Turbine Output Upgrade Methods and Concerns

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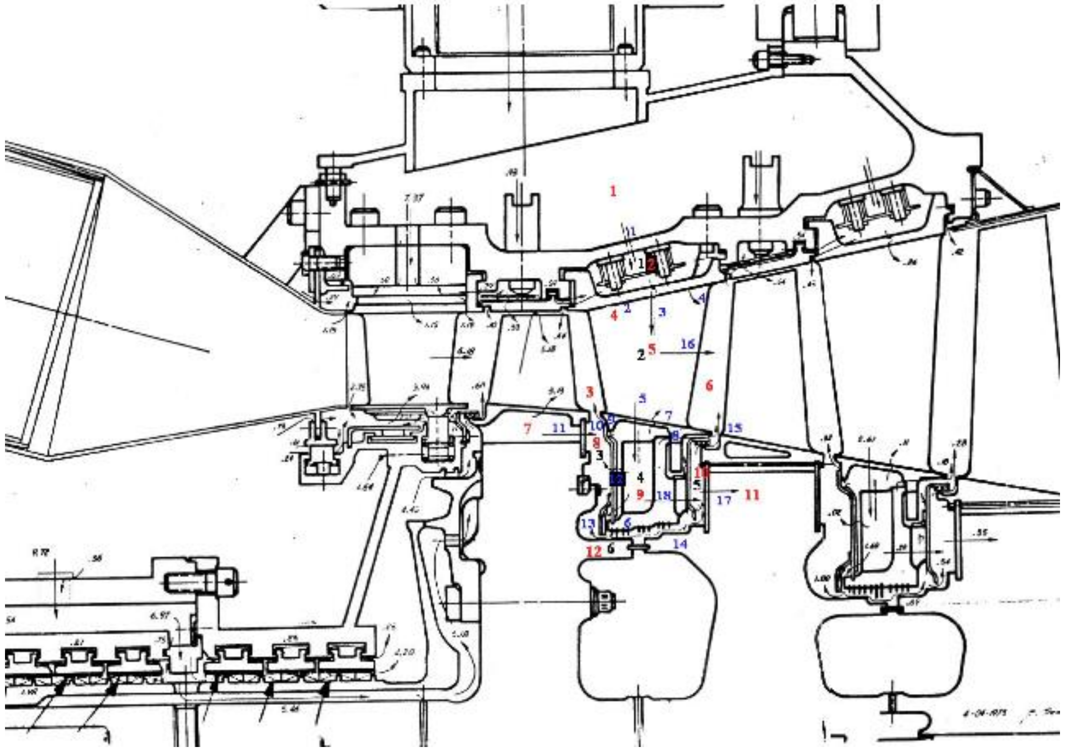
Frame Upgrades vs New Frames

Early combustion turbines were uncooled, limited in their choices of materials, and their compressors were designed with early NACA style airfoils.

As the technology progressed, there were many new innovations in all of these technologies.
Although some of these technologies could be applied backwards to current and older turbine frames, they often required substantial changes to the basic design of the turbine that required large redesigns and new turbine frames.

- Changes in compressor and turbine airfoil designs resulted in all new flow path shapes.

- The introduction of cooling required the introduction of internal cooling networks capable of supplying the cooling air



For operators, the main focus is on upgrades that can be applied to current frames. This is the primary focus of this presentation

