k - \frac{m_k\mu_{b,k}}{k_{b,k}}\hat{k}_k\right) + \frac{2m_k}{r_k R}\left(\hat{\rho}_k + 2\mu_{b,k}\hat{\phi}'_k\right)\right]$$
$$= i\alpha R\frac{\Gamma_k}{m_k}\left\{\left(u_{b,k} - c\right)\hat{\varepsilon}_k - \varepsilon_{b,k}\hat{\phi}_k\right\}$$

$$\hat{\mu}_k = c_{\mu,k}f_k r_k R\frac{k_{b,k}}{\varepsilon_{b,k}}\left(2\hat{k}_k - \frac{k_{b,k}}{\varepsilon_{b,k}}\hat{\varepsilon}_k\right)$$

Stability Equations cont.

Boundary conditions

$$\hat{\phi}_1 = \hat{\phi}_2 \qquad (3\text{-}18c)$$

$$\hat{\phi}'_1 + u_{b,1}\hat{f} = c\hat{h} \qquad (3\text{-}18d)$$

$$\hat{\phi}'_1 - \hat{\phi}'_2 = \hat{h}\left(u'_{b,1} - u'_{b,2}\right) \qquad (3\text{-}18e)$$

$$\hat{\phi}''_1 + \alpha^2\hat{\phi}_1 + \hat{h}u''_{b,1} = m_2\left(\hat{\phi}''_2 + \alpha^2\hat{\phi}_2 + \hat{h}u''_{b,2}\right) \qquad (3\text{-}18f)$$

$$\left(\hat{\phi}'''_1 + \Gamma'_{b,1}\hat{\phi}''_1 + u'_{b,1}\hat{f}'_1 - 3\alpha^2\hat{\phi}'_1\right) + i\alpha R\left(u'_{b,1}\hat{\phi}_1 - u_{b,1}\hat{\phi}'_1\right) - m_2\left(\hat{\phi}'''_2 + \Gamma'_{b,2}\hat{\phi}''_2 + u'_{b,2}\hat{f}'_2 - 3\alpha^2\hat{\phi}'_2\right)$$
$$- i\alpha r_2 R\left(u'_{b,2}\phi_2 - u_{b,2}\phi'_2\right) - i\alpha R\left[\left(1 - r_2\right)F + \alpha^2 S\right]\hat{h} = i\alpha Re\left(r_2\hat{\phi}''_2 - \hat{\phi}'_1\right) \qquad (3\text{-}18g)$$

$$\hat{k}_1 = \hat{\varepsilon}_1 = \hat{f}_1 = \hat{k}_2 = \hat{\varepsilon}_2 = \hat{f}_2 = 0 \qquad (3\text{-}18h)$$

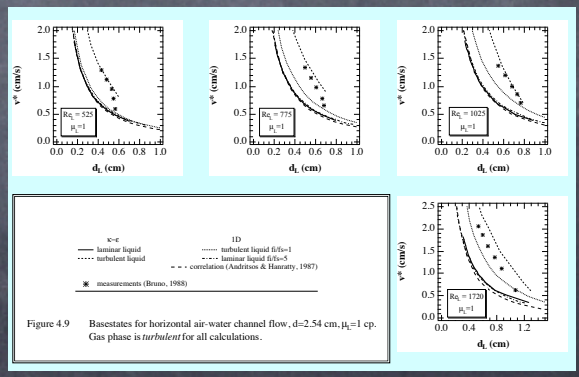


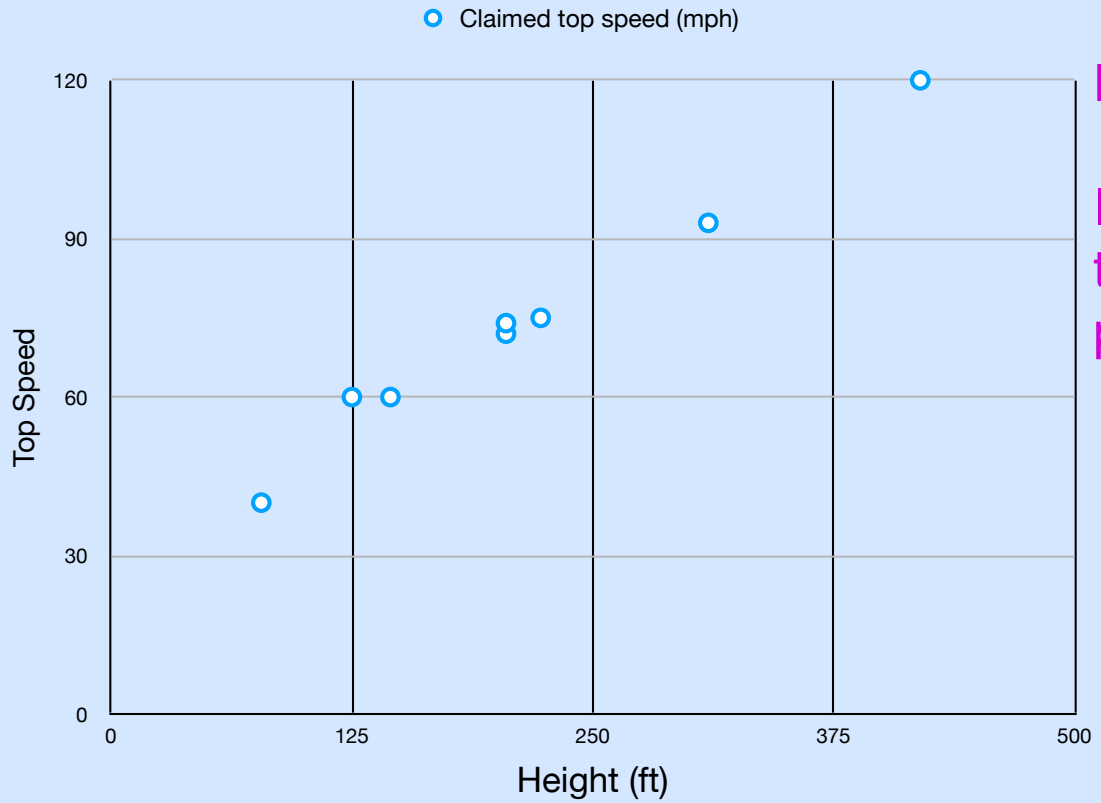
Figure 4.9 Basestates for horizontal air-water channel flow, d=2.54 cm, μ_L=1 cp. Gas phase is *turbulent* for all calculations.

