CAES

Compressed Air Energy Storage

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Overview

- Project Overview
- Project Scope Re-statement
- Risk Assessment
- Spring Schedule
- Conclusion

Project Overview

- What is CAES?
  - Compressed Air Energy Storage
- How can we store Wind Energy
  - Compress Air
- Storage
  - Man made pressure vessel for small scale
- Power Generation
  - Air Motor

Limitations Encountered

- Compressors as sold have an input Power limited to ±5% of electric power range
  - Otherwise operation is extremely inefficient and damaging to compressor
- Too wide of input Power Range
  - Wind doesn’t blow at constant velocity
  - Mechanically drive air compressor
- Pressure Vessel
  - Maximum operating pressure
  - Size

Project Scope

- Theoretical Analysis
  - Efficiency, Energy Balance
- Wind Data Analysis
  - Data provided by sponsors
- Recommend Parts based on Analysis
  - Parts too costly
  - Recommend parts for most efficient CAES system

Spring Semester

- Derive governing differential equations
  - Variable power input
  - Variable input with simultaneous power extraction
- Obtain numerical data
  - Compressor power curves for variable power input
  - Experimental wind data
  - Solve ODEs with numerical data
- Efficiency calculations
- Final recommendations
- Testing if possible

Obvious Risks

- Wind
- Variable Compression
  - Outlet Pressure
  - Volumetric Flow rate
    - Effects vessel fill time and efficiency
- Pressure Vessel
  - Controls for input/output
  - Air at high pressure
- Equipment
  - Size of project and equipment
  - We are not qualified to operate and maintain this equipment

Risk Management

- Wind
  - Outside of our control
  - Inherent with wind turbines and systems built with wind reliance
- Pressure Vessel Controls
  - Will require outside power source
- Air Motors
- Not purchasing equipment
  - Too large and maintenance intensive for our purpose
  - Making recommendations to sponsor instead

Governing Equation

Continuity Equation

$$0 = \left.\frac{\partial m}{\partial t}\right|_{CV} + \iint_{CS} \rho V_n dA$$

Ideal Gas Assumption

$$m = \frac{p\forall}{RT} \Rightarrow \left.\frac{\partial m}{\partial t}\right|_{CV} = \frac{\forall}{RT}\frac{dp}{dt}$$

Mass through the control surface

$$\iint_{CS} \rho V_n dA = \iint_{out} \rho V_n dA - \iint_{in} \rho V_n dA$$

Governing Equation Cont.

Case I. Assume Air motor not operating

$$\frac{\forall}{RT}\frac{dp}{dt}=\iint_{in}\frac{p}{RT}V_n\,dA$$

V – tank volume
p – pressure
V_n – flow rate

Solve for Pressure differential

$$\frac{dp}{dt}=\frac{1}{\forall}p_{in}(t)\dot{\forall}(t)$$

Governing Equation Cont.

