Chemical Engineering 374

Fluid Mechanics

Turbines

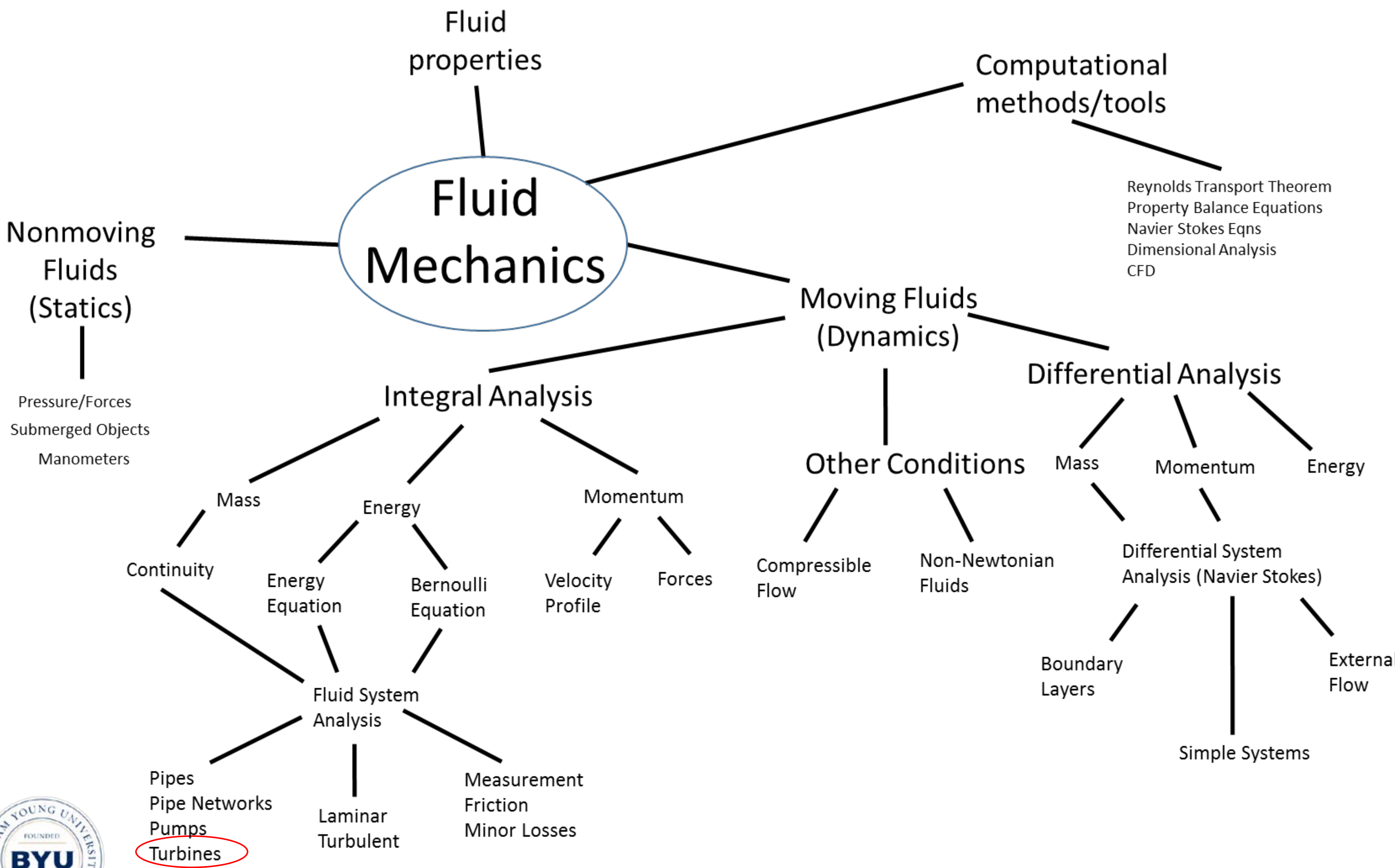
Spiritual Thought

"Like the Savior, His followers are sometimes confronted by sinful behavior, and today when they hold out for right and wrong as they understand it, they are sometimes called "bigots" or "fanatics." Many worldly values and practices pose such challenges to Latter-day Saints. Prominent among these today is the strong tide that is legalizing same-sex marriage in many states and provinces in the United States and Canada and many other countries in the world.

…On the subject of public discourse, we should all follow the gospel teachings to love our neighbor and avoid contention. Followers of Christ should be examples of civility. We should love all people, be good listeners, and show concern for their sincere beliefs. Though we may disagree, we should not be disagreeable. Our stands and communications on controversial topics should not be contentious. We should be wise in explaining and pursuing our positions and in exercising our influence. In doing so, we ask that others not be offended by our sincere religious beliefs and the free exercise of our religion. We encourage all of us to practice the Savior's Golden Rule: 'Whatsoever ye would that men should do to you, do ye even so to them'"

Elder Dallin H. Oaks

Fluids Roadmap



Key Points

- Pumps vs. Turbines
- Types and classes of Turbines
  - Positive Displacement (measurement)
  - Dynamic
  - Reaction
- Wind Turbines
- Scaling Laws
- N_{st}
- Examples