Engineering always involves data:
Cedar Point Coaster Data

Table 1

Coaster name	Height (ft)	Claimed top speed (mph)
mine ride	48.0	40.0
Blue Streak	78.0	40.0
Gemini	125.0	60.0
Raugarou	145.0	60.0
Magnum	205.0	72.0
Steel Vengence	205.0	74.0
Valravan	223.0	75.0
Millennium Force	310.0	93.0
Dragster	420.0	120.0

Cedar Point Coaster Data



Speed increases as height increases.

How do we quantify?

Is there a general "law" that could be used for prediction?

FORMULATING A "MODEL" FOR SPEED

- If the hill is higher, the top speed is greater.
- If we wish to accurately describe "speed", we need to include the dimensions, "length/time", in some understandable units.
- This could be ft/s, miles/hour, meters/sec, furlongs/fortnight….

ENGINEERS LIKE TO COMPARE THINGS

- If I asked: ".. how far is it to Chicago?"
  - would you answer?
    - "a couple of hours" or...
    - "about 90 miles"
- If I asked: ".. is a meter a long distance?" what would you say
  - "No", compared to the distance to Chicago
  - "Yes", compared to a micron
- For our conclusion to be valid we need to
  - **compare** <u>like</u> (same dimensions) quantities.

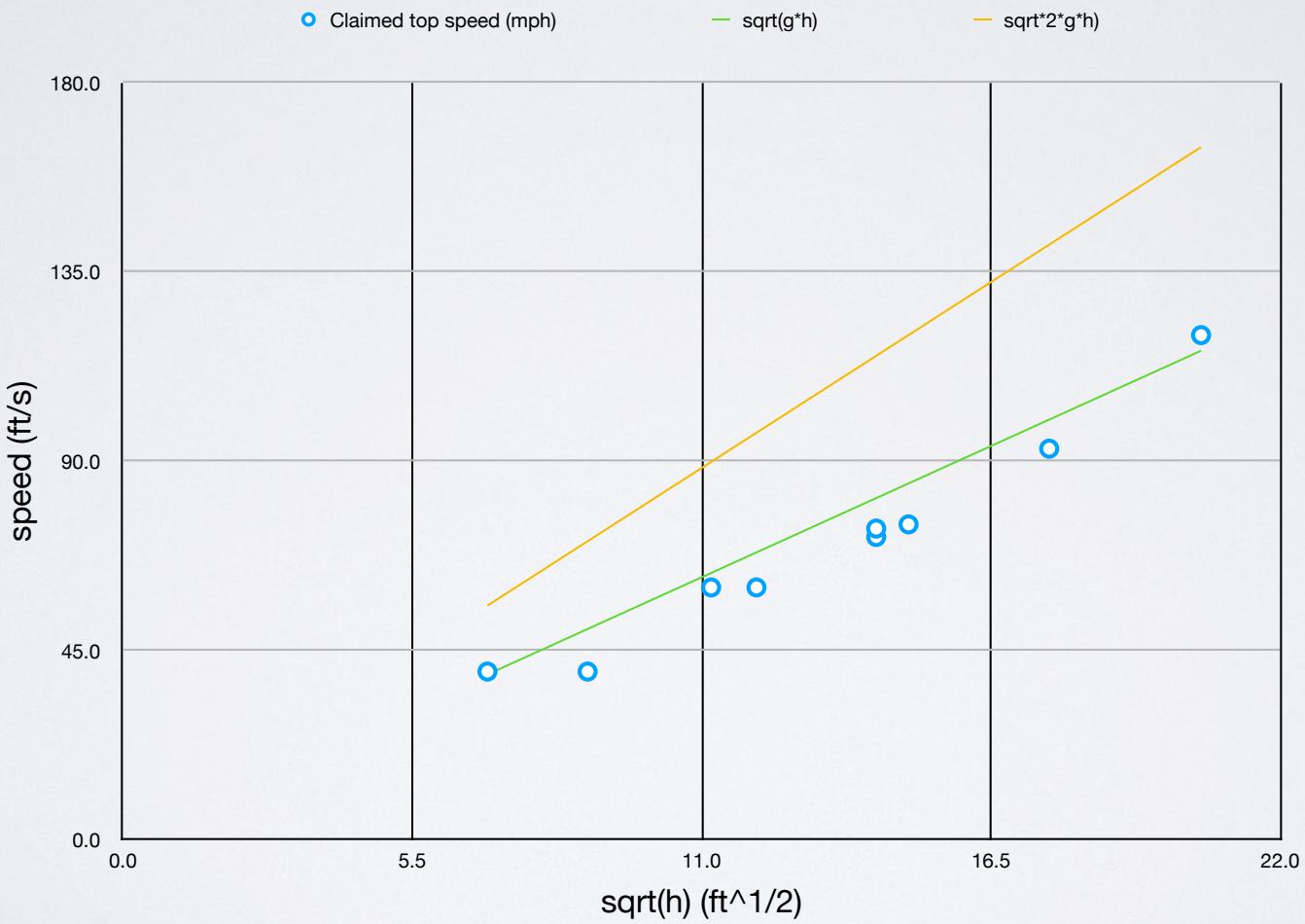
WHAT ELSE DO WE KNOW ?

