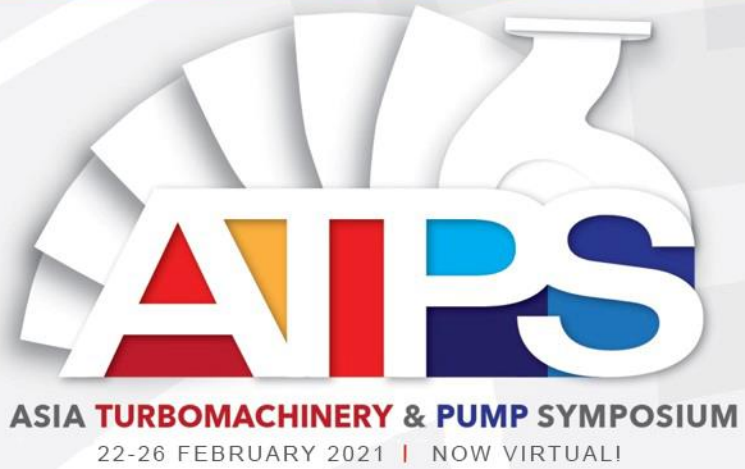

A Practical Data-driven Analysis Case Studies for Gas Turbine Operators:

Finding Gas Turbine Operating Limits and Benchmarking

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Abstract.

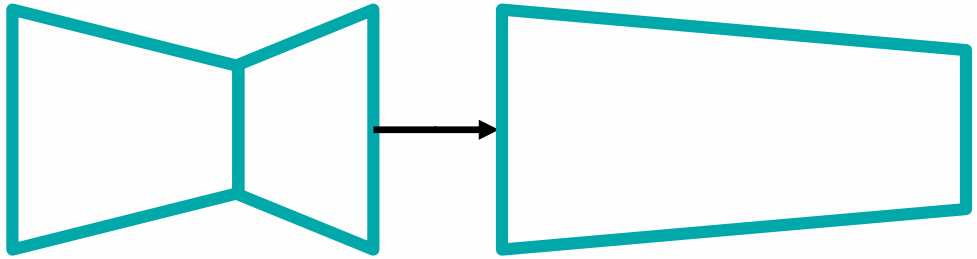
There is abundance of machinery performance data available nowadays due to recent development of sensors and computational power.

Usually those data left to complex/ advance tools (special software) and technique (AI, Machine Learning) for analysis.

However, operator also should be able to **practical**ly manipulate and analyze those data to come-out with useful information to help decision process.

This presentation elaborate how to perform data driven analysis on available data with existing tool and knowledge.

Introduction: A centrifugal compressor driven by gas turbine has a 390 mmscfd throughput to evacuate gas from offshore to onshore facility



Gas Turbine Centrifugal compressor

Problem Statement

Case 1 (Findings Limit)

- What is the maximum centrifugal compressor throughput based on current gas turbine and compressor condition if business require more production?

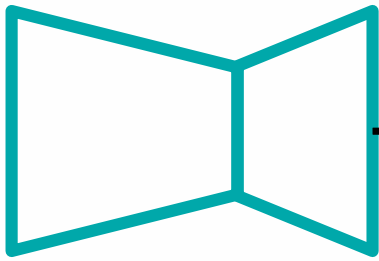
Case2 (Benchmark)

- How well operator performed crank wash to gas turbine?
- How well the GT performance after reach 24,000 RH compared to other GTs

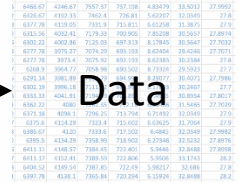
Approach

Data-driven method, leveraging available data and tools to provide analysis instead of conventional thermo model-based method.

Background: More data available, makes data-driven analysis more accurate compare to model-based approach. And it becomes more practical.