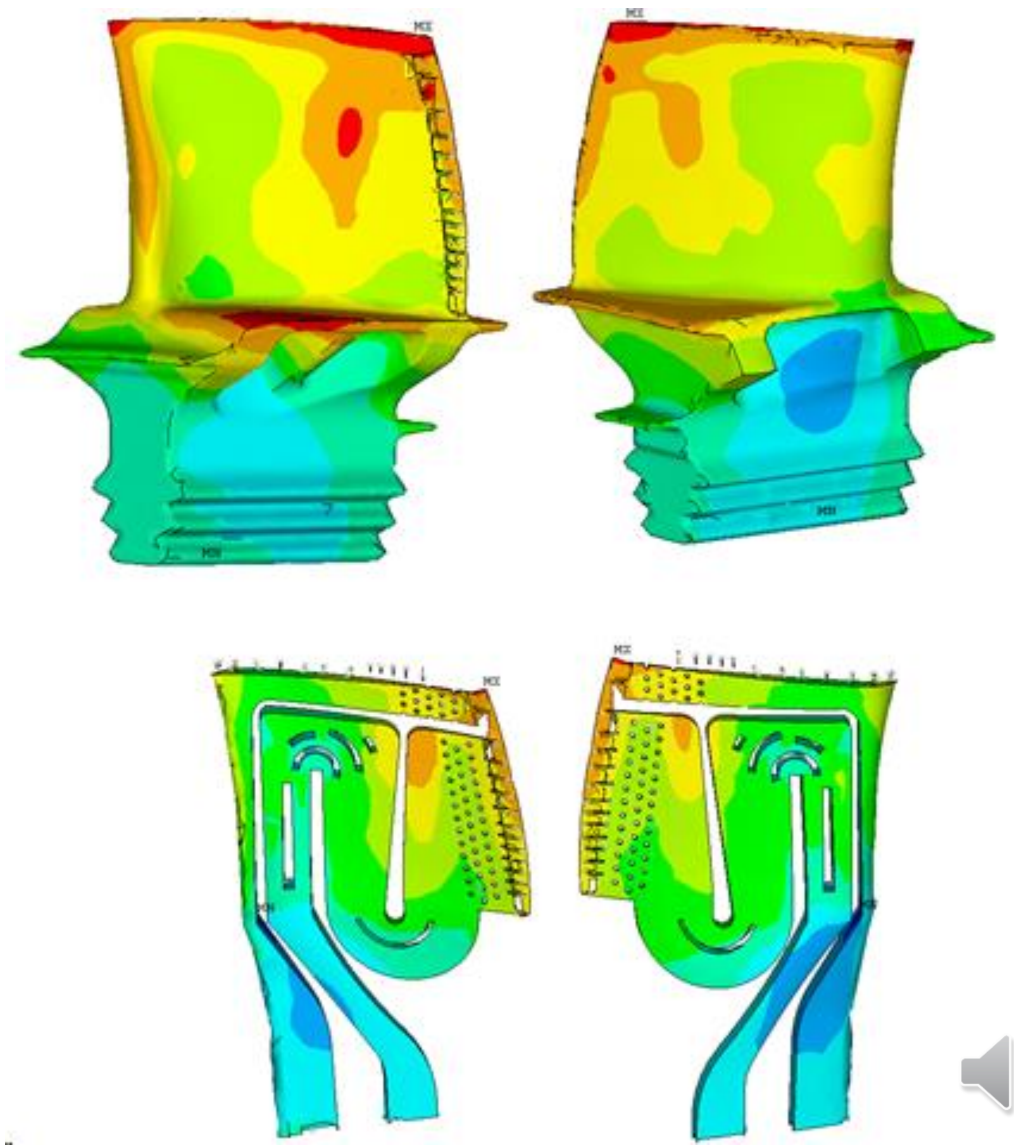
Frame Upgrades vs New Frames

There are several types of upgrades that can be applied to existing frames by applying newer technology

1. The introduction of Double Circular Arc (DCA) and Controlled Diffusion Airfoils (CDA) can produce increased compressor efficiencies.
2. The introduction of improved cooling and advanced airfoil shapes into critical turbine components allows for increases in firing temperature and turbine efficiency
3. The introduction of newer material alloys can allow for increased firing temperatures or improved life cycles
4. The introduction of TBC coating provides opportunities for further increases in firing temperatures

Key items to consider when looking at turbine outputs

- Increased Power means increased revenues
- Improved Heat Rate / Efficiency means lower fuel costs and may result in increased dispatch opportunities
- Exhaust flows (mass flow and temperature) are critical for combined cycle operations



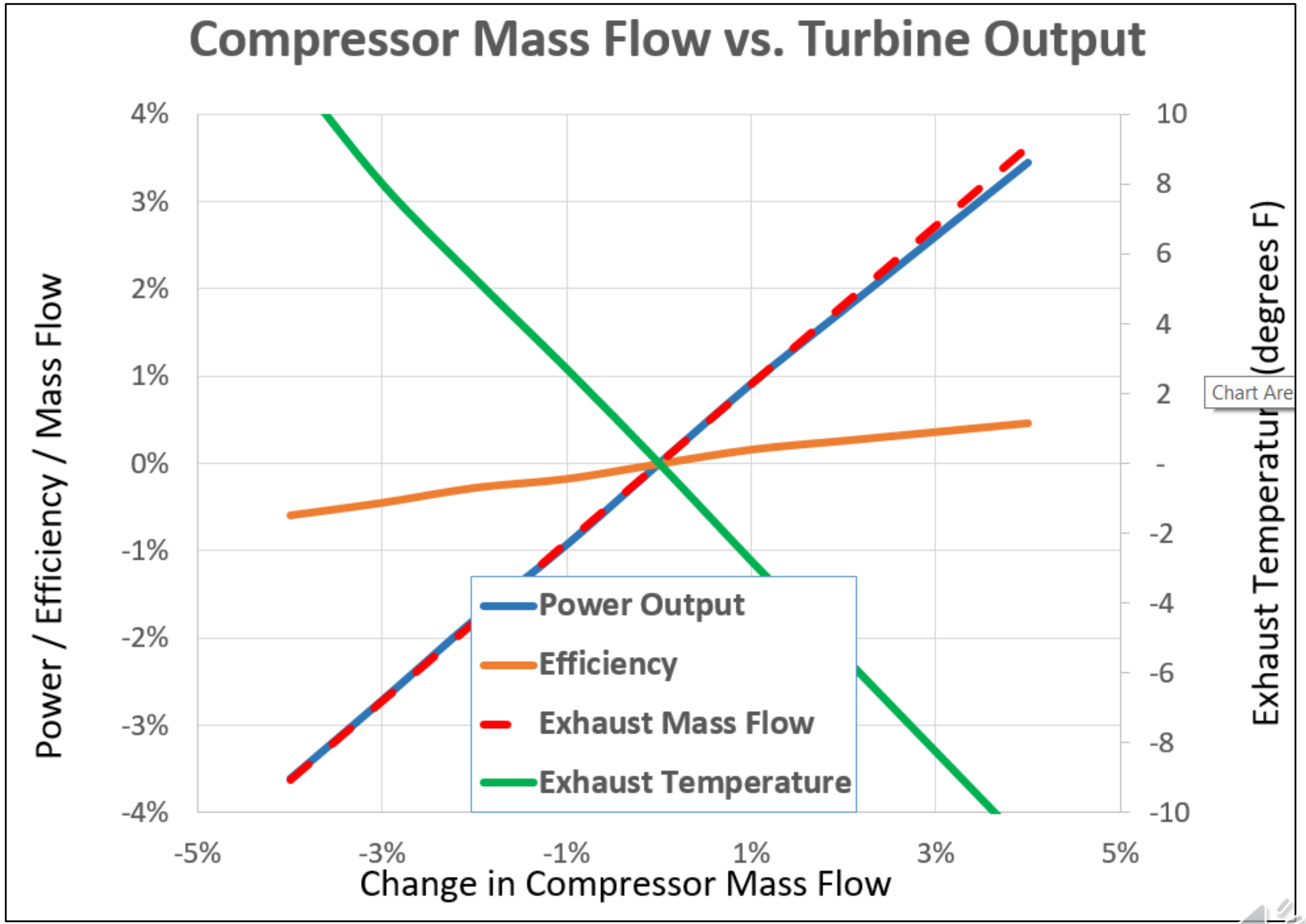
Performance Effects From Increased Compressor Mass Flow