- For a correct mathematical equation, each side of the equation has to either be "dimensionless" (just numbers!) or the same physical dimensions.
- So, if I make an equation that correctly calculates the speed (from physics), the dimensions need to be length/time on both sides!
- So, which "variables" (physical quantities) must contribute to how fast the roller coaster is going?
  - gravity (length/time^2)?? , height (length)??, mass (mass)?? ????

EQUATION FOR SPEED

- We conclude that to make a speed, v, out of g, h and m?
  - The result is the v ~ Sqrt(g*h)

PLOT OF DATA AND MODEL



EQUATION FOR SPEED

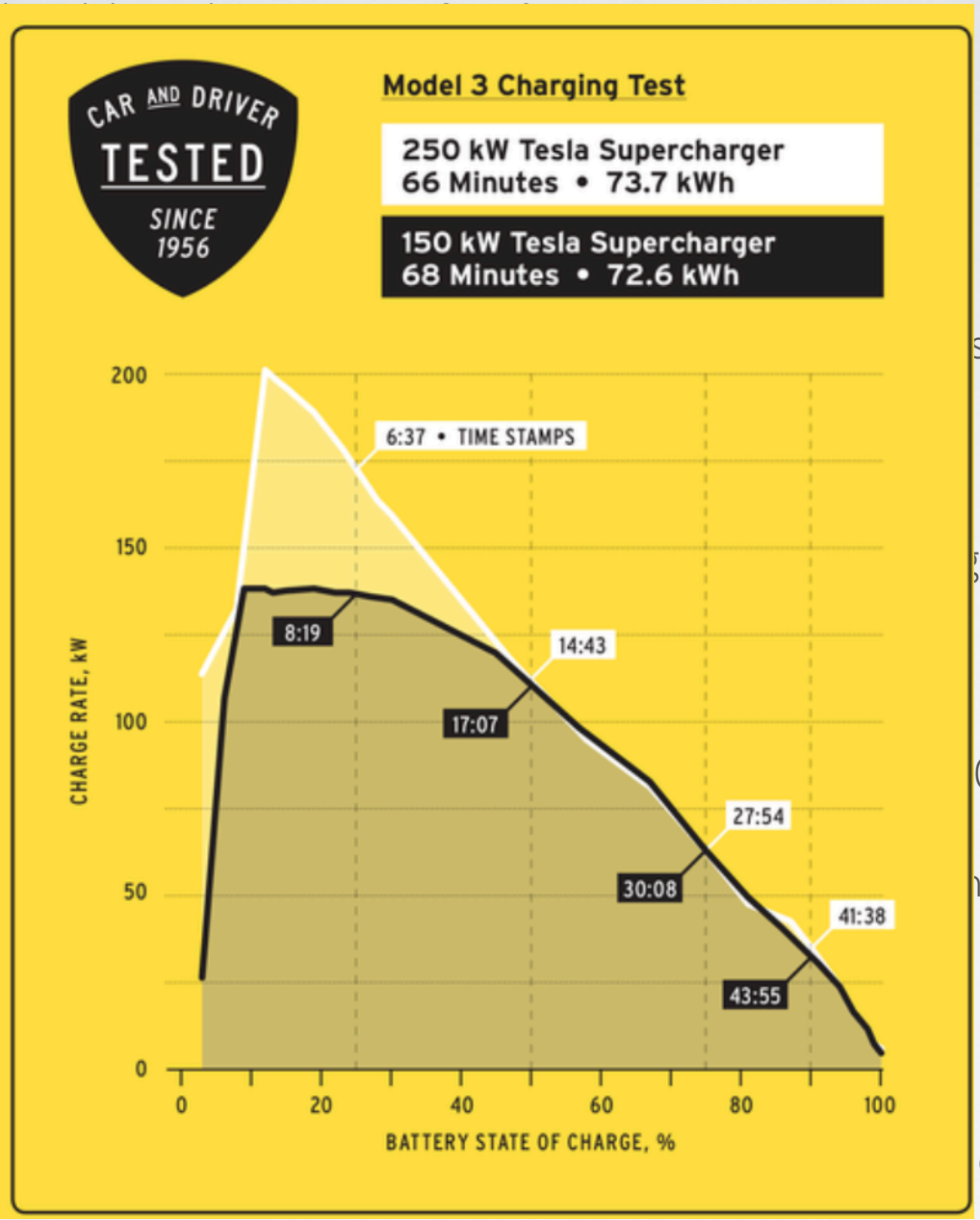
- We conclude that to make a speed, v, out of g, h and m?
  - The result is the v ~ Sqrt(g*h)
  - The actual equation is v = Sqrt(2*g*h)
- What could be the reasons that data do not match "model" exactly?
- If you want ever faster, the cost will go up substantially!