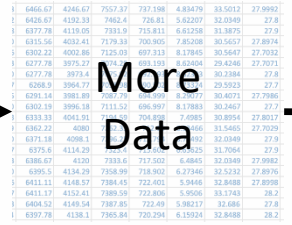
Gas Turbine



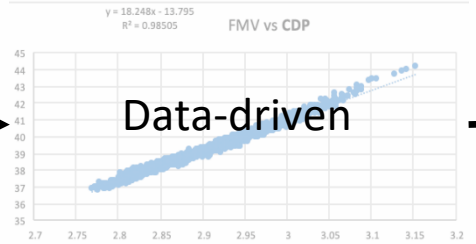
Data

Thermo-model

- Model-based ie. OEM curves
- Thermodynamic based, lot of constant.
- Sensitive to operational change



More Data



Data-driven

- Correlation between parameter
- Predict parameter from learned data
- Less sensitive to operational change

Practical

Data

- From engine sensors.
- Stored in historian server.
- Downloadable in various format.

Knowledge

- Fundamental mathematics.
- Basic spreadsheet 'function' knowledge.

Tools

- Spreadsheet software available to everybody
- Decent computers.

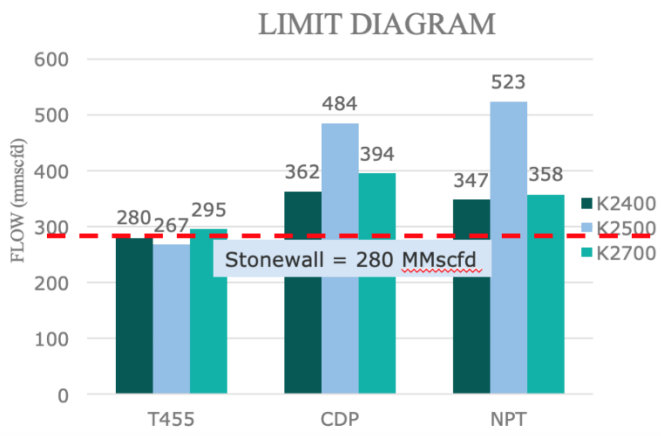
Data-driven analysis gives gas turbine operator opportunity to accurately find current operating limit and perform benchmarking.

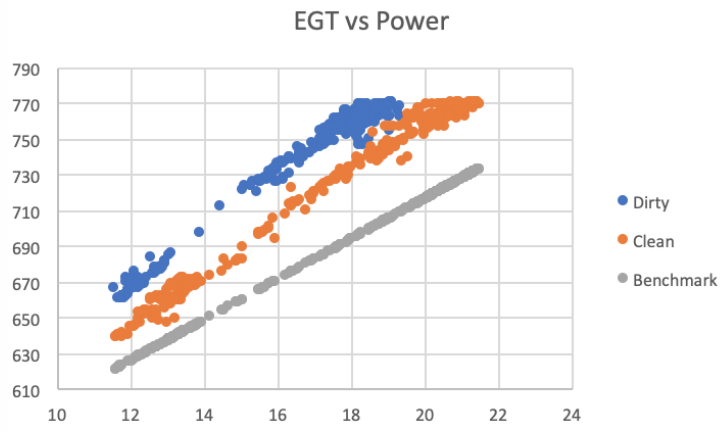
Finding Limits

- Predict max throughput based on current engine performance.
- Important for production planning.

Benchmarking

- New engine performance benchmark.
- To compare against with other engines or performance monitoring.





Open

Data-driven Analysis

Data preparation : not all the data is useful, outliers shall be removed from analysis.

Data Collection

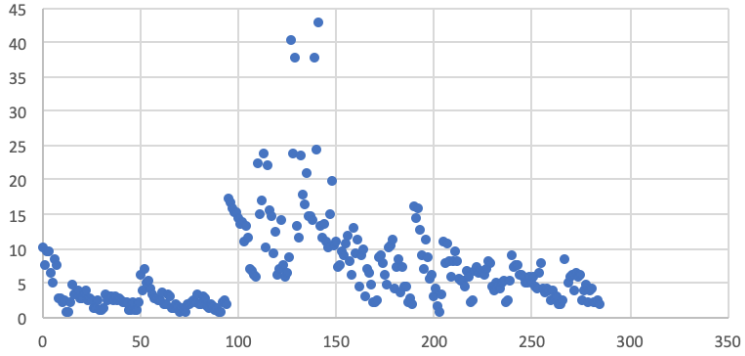
- Data download from engine performance monitoring systems.
- Converted to spreadsheet raw data.
- Not all data is useful as it contains outliers.