Significant changes in compressor mass flow usually require substantial changes to the engine frame. However, increases in compressor mass flows of ~5% have been achieved by modifications to the compressor inlet and upgrades to the design of the first few compressor stages.

Power and Exhaust Mass Flow are directly related to changes in the compressor mass flow

Exhaust temperatures decrease substantially with increased mass flow as a result of higher turbine pressure ratios.

Efficiency increases marginally. This increase is related to the increased pressure ratio and the decrease in exhaust temperature.

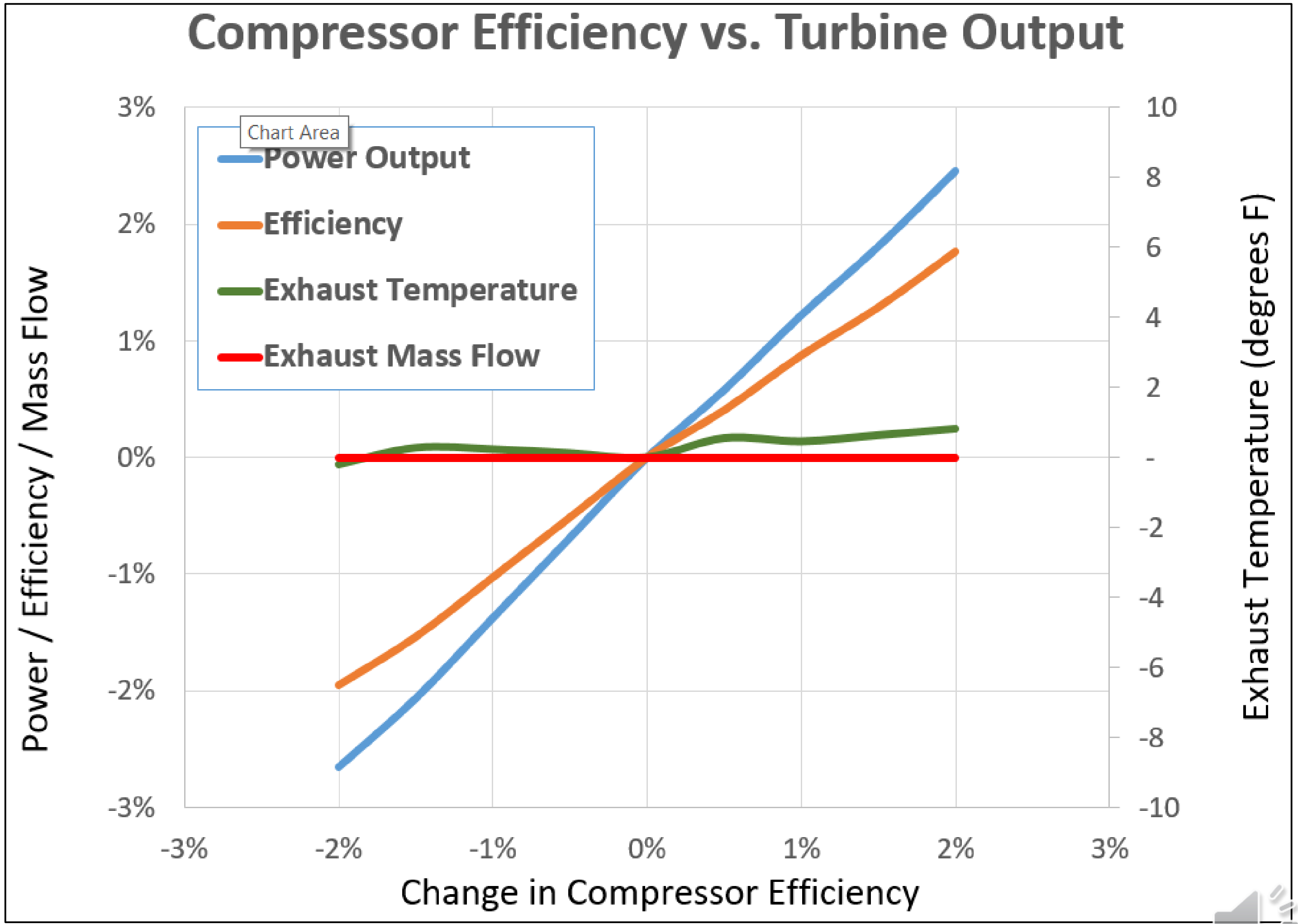


Performance Effects From Increased Compressor Efficiency

As with compressor mass flow, Compressor efficiencies may be improved with the use of more advanced airfoils in the early stages along with minor changes in the rest of the compressor.