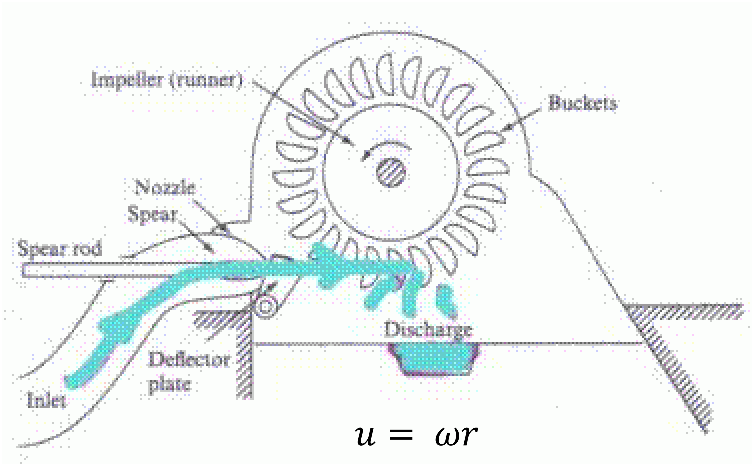
Turbines

- Pumps – Add mechanical energy to fluid via head
- Turbines – remove mechanical energy from fluid via head
- Classes
  - Hydraulic
  - Wind
  - Steam
  - Gas
- Turbines like “inverse” pumps, some machines can do both!
- Turbines more efficient than pumps, typically:
  - Larger (less viscous effects)
  - Less separation (pressure drops)
  - Lower speed (lower friction)
  - Narrower operating range (more specific design)

Turbine Types

- Positive Displacement
  - Typically only flow measurement
- Dynamic
  - Flow measurement and power
  - Nomenclature
    - Pumps → impellers
    - Turbines → runners
  - 2 subtypes
    - Impulse
    - Reaction

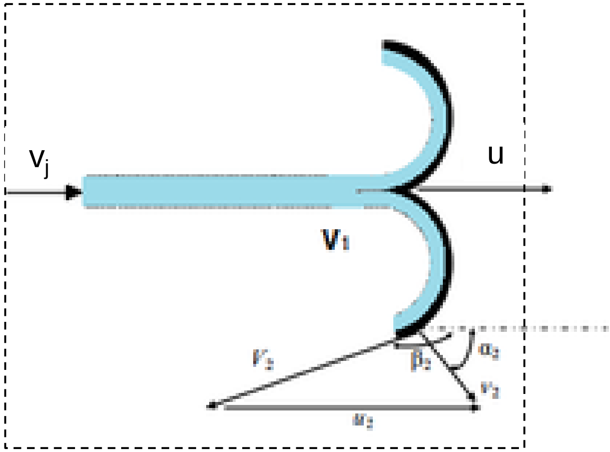
Impulse (Pelton Wheel)



- High head, low flow
- Fluid through nozzle
- P → Ke → bucket move
- Flow is split and redirected
  - Think of the momentum balance examples
  - Water redirected, change in momentum
  - Creates force, pushes bucket
  - $\vec{F} = (\dot{m}v)_{out} - (\dot{m}v)_{in}$

Pelton Wheel Analysis

- $v_{in} = v_j - u$
- $v_{out} = v_{in} cos\beta_2$
- $v_{out} = (v_j - u\ )cos\beta_2$
- $\dot{m}_j = \rho A v_j \rightarrow A = \frac{\dot{m}_j}{\rho v_j}$
- $\dot{m}_{rel} = \rho A v_{rel} = \rho A(v_j - u\ )$
- $\dot{m}_{rel} = \dot{m}_j \left(1 - \frac{u}{v_j}\ \right)$



Optimization of Buckets

- $-F = (\dot{m}v)_{out} - (\dot{m}v)_{in}$
- $-F = \dot{m}_j \left(1 - \frac{u}{v_j}\right)(v_j - u)(cos\beta_2 - 1)$
- $F = \dot{m}_j \left(1 - \frac{u}{v_j}\right)(v_j - u)(1 - cos\beta_2)$
- $\dot{W} = Fu = \dot{m}_j u \left(1 - \frac{u}{v_j}\right)(v_j - u)(1 - cos\beta_2)$
- Optimized → $\frac{d\dot{W}}{d\beta_2} = 0$ → $sin\beta_2$→$\beta_2 = 0\ or\ 180$
- Optimal u = $\frac{d\dot{W}}{du} = \frac{v_j}{3}$

Reaction Turbines

- Similar to pumps, can be:
  - Radial (centrifugal)
  - Axial
  - Mixed Flow
- 2 Types:
  - Francis
  - Kaplan

Francis Turbine

- Radial flow
- Mixed flow
- Medium head
- Medium flow
- Standard turbine in steam power industry