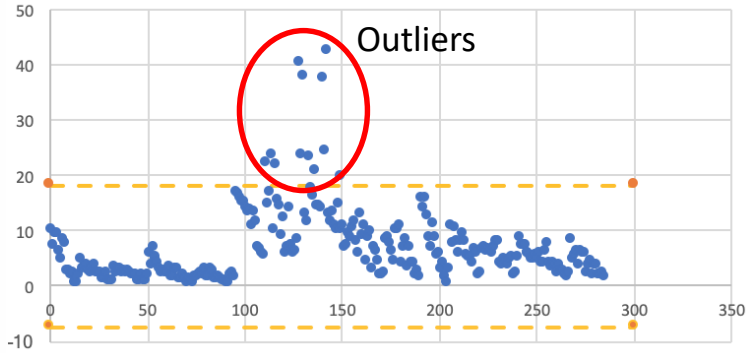
Remove Outliers

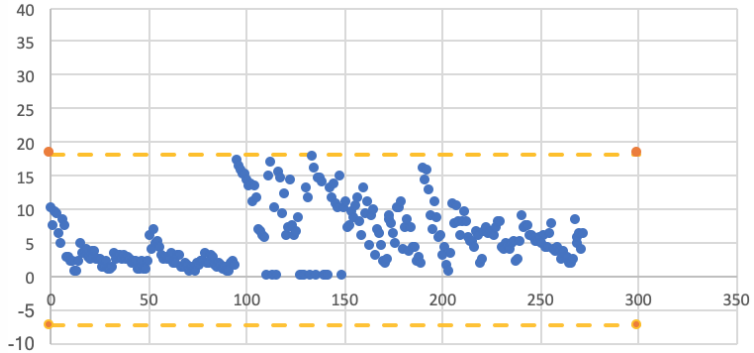
- Upper bound and lower bound is setup using *Quartile Function.*
- Anything beyond this bound will be consider outliers, means contain insignificant info for analysis.

Prepared Data

- Remaining data is useful to produce accurate analysis based on current state of engine.