Case II. Assume Air motor operating at constant speed

$$\iint_{CS} \rho V_n dA = \iint_{out} \rho V_n dA - \iint_{in} \rho V_n dA$$

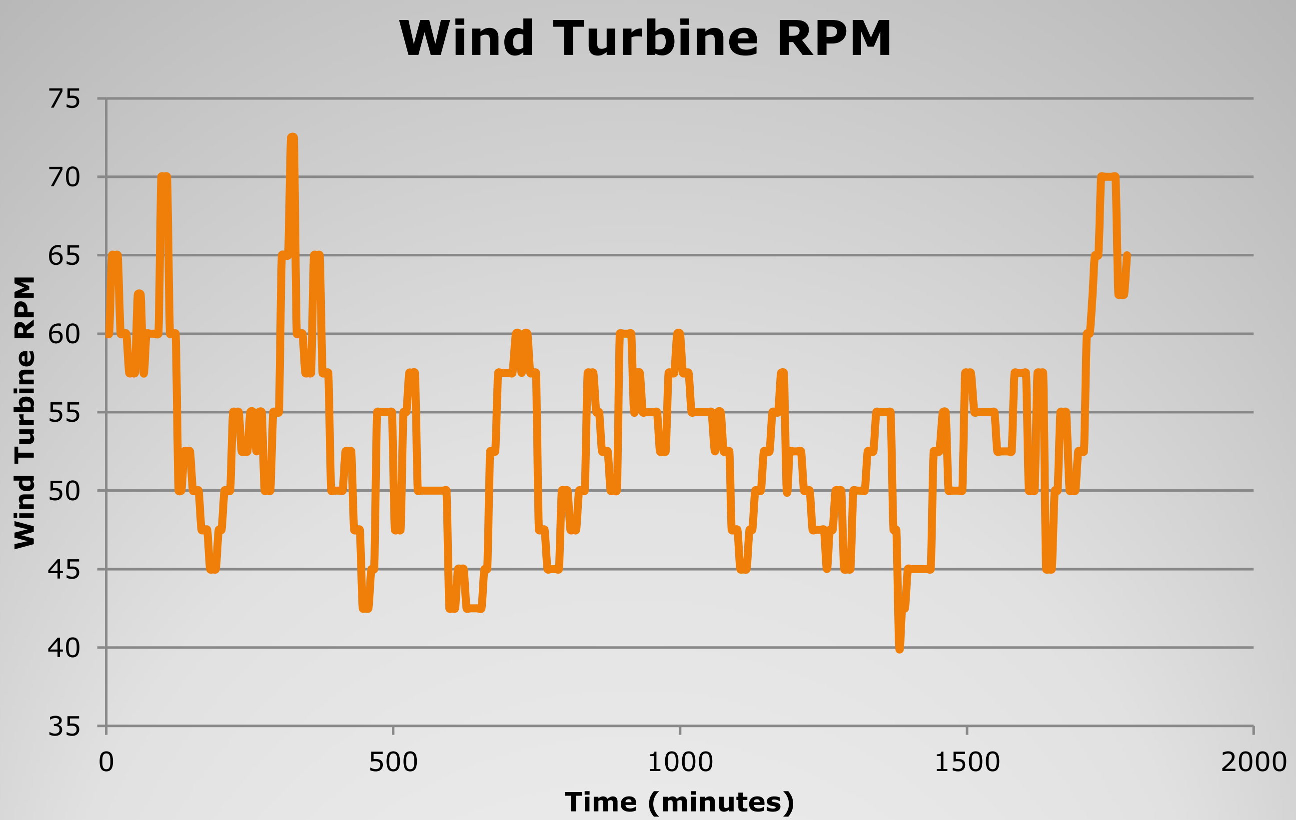
Solve for Pressure differential

$$\frac{dp}{dt} = \frac{1}{\forall}\left[p_{in}(t)\dot{\forall}(t) - p_{out}\dot{\forall}_{out} \right]$$