WHY BE AN ENGINEER?

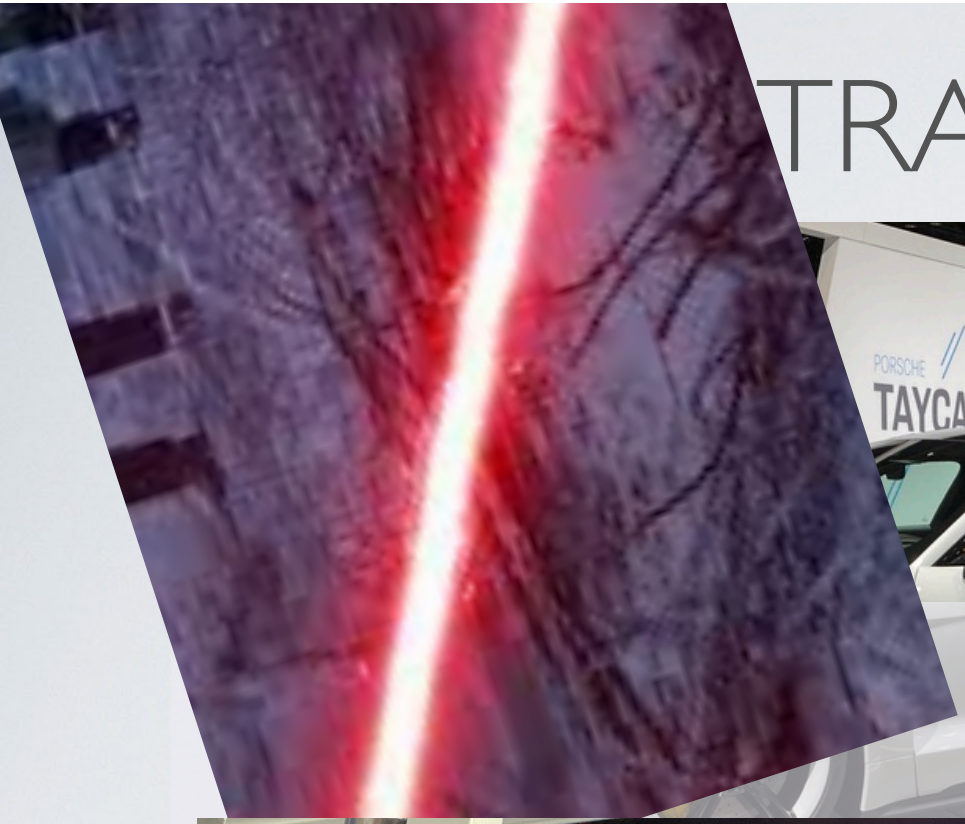
- We need you!
- Many critical challenges remain!
- For example:
  - Reduce CO2 emissions by powering cars without hydrocarbon fuels

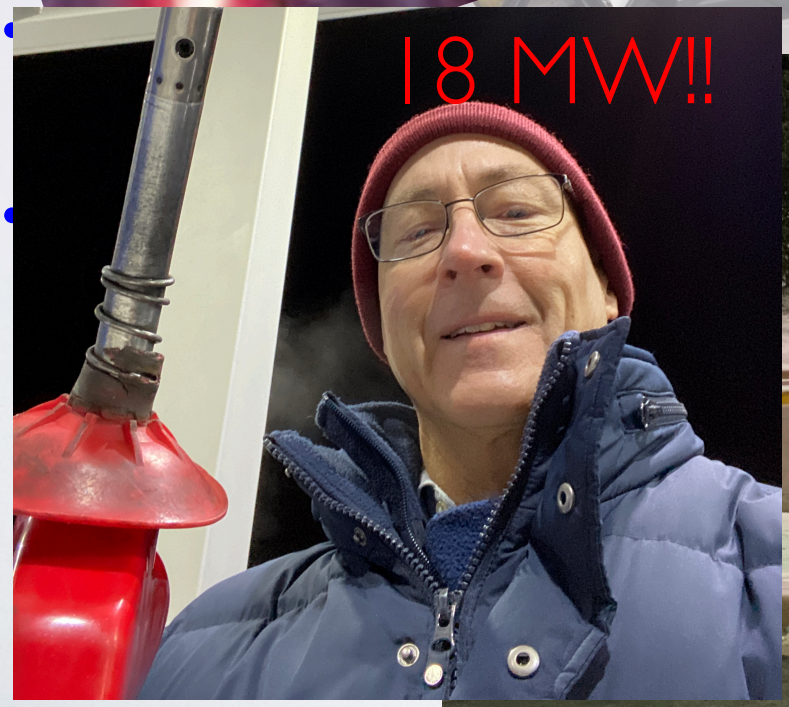
ELECTRIC CARS: SOME ENGINEERING CALCULATIONS TO DEFINE PROBLEM

- Where is the e
- How long will t
- Indiana Toll Road +
- On a really busy tra soline pumps.
  - While there is
  - One tank will p gas only 1 time.
- What if all cars wer
  - Today, a Tesla su 0 minutes.
  - We need to pr ng each plaza would need 144 charging p
  - Total power ne
  - You can find pe cars — you can decide,.