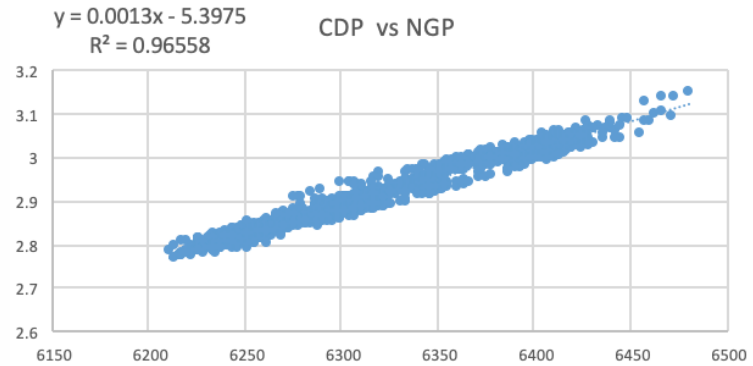


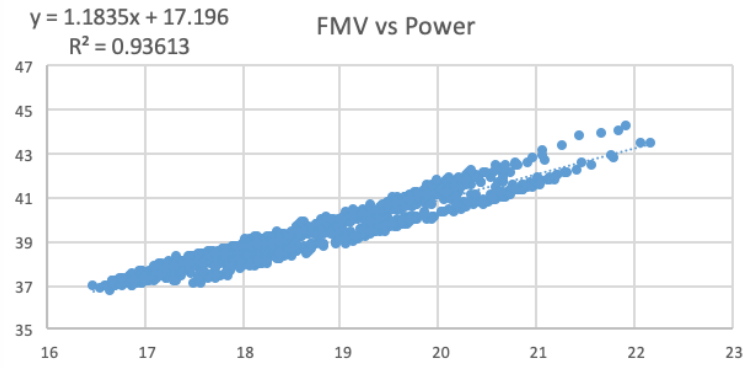


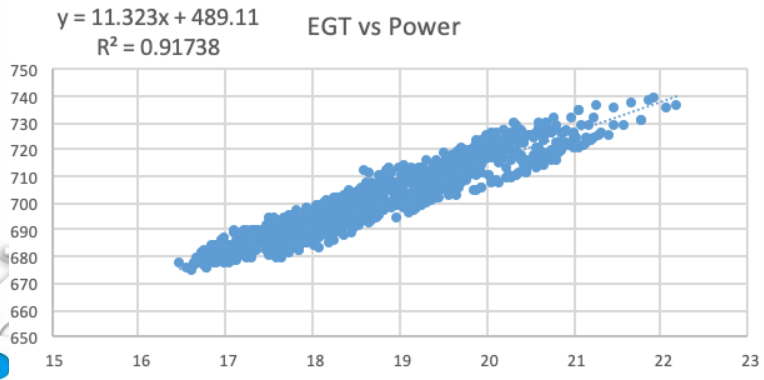


Open

Correlations: Data collected and investigate the correlations to find 'how close' (r^2) data correlate to each other.







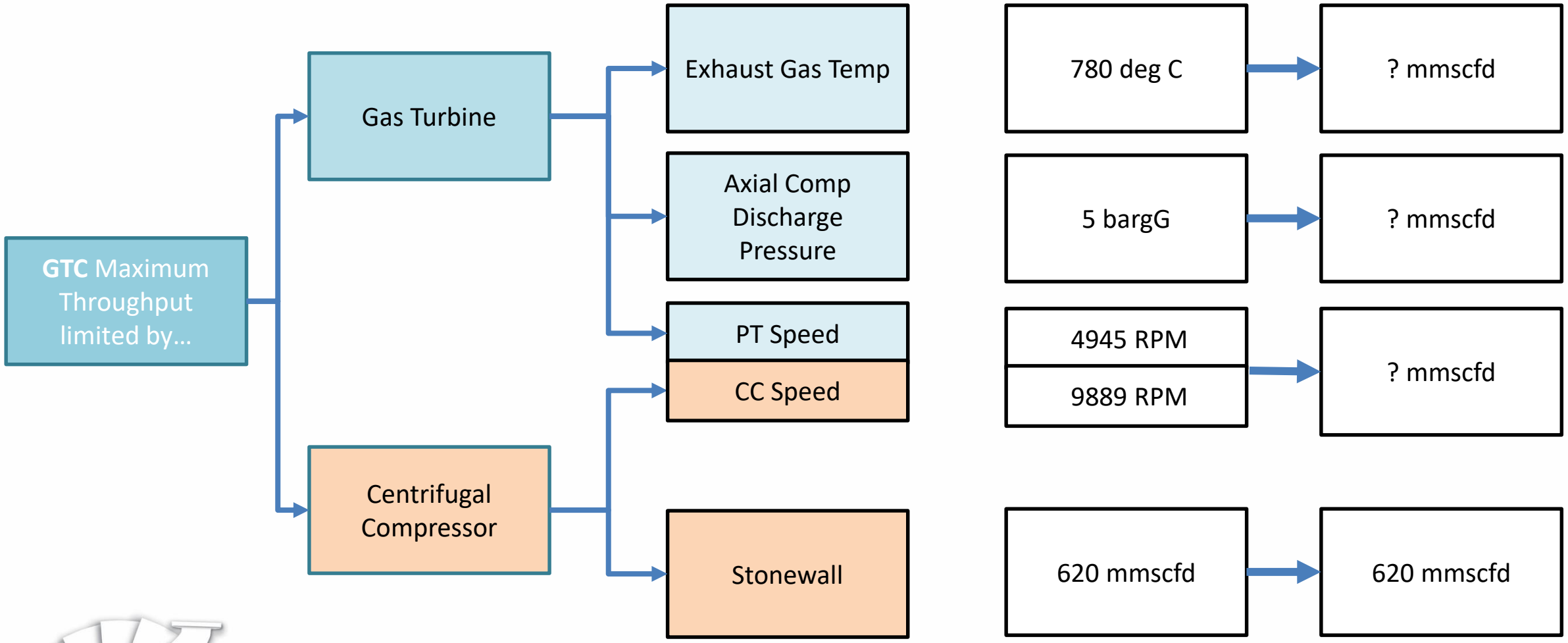
R-square				
FMV	0.9862			
EGT	0.9545	0.9755		
NGP	0.9656	0.9805	0.9949	
PWR	0.9399	0.9361	0.9174	0.9204
	CDP	**FMV**	**EGT**	**NGP**