Typically, the compressor can consume between 60% and 70% of the power produced in the turbine end. Therefore improvements in compressor efficiency can have a substantial impact on power and overall efficiency.

These changes have a minimal impact on both exhaust mass flow and exhaust temperature.



Performance Effects From Increased Compressor Efficiency

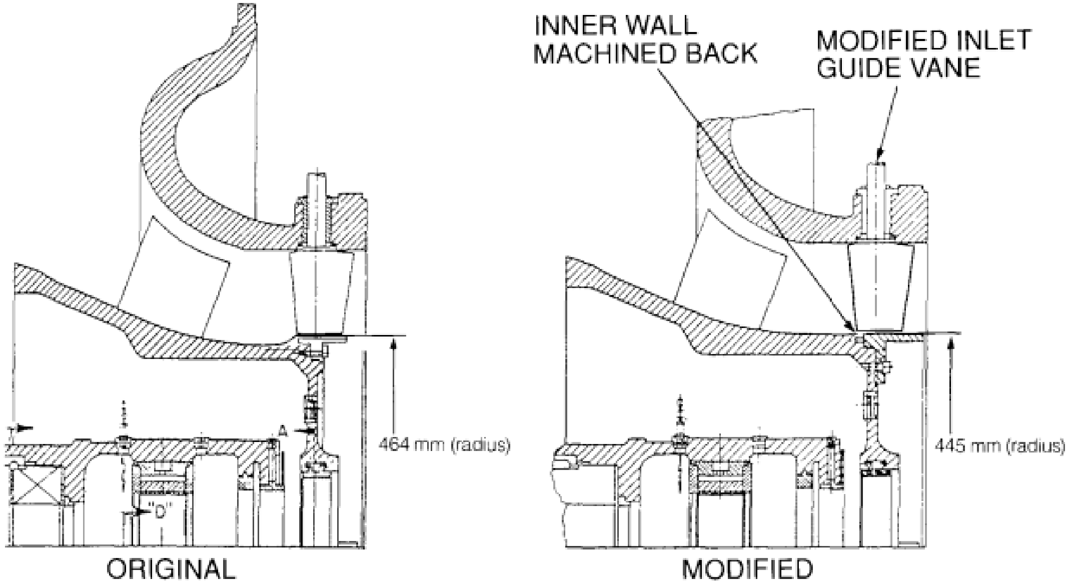
Substantial Changes in compressor performance can require significant investments in compressor blading and even cylinder modifications.

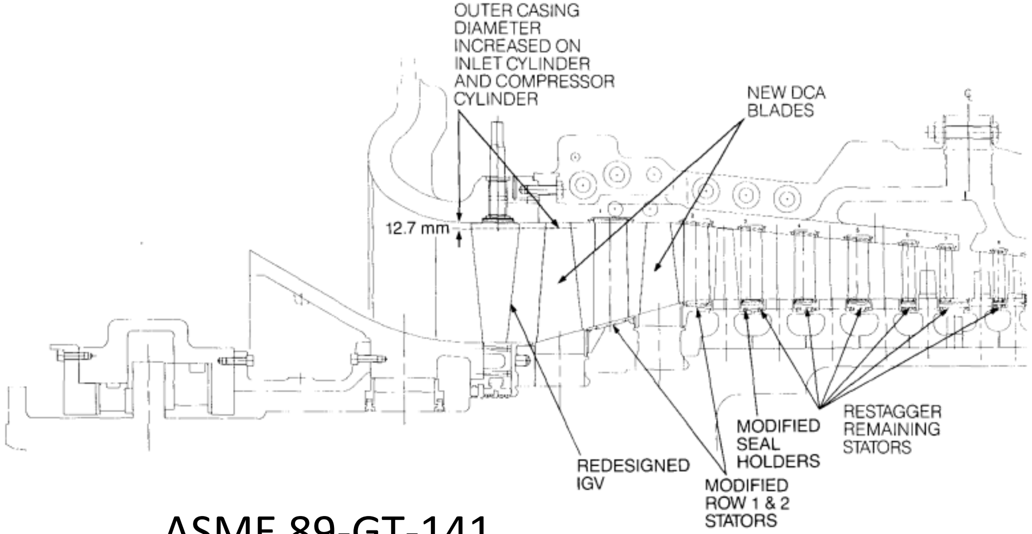
An example of such an upgrade was presented to ASME in 1989 (89-GT-141)

An older style compressor based on NACA65 airfoils was upgraded to DCA airfoils on the first 3 stages with an accompanying change to the inlet cylinder.