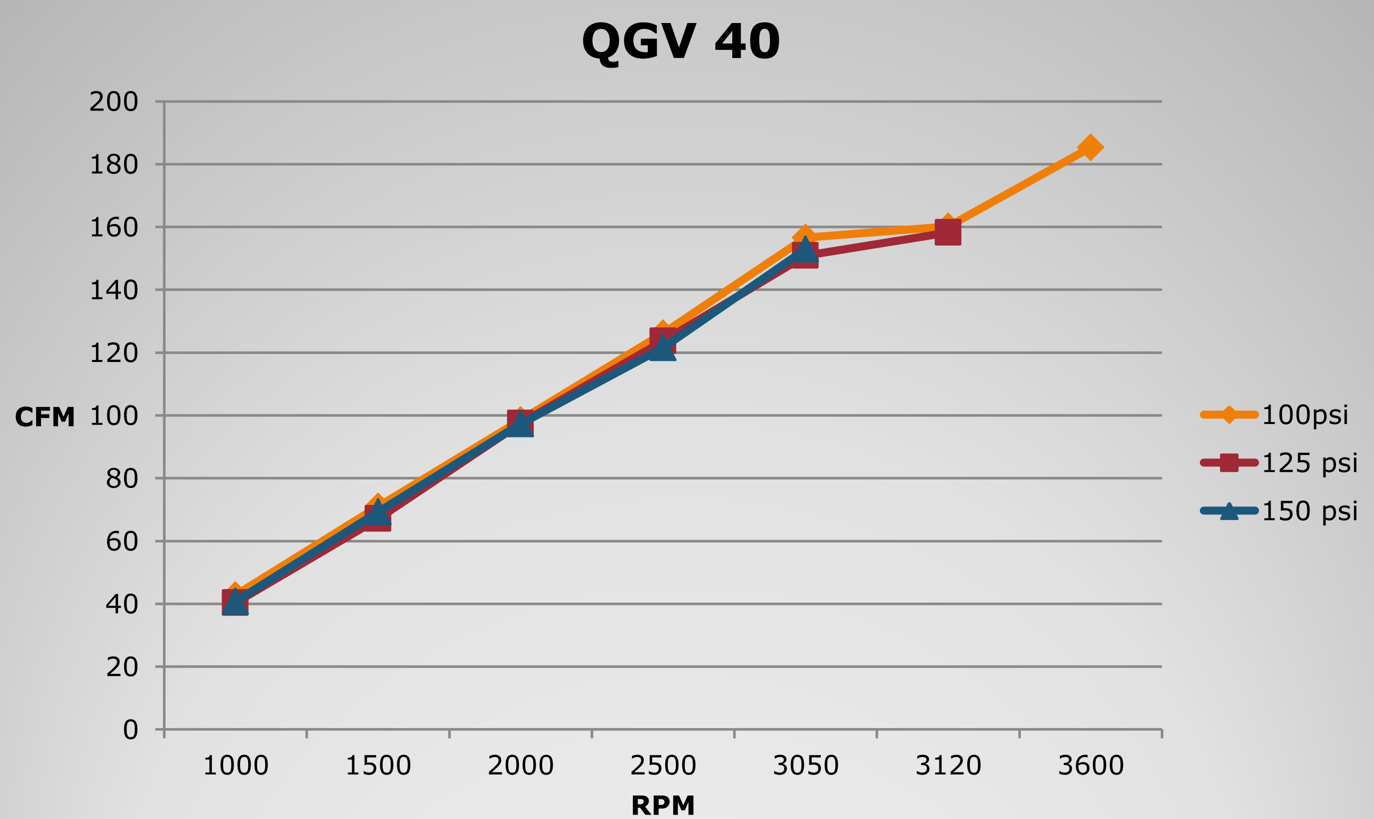
Solving Differential Equations

- Experimental data for wind speed over time
  - Power/rpm output of turbine
- Compressor data
  - Compressor power curves for variable power input
  - Flow rate for variable rpm
  - Constant pressure output
- Air Motor data
  - Constant operating pressure and flow rate
- Numerical integration