- Since all the parameters is linearly related, hence equation *y=mx+c* is used.
- *Coefficient of determination* or r^2 more than 0.85 is good enough for benchmarking.
- Parameter relationship shows all the r^2 is more than 0.85, hence this benchmarking model is accurate.
- Method
  - Graphical using '*add trendline*'.
  - Function using '*LINEST*' array function.
- Application
  - Benchmark similar engine at different berth
  - Benchmark current performance

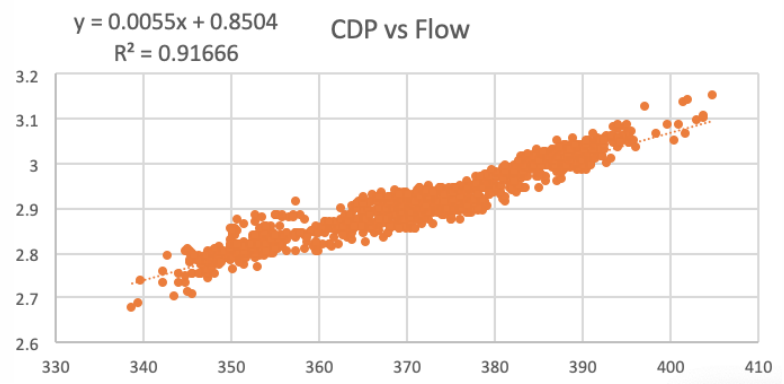
Open

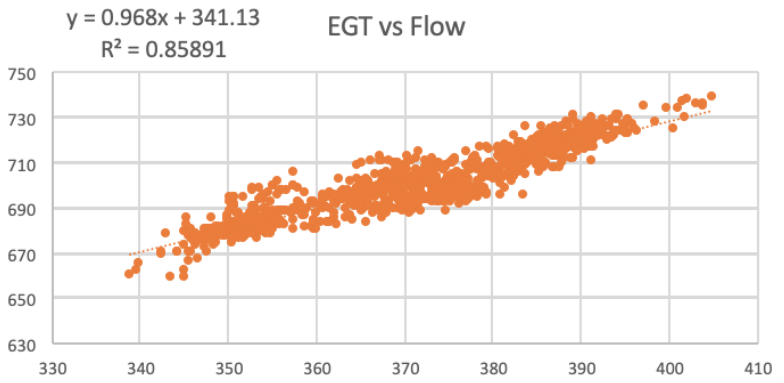
Findings Current Operating Limit

