

**Output Control Strategies for Aero-Derivative Gas  
Turbines which Maximize Unit Capacities and  
Reliability**

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## GG Engine Output versus Time Between Overhauls

The Time Between Overhaul (TBO) of Gas Generator (GG) engines is a critical parameter operations religiously monitor to ensure engines are removed for overhaul before the risk of failure rises to unacceptable levels. Manufacturers usually provide TBO guidance, based on the usual assumptions of clean air and dry fuel gas will be supplied to the engine. It is also assumed by the manufacturers that the engines will be operated at (or less than) Base Load Outputs. As shown below in **Figure 1**, the engine's output has a significant influence on its TBO schedule.

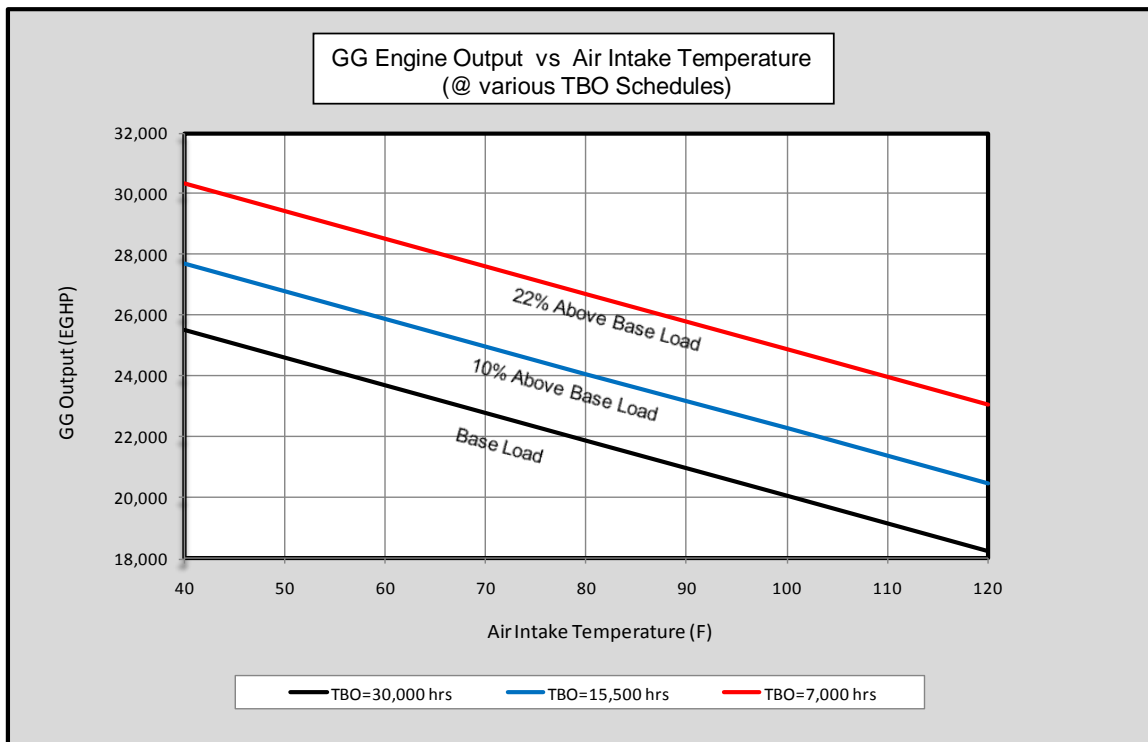


Figure 1

## Engine Output Control (Manufacturers Standard)

Gas Turbine Units are typically installed with fixed control set points, established by the Manufacturer to prevent the operators from exceeding "Base Load" Outputs. Turbine Controls typically use the raw GG engine Speed and Exhaust Gas Temperature as the Control Parameters to accomplish this. These set points are often defined as a result of the project's shop test performance analysis and then become sacred fixed settings, which usually remain untouched throughout the operating field's life. This control strategy however, when applied to aero-derivative gas turbine units does not accurately manage Base Load Output control, after the initial GG engine is replaced with a spare units.