The performance enhancements were substantial and in line with expectations.

This type of upgrade is possible for existing equipment with old technology blading, but it is costly.





ASME 89-GT-141

Performance Effects From Increased Rotor Inlet Temperature

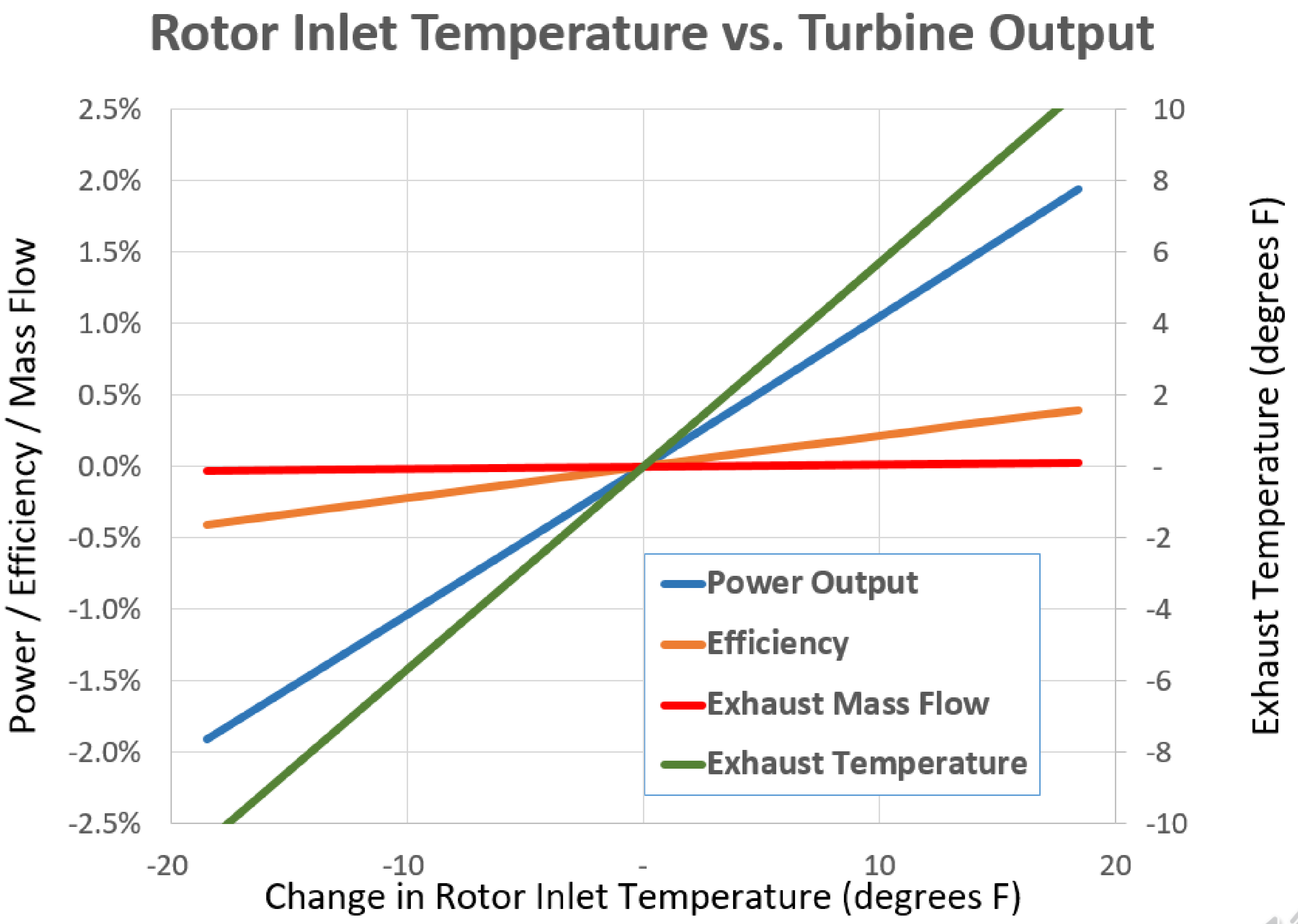
Increased firing temperatures offer an immediate impact on turbine performance.

Over generations of combustion turbines, Rotor Inlet Temperatures (RIT) have steadily increased to provide higher powers and higher efficiencies. The vast majority of performance gains have come from increases in firing temperatures.