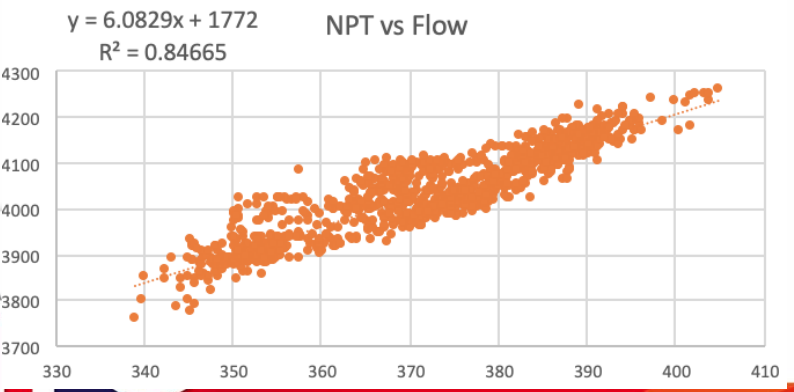
Case Study 1 : What is the current maximum compressor throughput? To use data-driven analysis analyze each GT limits correspond to compressor throughput.



Case Study: Relationship between GT limits and compressor throughput use to predict maximum compressor throughput. Help in making business decision.



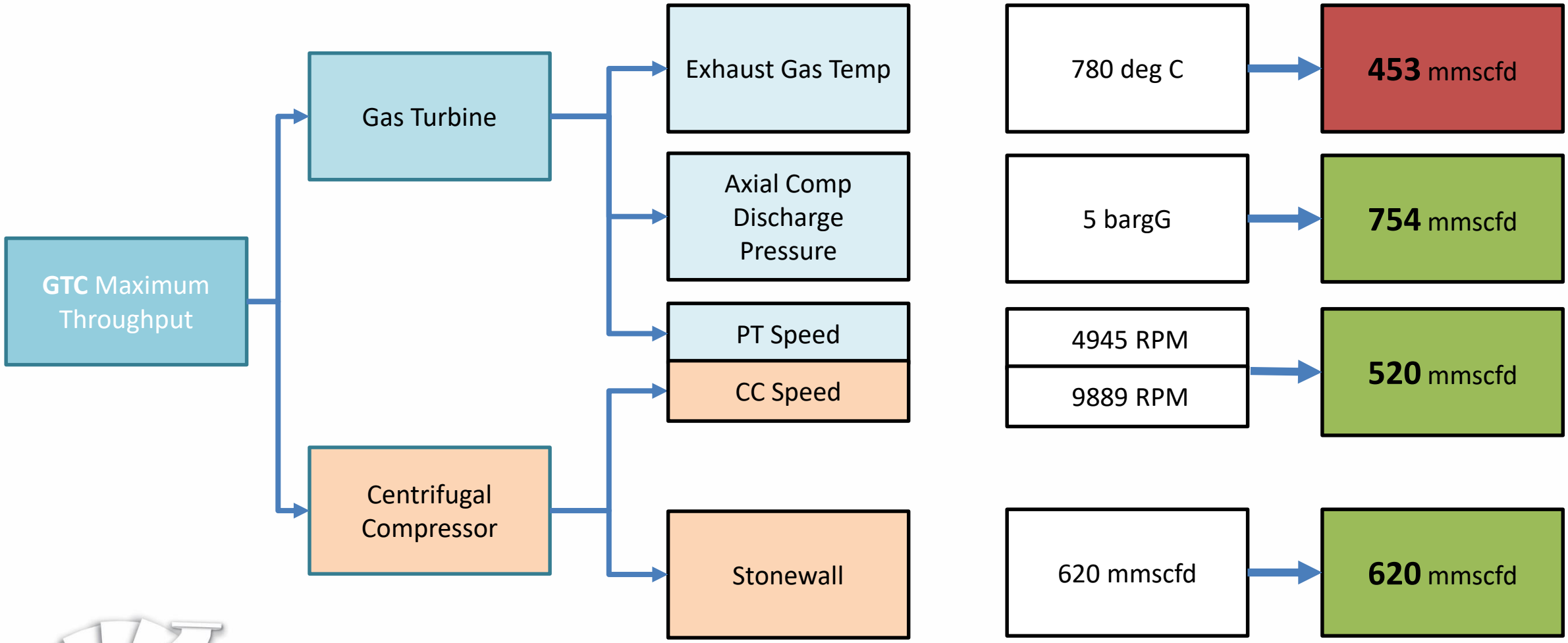




- **Questions : Current compressor throughput is 390mmscfd. With current operating condition, what is maximum potential compressor throughput if plant need to maximize the production?**