TRANSPORTATION





Why be an engineer?

Gene Therapy Hits a Peculiar Roadblock: A Virus Shortage

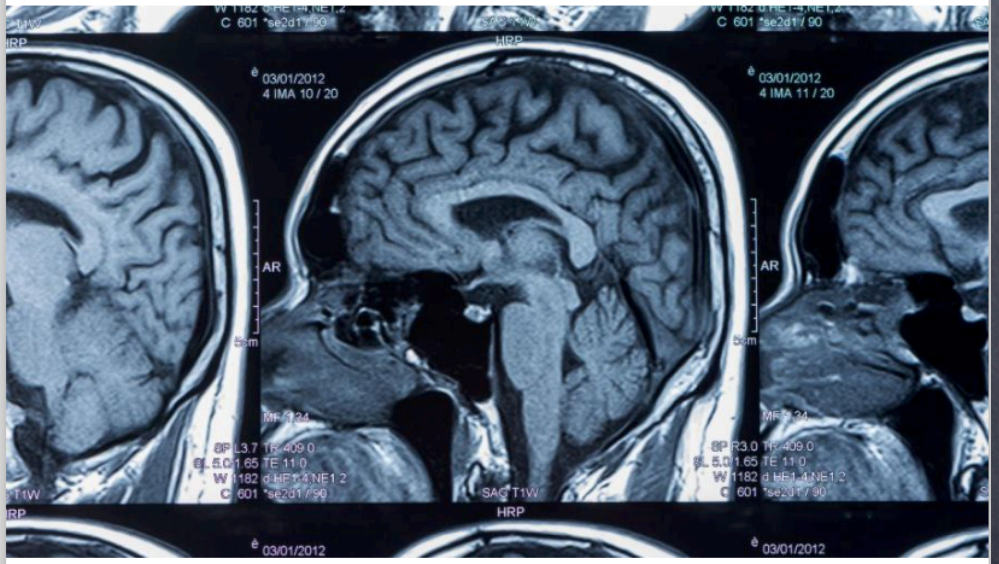
Nov. 27, 2017

Laboratory technicians working with viral vectors used in gene therapy. Custom-made viruses, required to insert good genes into cells, are in short supply.Phanie/Science Source

https://crossroads.nd.edu

First CTE diagnosis on living NFL player confirmed by autopsy, report shows

Fox News



A medical breakthrough in CTE research on NFL players

A new report shows doctors have accurately diagnosed a living former NFL player with chronic traumatic encephalopathy (CTE). How could these new findings help early detection and treatment?

http://www.chemeprof.com/

Why be an engineer?

PERSONAL HEALTH

Unlocking the Secrets of the Microbiome

Paul Rogers

By Jane E. Brody

Nov. 6, 2017

105

Modern technology is making it possible for medical scientists to analyze inhabitants of our innards that most people probably would rather not know about. But the resulting information could one day save your health or even your life.

This is a “systems” problem as much as a biological problem.

How can we keep track of and interpret all of the biological data!

Why be an engineer?

The New York Times

F.D.A. Approves First Gene-Altering Leukemia Treatment, Costing $475,000

A technician working with human cells belonging to cancer patients at Novartis Pharmaceuticals in Morris Plains, N.J. The Food and Drug Administration on Wednesday approved Novartis's gene therapy for leukemia, the first-ever treatment that alters a patient's own cells to fight cancer. Brent Stirton/Novartis Pharmaceuticals Corp., via Associated Press

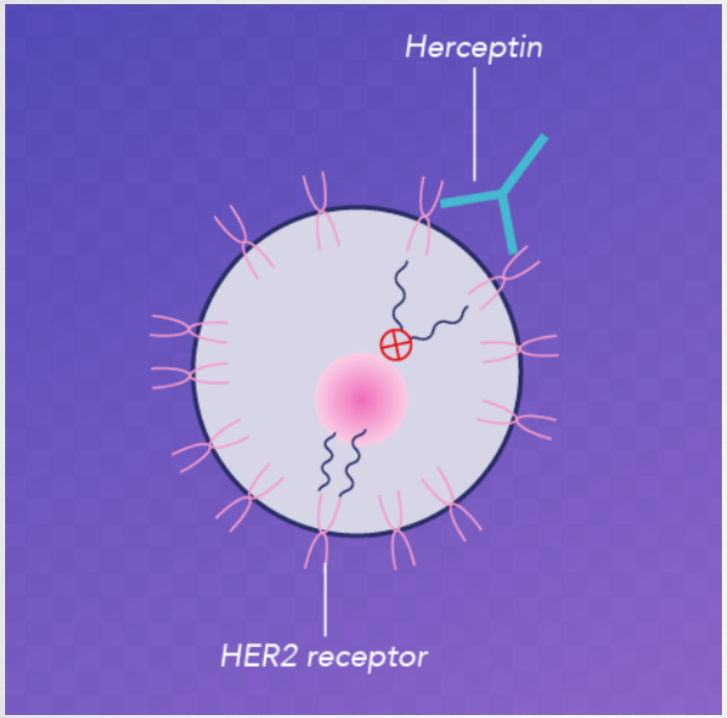
A massive challenge will be scaling up. Currently, each patient requires a team of highly trained, specialized scientists and technicians to re-engineer his T-cells. "If you have 100,000 lung-cancer cases each year, there aren't 100,000 Ph.D.s to grow the cells," Dr. June says. "So it needs to be done with robotics."