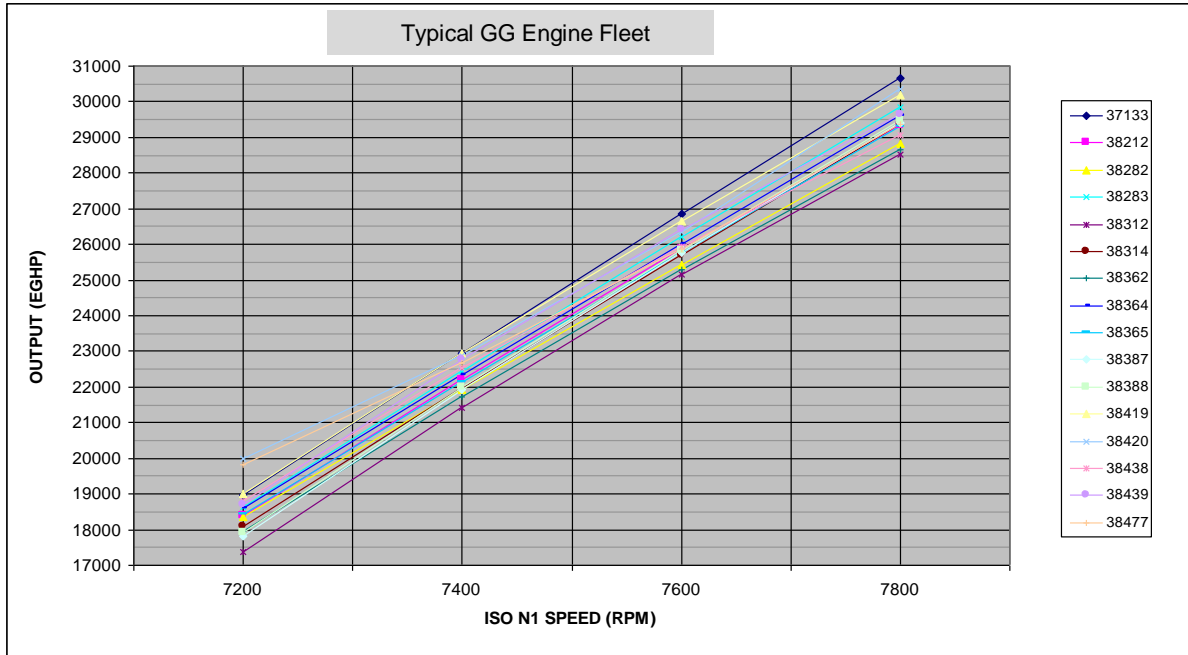


Figure 2

This is because of the large variation (~ 2,000 EGHP) in GG engine outputs at given ISO corrected GG speeds, as shown in **Figure 2**. As a result of this variation, upon GG engine change out, it is possible for units to exceed base load outputs by as much as 10% and even more likely units will be limited by control set points at levels below base load output. In the extreme, units have been observed with output constraints limiting maximum output to levels of 40% below base load!

This inability to accurately manage base load output places the unit in jeopardy of exceeding the TBO. For example if the operator assumes the unit is operating at base load output (but due to the newly replaced GG engine the unit is actual producing 10% above base load outputs) and attempts to operate the unit for 30,000 running hours, there is a high risk that the unit could fail at some point after 15,500 hrs and well before the planned 30,000 hour interval. This scenario unfortunately vastly increases the risk of catastrophic failure related to a variety of failure mechanisms. Unfortunately failures related to over firing (or exceeding TBO's) do not provide incipient warnings and result in massive collateral downstream failure of power turbine, couplings, gearbox and even driven equipment. The repair costs associated with these failures are in the millions of dollars, but more importantly, it usually takes 4-12 months to restore unit operation and the associated production losses usually dwarf the value of the repair costs.

Another more likely consequence of not accurately managing base load output control, and yet just as costly, occurs as a result of unit controls pre-maturely limiting unit output. As mentioned above, this can result in unit output reductions of up to 40% and the

consequences of this is chronic unit capacity loss, along with the associated Production losses. If operating a fleet of aero-derivative units experiencing this phenomenon, the capacity losses can easily equate that of a single unit being shutdown continuously!