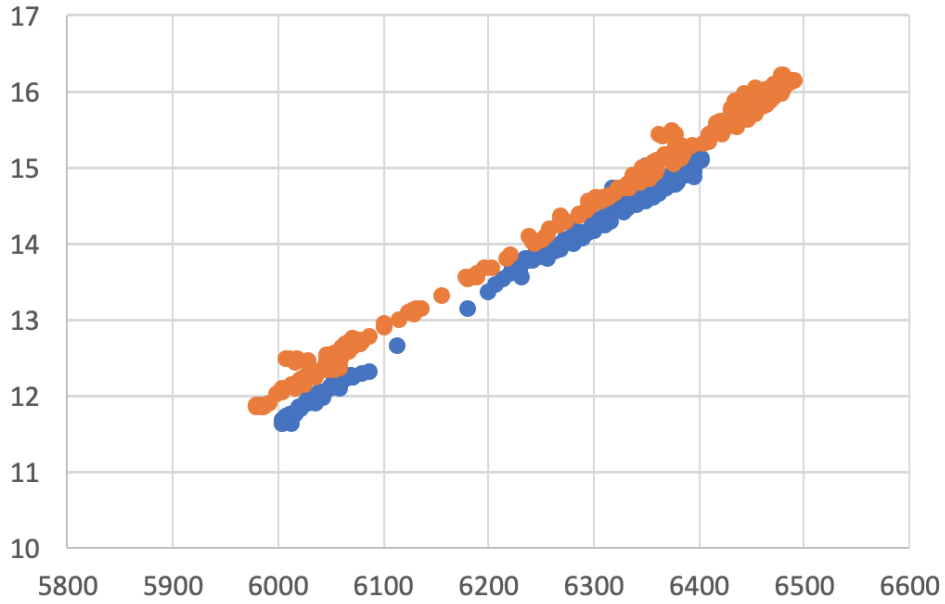
- Base on the actual data collected, performance model of flow limiter is established. In this case;
  - CDP vs centrifugal compressor flow
  - EGT vs centrifugal compressor flow
  - N1 vs centrifugal compressor flow
  - NPT vs centrifugal compressor flow
- The the relationship is linear, *y=mx+c* model can be used.
- Based on each parameter limit (CDP, EGT, N1 and NPT), the corresponding flow is predict.
- The least predicted flow is consider as the maximum limit of the GT and compressor.

The analysis shows compressor can increases production from 390 mmscfd to 453 mmscfd. This kind of information is very useful for business decision.



Performance Benchmarking

A solid way to compare one GT performance to another GT (or itself).