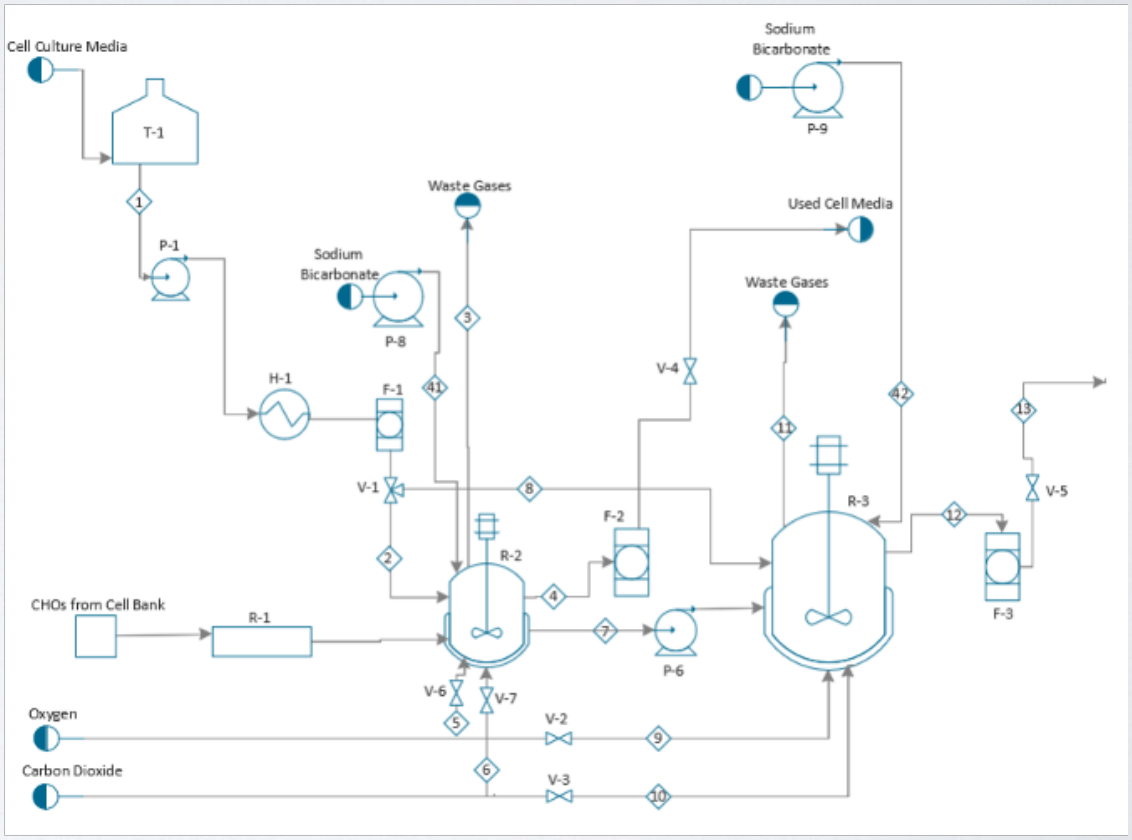
No, Actually, probably clever chemical engineering!

http://www.chemeprof.com/

SPRING 2021-22

- Chemical Engineering seniors created designs to produce: artificial insulin, tetanus vaccine the monoclonal antibodies, *Alemtuzumab*, *Trastuzumab*, *Rituximab*, the pharmaceutical *Valacyclovir* and a trivalent flu vaccine.





ONE MORE ENGINEERING PROBLEM

- A "field" of 40 wind turbines covers about 1400 acres
- This field is producing **56 MW** of power for a wind speed of 10 m/s (22 mph) — which is about the optimal/maximal value
  - This is .04 MW/acre
    - A coal fired power plant would produce about 10 MW/acre!
- **If the wind speed drops to 5m/s, how much power will the field produce?**

POWER AND WIND SPEED?

- How does the power generated by the windmill change with wind speed?
  - How is power being generated?
    - Wind flows through area swept by blades
    - Windmill converts this kinetic energy to electric power

POWER AND WIND SPEED?

- How does the power generated by the windmill change with wind speed?
  - Let's see if we can figure this out based on dimensional reasoning
    - Power is work/time which is force * distance/time which is mass* acceleration *distance/time
    - Thus we could write

$$power = m\ l / t^2 l / t = \frac{ml^2}{t^3}$$

    - What variables could be used?