Adding or upgrading TBC to cooled components is an effective method for allowing increased component lives or turbine firing temperatures.

A 20F increase in Rotor Inlet Temperature can provide an increase in power of close to 2% and a small increase in efficiency.

It also provides higher exhaust temperatures (~10F) which is useful in combined cycle operations.



Performance Effects From Increased Rotor Inlet Temperature

GE presented a brief history of the evolution of their F Technology through the 90s which shows the importance of increased firing temperatures on Turbine power and efficiency.

Over 8 years, firing temperatures were increased by 120F while achieving a 13% power gain

Although other technology was introduced to the frame over this period, the vast majority of the increases in performance came from higher firing temperatures

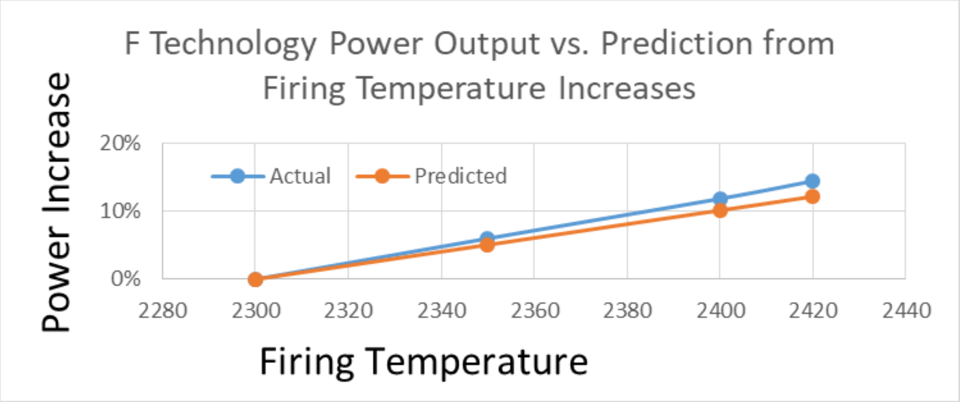
A Liburdi customer has had experience with increased firing temperatures on an MS7001EA firing ~30F above the standard firing temperature also showed a power increase of ~3%.

The F Technology Experience Story

	PG7191(F)	PG7221(FA)	PG7231(FA)	PG7241(FA)
Output	150 MW	159 MW	167.8 MW	171.7 MW
Heat Rate (LHV)	9880 BTU/kWh	9500 BTU/kWh	9380 BTU/kWh	9360 BTU/kWh
Pressure Ratio	13.5:1	15.1:1	14.9:1	15.5:1
Firing Temp.	2300°F	2350°F	2400°F	2420°F
Introduction	1991	1993	1997	1999

Table 1. Evolution from PG7191(F) to PG7241(FA+e)