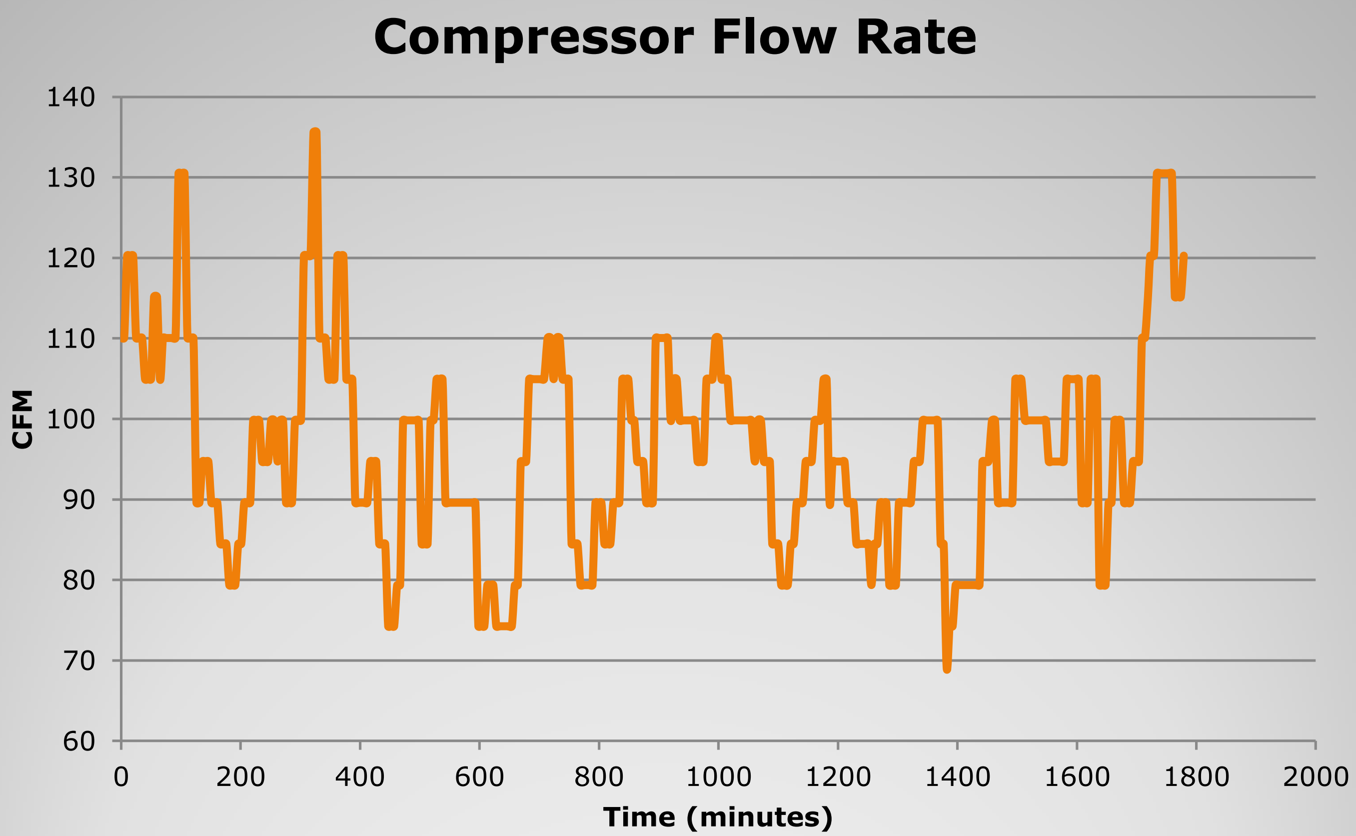
Wind Data

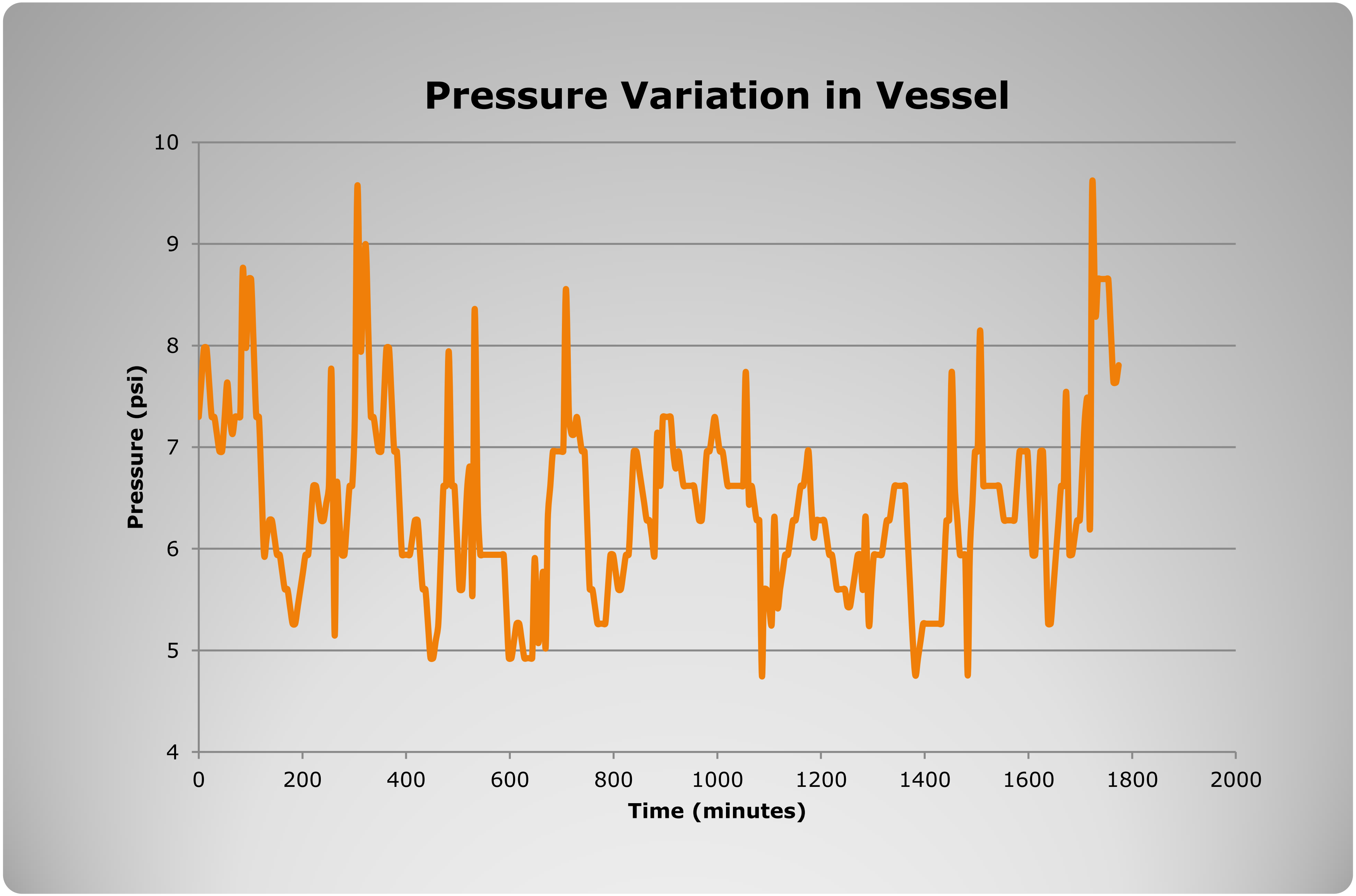

Wind Turbine RPM
75
70
65
60
55
50
45
40
35
Wind Turbine RPM
0
500
1000
1500
2000
Time (minutes)