Kaplan Turbine

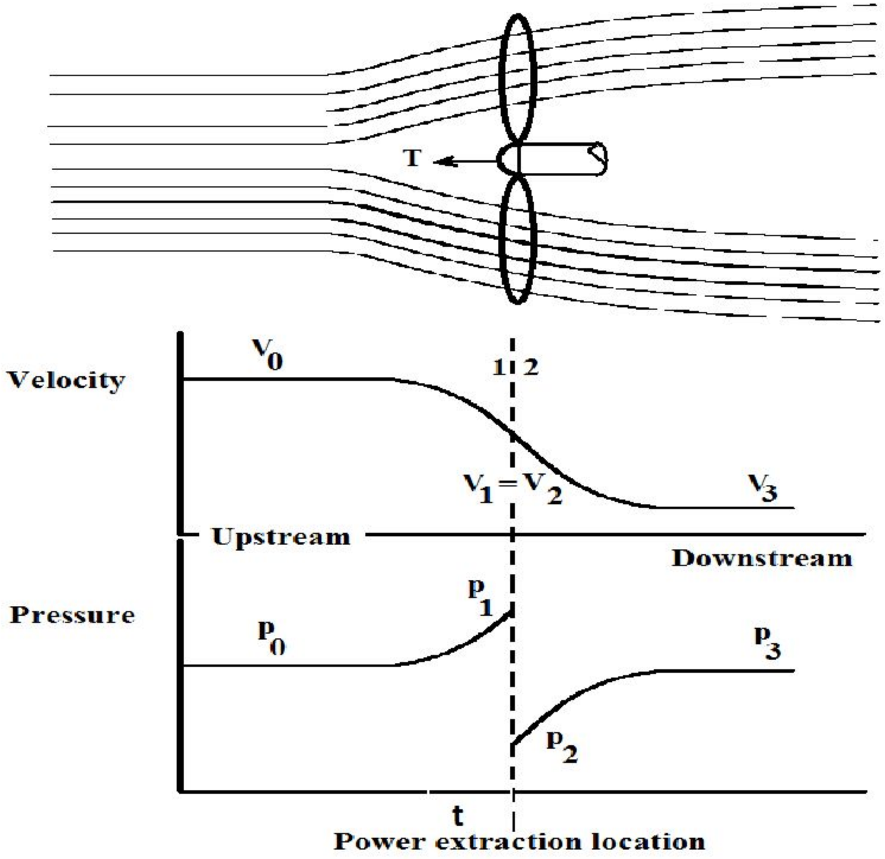
- Axial flow
- Propeller w/ variable pitch
- Low head
- High flow

Wind Turbines

- $\dot{W}_{avail} = KE\ x\ flow$
    - $= \frac{1}{2} v^2\ \dot{m} = \frac{1}{2} \rho v^3 A$
  - Power $\propto A$

    $\propto v^3$

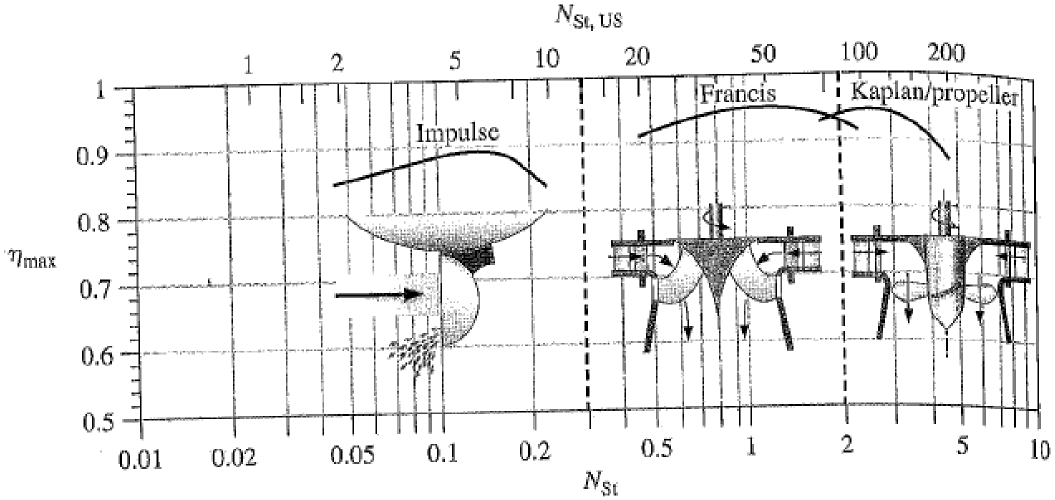
- $\eta = C_p = \frac{\dot{W}}{\frac{1}{2}\rho v^3 A}$
- $C_{p,max} = 0.5926$
- In practice = 45%!!



Scaling Laws

- Like Pumps:
  - C_H, C_Q, C_P, η
  - Use C_P as independent variable, not C_Q
- $C_H(C_P)$
- $C_Q(C_P)$
- $\eta(C_P)$
- $N_{ST} = \dfrac{\omega(bhp)^{1/2}}{\rho^{1/2}(gH)^{5/4}}$

Example



$N_{St, US}$
1
2
5
10
20
50
100
200
Impulse
Francis
Kaplan/propeller
η_{max}
1
0.9
0.8
0.7
0.6
0.5
0.01
0.02
0.05
0.1
0.2
0.5
1
2
5
10
N_{St}