GER-3950C

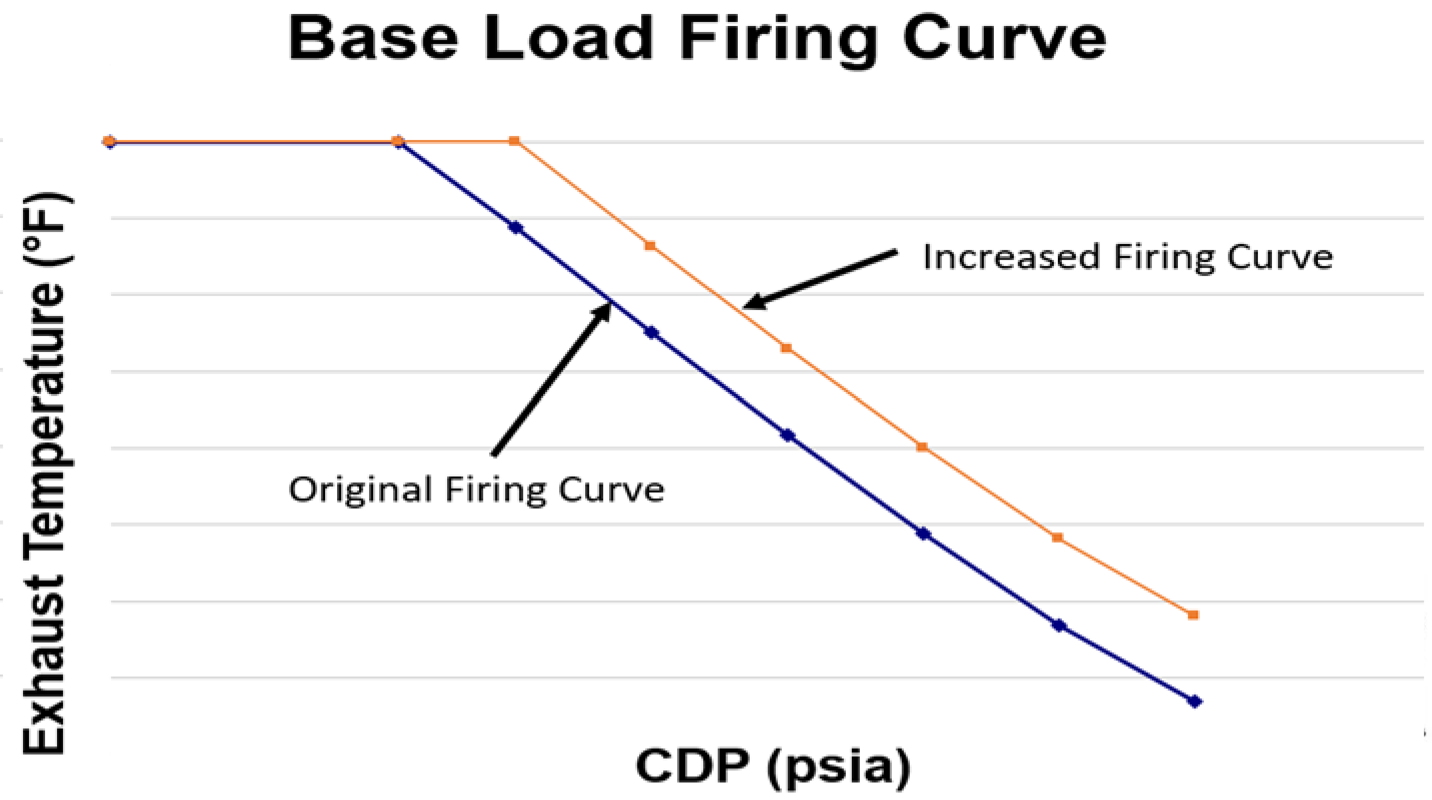


Performance Effects From Increased Rotor Inlet Temperature

Increasing firing temperatures can have a number of adverse limitations;

Coating lives, material creep lives, and Low cycle fatigue lives of components decrease exponentially with increasing operating temperatures.

Additional power output can be limited when the exhaust temperature is at the maximum limit.



The introduction of higher firing temperatures on an existing turbine requires engineering analysis to determine where to provide increased thermal management in the turbine and verification that other systems will not be negatively affected.

Performance Effects From Turbine End Efficiency Increases

Turbine Efficiency Improvements can be accomplished in a number of ways such as;

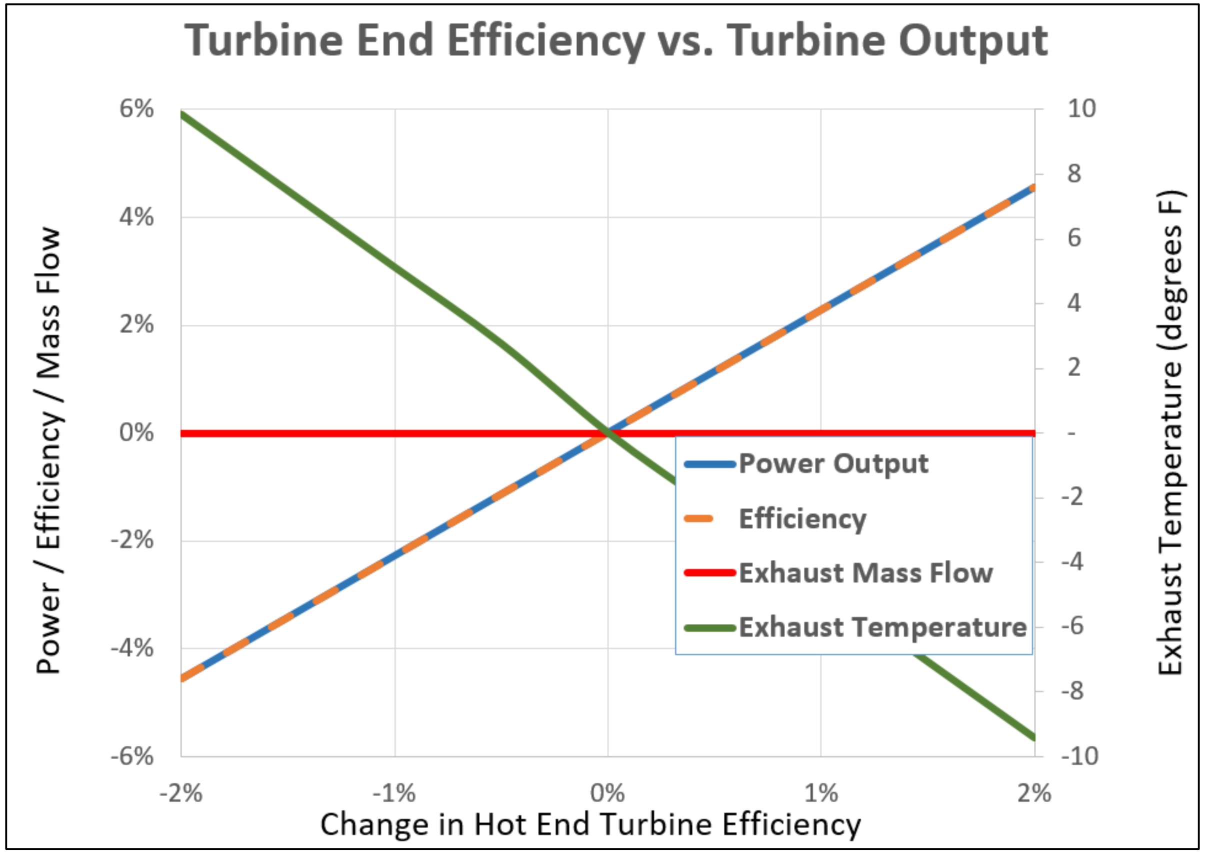
- More efficient use of cooling air
- Improved sealing
- Advanced airfoil designs

Power output and overall efficiency are very responsive to changes in turbine end efficiency.