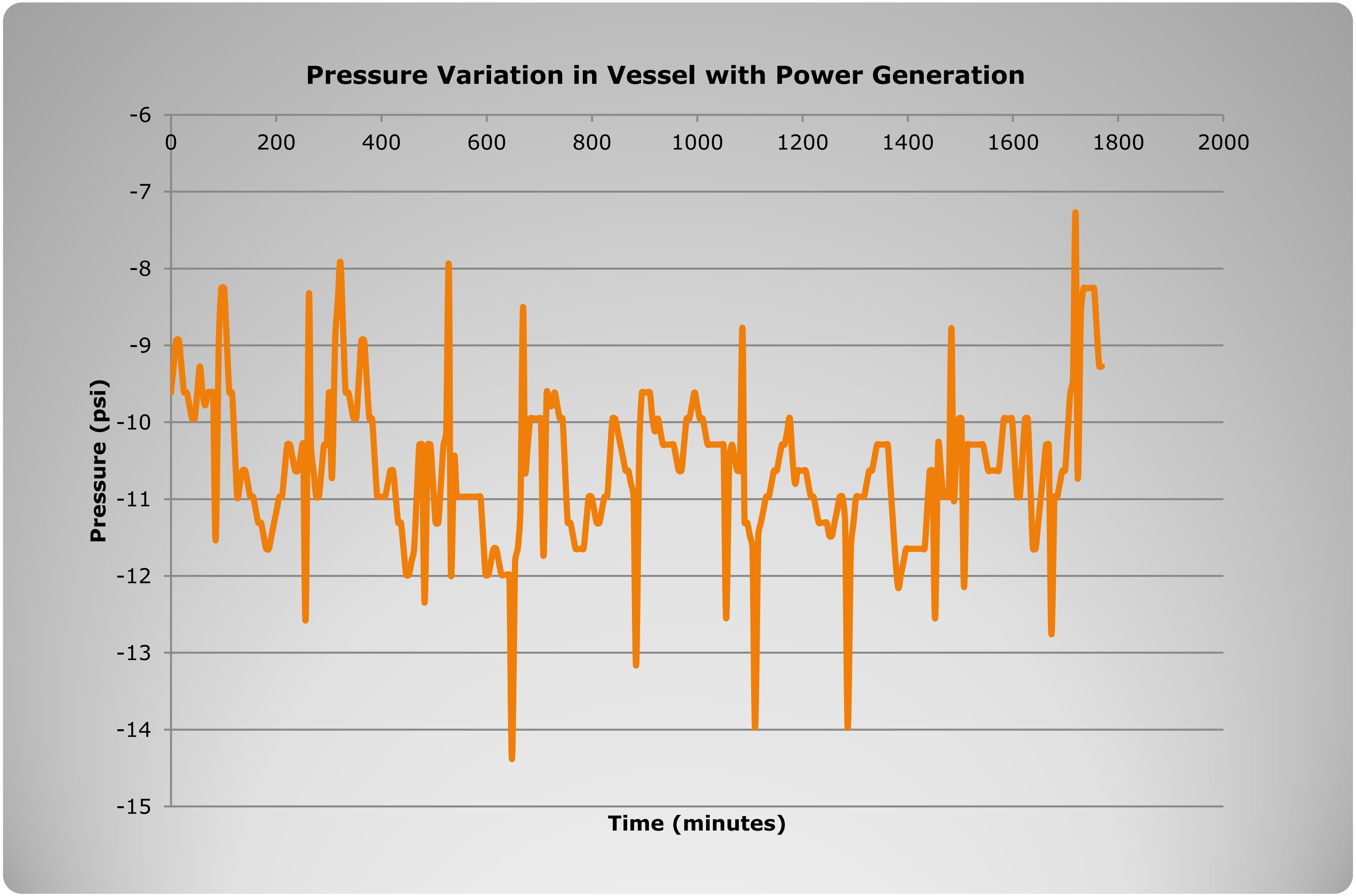
Compressor Data



Actual Compressor Flow Rate




Pressure Variation in Vessel
Pressure (psi)
10
9
8
7
6
5
4
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Time (minutes)


Pressure Variation in Vessel with Power Generation
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Pressure (psi)
Time (minutes)

What's Next?

- Finish calculations and analysis
- Automate calculations for new data
- Final recommendations
- Testing if possible

Sponsors

- Dr. Srinivas Kosaraju
- Dr. Rob Hovsapian
- Keuka Wind

Questions?