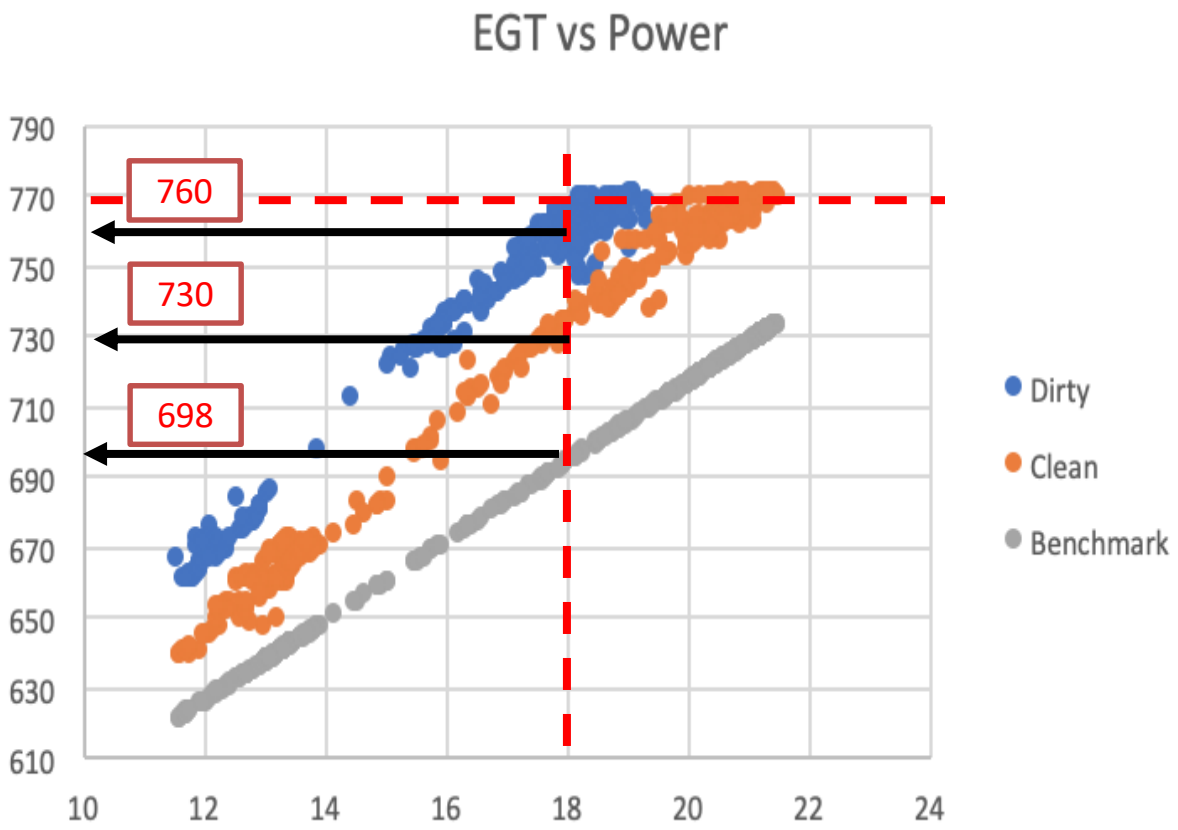


- New vs New
- Clean vs Dirty
- Operating vs New
- Here vs There

Benefit: Benchmarking can be used to compare many conditions to each other.

New vs New	Operating vs New	Clean vs Dirty	Here vs There
• How better new GT compared to previous GT • Deviation also may indicate system performance degradations i.e suction loss increase, exhaust loss increase.	• How bad the current operating compared to new condition. • Indication how much the engine degraded. • Identify current limit of operation	• How well the crank wash is done. • Indication how well the offline crank wash is done.	• How well the GT here compare to somewhere else. • Identify gap in operating & maintenance practice.

Case Study 2: A gas turbine at 24,000 running hours. Benchmark how well the crank wash is done, and how much current deviate from new gas turbine.



- Benchmarking Crank Wash (Clean vs Dirty)
  - EGT at Dirty Condition : 760^{o}C
  - EGT at Clean Condition : 730^{0}C
  - Improvement : 30 deg^{0}C (4% reduces)
  - Historical average : 3.5%
  - **Conclusion-** The crank wash is done is effective to recover performance like historical average.
- Benchmarking GT performance at 24,000 RH (Operating vs New)
  - EGT at Clean Condition : 730^{0}C
  - EGT at New Condition : 698^{0}C
  - Deviation : 32^{0}C (5% increase)
  - Historical average : 4% increase
  - **Conclusion-** at 24,000 RH current performance is worse compare to historical average. Need to investigate the cause i.e air filtration issue, crank wash frequency

Conclusions

- In the new era of data, more accurate analysis on machinery performance can be done.
- With existing data, knowledge and tools, a practical analysis can done to help engineers do **practical** data-driven analysis. Without require more advance tools and knowledge.
- Among area of application is findings the current limit of operation that help operators predict their current machine performance.
- Practical data driven analysis also can help to accurately benchmark gas turbines with other gas turbines or itself during various condition.

Thank You