EQUATION FOR POWER FROM WIND

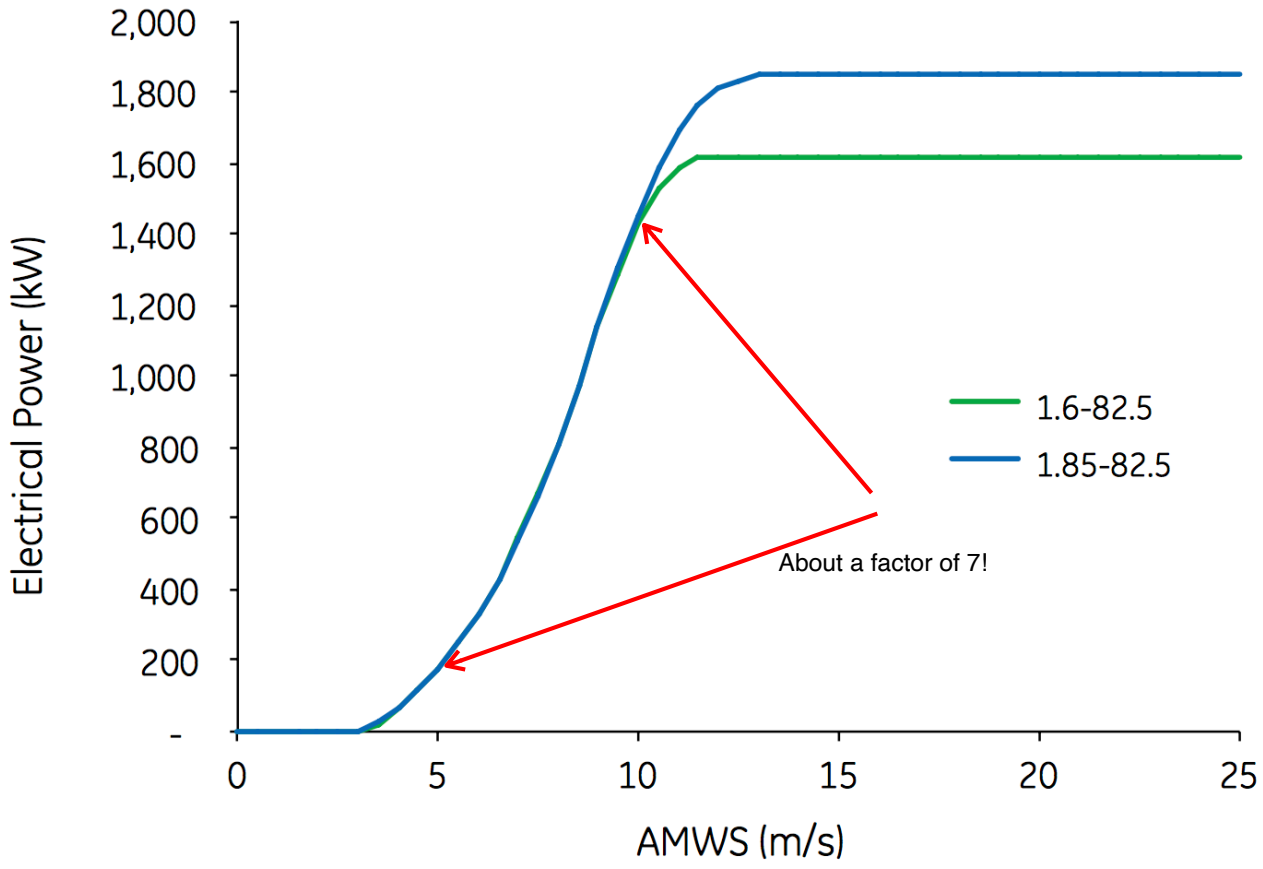
- Windspeed, blade diameter, air density
  - v [=] l/t
  - d, r [=] l
  - Density of air ρ [=] m/l^3
  - Arrange these variables to get dimensions of power:

$$power \sim \rho v^3 d^2 [=] \frac{ml^2}{t^3}$$

  - If the wind speed is cut in half, the power reduced to 1/8!
  - So our 40 wind turbines will produce about….
    - 7 MW!

WIND TURBINE POWER

Power Curve



https://www.gerenewableenergy.com/content/dam/gepower-renewables/global/en_US/downloads/brochures/wind-onshore-turbine-1.85-82.5-gea18755g-r1.pdf

What could be better than…

- A large muffin…
  - Why not even bigger? Can we decide if this is possible?
  - Of course, use the "cooking number"

Cooking Number

- $N_{cooking}$ = ratio of time scales: outside reaction/inside heating

Interior heating

- A cooking time scale for the interior of something is

- $$t \sim \frac{C_p l^2 \rho}{k}$$

- in this equation k is the thermal conductivity, ρ is the density, C_p is the heat capacity and l is the length scale of the object.

Surface cooking

- The surface time scale can be the chemical reaction time scale. The exterior cooking could be a chemical reaction time scale for dehydrolysis (removal of water from sugars and starches) If we have

- $$\text{Rate} = K\,C$$

- where C is the concentration for a first order reaction and *K* is the first order rate constant (usually otherwise a lower case k).