As an example of this, below **Table 1** summarizes the performance assessment of several Aero-derivative Gas Turbine powered compression units in the gas export duty in Asia Oil/Gas operation. While the compressors experienced moderate efficiency losses, the Gas Turbine drives suffered extreme 36% to 40% Output losses!

		Unit 1	Unit 2	Unit 3
Capacity Loss Summary	Driver Efficiency	3.0%	5.5%	4.4%
	Driver Output Constraint	40.5%	36.2%	40.1%
	1st Stage Compr Efficiency	1.3%	0.0%	0.0%
	2nd Stage Compr Efficiency	1.3%	0.0%	1.9%
	3rd Stage Compr Efficiency	1.7%	1.4%	0.0%
	Total Capacity Loss	47.8%	43.1%	46.4%
	Capacity Availability Metric	52.2%	56.9%	53.6%
Capacity Loss Summary (MM <sup>3</sup> /HR)	Driver Efficiency	5,706.1	9,517.7	8,326.1
	Driver Output Constraint	76,968.2	62,473.8	75,072.4
	1st Stage Compr Efficiency	2,476.3	0.0	55.4
	1st Stage Compr Recycle	NA	NA	NA
	2nd Stage Compr Efficiency	2,508.6	0.0	3,470.3
	2nd Stage Compr Recycle	NA	NA	NA
	3rd Stage Compr Efficiency	3,223.6	2,440.4	0.0
	3rd Stage Compr Recycle	NA	NA	NA
	Total Capacity Loss	90,882.8	74,431.8	86,924.2
	Test Flow	99,234.0	98,118.0	100,312.0
	Potential Flow	190,116.8	172,549.8	187,236.2

Table1

The performance assessment ultimately revealed a total export capacity loss of 252,239 million cubic meters/hr, most of which was the result of a poor GG/PT match. This is equivalent to almost 40,000 bbls of Oil equivalent/day or ~\$570 Million/yr.

The solution to the above output constraint issues is not something that is solved overnight, but the first step toward progress is to accurately quantify the GG Engines output. Next step requires extensive troubleshooting to recognize engine and package component failures that contribute to elevated operating exhaust gas temperatures relative to GG ISO corrected speed. Next steps involve review of what can be accomplished during GG engine overhauls to reduce relative operating exhaust gas temperature. Usually replacement of axial compressor blades can help significantly. If the above steps

fail to solve the problem, the Power Turbine's Stator assembly match area should be changed either by manual adjustment (if so designed) or replaced with units of specified Match Area and validated at the manufacturers shop with extensive dimensional inspection checks.

### Engine Output Control (Turboperf's Solution)

Turboperf utilizes proven technologies, developed in the early 1990's, to accurately assess GG Engine output. The algorithms use custom developed performance models, based on a variety of parameters generated from each engines unique shop performance tests. This approach was developed as a means to accurately monitor and correct the TBO hours of GG Engines operating continuously at levels of up to 15% above base load. The research program that spawned this technology was successfully executed on 15 operating units over a period of 15 years, without failures and while achieving a significant reduction Fired Hour Cost per Unit Output (usd/hrs/eghp).

In addition to the engine algorithms, mentioned above, an essential element in accurately assessing engine output is the understanding of the Power Turbine Stator's Match Area. Specifically, the understanding of the unit's PT Stator flowing area relative to that of the restriction orifice used in the shop testing of the GG engine under analysis. Unfortunately the Power Turbine Stator flow areas can vary significantly (up to 6%) in the field and depending on the equipment and has a substantial impact (a 1% reduction in the stator flow area can increase engine output by 800 eghp at a given ISO corrected GG speed) on engine output.

### Summary

The value of accurately assessing GG Engine output cannot be overstated. It will eliminate risk of over firing (or exceeding TBO's), as well as to maximize unit output capacities, hence operating profits. The Gas turbine industry's strategy of maintaining fixed control set points is outdated and was designed for a low tech Industry. The current production operating environment is capable of managing more sophisticated technologies, which will mitigate catastrophic failure risks, while maximizing turbomachinery capacities/production.

If your aero-derivative Gas Turbine units are experiencing significant capacity reduction, it could be related to a GG engine/PT Stator match area issue. We can provide an assessment and offer a plan and to restore your performance.

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