Exhaust temperatures decrease substantially as the turbine end is able to convert more heat in to power. These types of changes are usually accompanied by firing temperature increases

Unfortunately, even small changes in Turbine Efficiency are a challenge to achieve.

Significant increases are only possible when advanced technology replaces old technology components. Changes to airfoil designs and cooling designs could require multi-million dollar upgrades for the new components.



Performance Effects From Turbine End Efficiency Increases

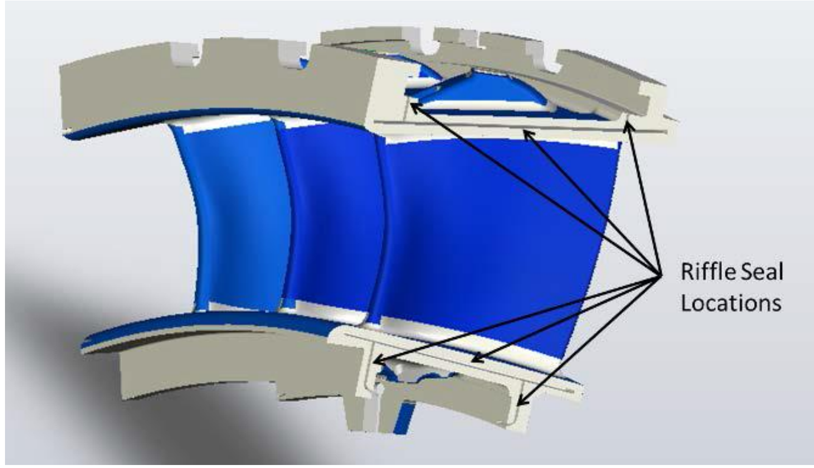
Turbine retrofit designs have become available for a number of turbine frames.

They are the most effective when being applied to older turbine classes. Currently, there is a big push for these upgrades on E class turbines.

An example of such an improvement was presented in 2015 in ASME **GT2015-43924.** This upgrade included changes to turbine seals, changes to turbine airfoil shapes, and is likely to have included an increase in Rotor Inlet Temperature in order to maintain the same exhaust temperatures.

Even with the addition of advanced seals and airfoils, most of the power increase came from increase Rotor Inlet Temperature.

Improved sealing is a cheap and useful tool for upgrades. Both spring-based and compliant seal systems help initial efficiency. More durable seals systems help maintain efficiency over the long run



3D Airfoil Design

	Delta Power Benefit*	Delta Heat Rate Benefit, HHV*	Delta Exhaust Temperature*
W501D5 - upgraded to Si3D with no firing temp increase	+ 5.0 MW	- 300 BTU/kW-hr	+0 °F
W501D5– upgraded to Si3D and firing temperature increase	+ 8.0 MW	- 320 BTU/kW-hr	+21 °F
W501D5 with Phase 1 Upgrade – upgraded to Si3D and firing temperature increase	+ 3.7 MW	- 140 BTU/kW-hr	+15 °F
W501D5A– upgraded to Si3D	+ 3.5 MW	- 240 BTU/kW-hr	+0 °F

ASME **GT2015-43924**

Costs vs. Benefits

The benefits for Original Equipment Manufacturers (OEMs) in delivering these upgrades is clear;

- Large upfront sales of new turbine components
- Extending the market life on existing installed equipment base
- Recapturing the market on maintenance and replacement components

Costs vs. Benefits

For operators, the costs and benefits are more balanced.

Benefits

- Increased power output means higher revenues
- Increased efficiency can result in being dispatched more often

Costs

- Typically requires a multi-million dollar investment in new parts
- May require added downtime to install (dependent on the upgrade)
- Upgrading will usually limit operator options on maintenance and result in increased future refurbishment and replacement costs

Of course, every situation is different. Only you know what is best for you.

Other Considerations

One other key item to consider, where there can be performance gains there can also be performance losses.

While significant performance gains may cost millions of dollars to produce, performance losses due to degraded or dirty compressors and turbine components can be equally large in scope.

Turbine software capable of identifying degradation levels and optimizing cleaning and outage schedules can often provide large relative investment returns by ensuring that your turbine is operating at peak performance.
(Ref. GPPS-2018-0175 - "Gas Turbine Performance Analysis and Hot-Section Life Prediction Using the GTHM System")(Global Power & Propulsion Society)

A healthy turbine is a productive turbine.

Thank you!

Questions?