Arrhenius Kinetics

- Most (elementary) reactions follow a temperature dependence that is called Arrhenius kinetics:

$$k = A_0 e^{-\frac{E_a}{RT}}$$

- In this equation, k is the reaction rate constant, R is the gas constant, T is absolute temperature, E_a is the activation energy and A_0 is the "pre-exponential" factor that is related to the rate at which molecules can rearrange internally, a normalization number of collisions between molecules for unitary values of concentrations and the efficiency of these collisions (which is again related to the rate of internal rearrangement but also has a geometry/structure component).

Cooking (continued)

- The (interior to exterior) cooking ratio is:

$$\frac{KC_p l^2 \rho}{k}$$

- Expectation is that for a certain food, this number is universal. That is, for a bigger muffin you would have to use a cooler oven.

If you are still doubting: Don't we already know everything?

- You might say...
  - "Maybe there is little that I could contribute."
- Over the years, many claims of certainty have proven to be completely wrong!

It is OK to challenge accepted thinking!

- Some things we thought we knew:
  - Margarine was considered a health food
  - Left-handed people die sooner because of the hazards of the right-handed word
  - Stomach Ulcers are caused by stress
  - Plants absorb CO2 and emit O2
  - The adult brain has no capacity to regenerate itself
  - Komodo Dragons bit their prey and waited for them to succumb to bacterial infections
  - The SARS CoV-2 virus was spread to a significant extent by surface contacts.

MUCH OF WHAT IS BEING PUBLISHED IS PROBABLY NOT CORRECT!

Essay

Why Most Published Research Findings Are False

John P. A. Ioannidis

Over half of psychology studies fail reproducibility test

Largest replication study to date casts doubt on many published positive results.

Monya Baker

ESSAY

Why Most Clinical Research Is Not Useful

John P. A. Ioannidis[1,2]*

Studies show only 10% of published science articles are reproducible. What is happening?

Posted on May 3, 2012 by Moshe Pritsker

Studies show a very low reproducibility for articles published in scientific journals, often as low as 10-30%. Here is a partial list:

SOME DOUBT BUT…

The Diet-Heart Myth: Cholesterol and Saturated Fat Are Not the Enemy

on APRIL 19, 2013 *by* CHRIS KRESSER 619 *comments*

How did we come to believe saturated fat and cholesterol are bad for us?

17 JUL

325

CHOLESTEROL IS NOT BAD FOR YOU

Home > Blog > Cholesterol is not bad for you

Published on: Wednesday, 27 May, 2015

A sixty-year torrent of bad dietary advice is coming to an end

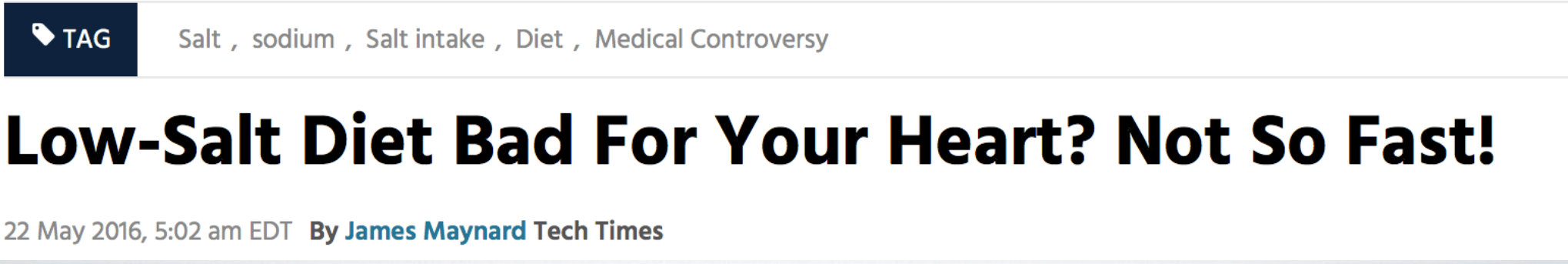
My Times column on the U-turn over cholesterol and saturated fat:

Cholesterol U-turn as research shows fatty foods might not be bad for us after all

Doctors are now focusing on sugar as the biggest danger to public health

SALT?


Go to Well Home
Well
HEART
A Low-Salt Diet May Be Bad for the Heart
By NICHOLAS BAKALAR MAY 25, 2016 1:45 PM 69


TAG
Salt , sodium , Salt intake , Diet , Medical Controversy
Low-Salt Diet Bad For Your Heart? Not So Fast!
22 May 2016, 5:02 am EDT By James Maynard Tech Times

WE NEED YOU!

- Desperately!

RECAP

- Engineering involves analyzing a specific device or system using mathematical analysis based on physical laws or empirical understanding
- All problems of real importance have some degree of uncertainty and so judgement is needed
- Many big questions remain and you can contribute to their solution
- You may find fulfillment in the problems of global importance that are being addressed by engineers!

Dimensionless Confucius Proverb

$$Cr \equiv \frac{How\ \ Smart\ \ You\ Are}{How\ \ Smart\ \ You\ \ Think\ \ You\ \ Are}$$

- He who knows not and knows he knows not is a child, teach him, Cr~1
- He who knows not and knows not he knows not is a fool, shun him, Cr<<1
- He who knows and knows not he knows is asleep, awaken him, Cr>>1
- He who knows and knows he knows is wise, follow him Cr~1