SYMPOSIUM OF THE INDUSTRIAL APPLICATION OF GAS TURBINES COMMITTEE
BANFF, ALBERTA, CANADA
OCTOBER 2017

17-IAGT-104

SIEMENS INTRODUCES THE SGT-A45 MOBILE UNIT: SUPERIOR PERFORMANCE WITH TRUSTED TECHNOLOGY

Steven Lewis, Cristiano Balestrino

Siemens Power & Gas

steven.j.lewis@siemens.com   cristiano.balestrino@siemens.com

Keywords: *Aero-Derivative Gas Turbine, Fast Power*

ABSTRACT

As several areas of the world continue to require fast deployment of power solutions to address the needs of growing populations and electrification rates, mobile gas turbine units provide an ideal solution where infrastructure needs must be fast-tracked. The SGT-A45 mobile unit, launched by Siemens in March 2017, achieves the highest power density and fuel efficiency of any mobile power plant on the market providing a cost-effective, dependable solution to these needs.

Utilizing proven aero-derivative technology, the SGT-A45 is based on an innovative Gas Turbine core which now augments the Siemens aero-derivative gas turbine portfolio. The gas turbine core and all its auxiliary systems are packaged in a trailer-mounted solution engineered to be "road-ready", highly transportable and fast to install. Capable of producing up to 44MWe for 50 or 60Hz frequency, the product can be driven to site and provide power to the grid within 14 days of arrival.

This paper will focus on discussing the technical details of the gas turbine solution and only provide some context on the mobile package design, which is described in further detail in other publications. Running in parallel to the package development, the gas turbine development program addressed the technical challenge of integrating in the SGT-A45 components from existing gas turbine products (SGT-A65 and SGT-A35) through several "agile" methodologies, which have allowed accelerating the development cycle to a mere 18 months from launch to product release. This included the rapid build of the first SGT-A45 gas turbine prototype, which was then taken through a comprehensive engine test program.

This paper will discuss the technical details of the gas turbine solution, and the validation of its "critical to quality" attributes. It will also touch upon some of the "lean and agile" management methodologies implemented in the development program.

1 INTRODUCTION

Siemens acquired the Rolls-Royce Energy Aero-Derivative Gas Turbine (AGT) product line in December 2014. This portfolio encompasses the SGT-A65 (Industrial Trent 60), the SGT-A30 RB and SGT-A35 (Industrial RB211), and the SGT-A05 AE (Industrial 501K). This acquisition is part of Siemens' strategy to address the growing Distributed Generation markets [1], expanding its portfolio of gas turbine products and services to now include aero-derivative technology.

Amongst the several areas of application of aero-derivative gas turbines in Distributed Generation, the use in mobile power units has seen a major growth in recent years to become the largest single segment of application for aero-derivative gas turbines in the 30 MW class, with an average of over 1.5 GW of new capacity per annum added in the last five years.

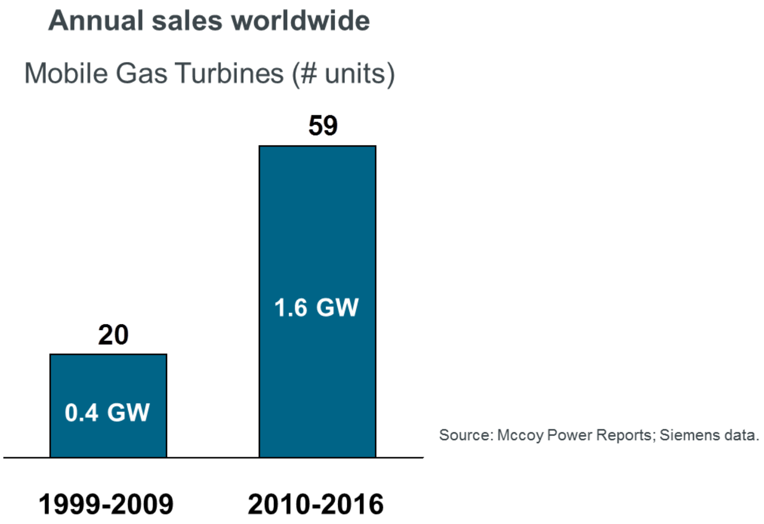

Figure 1: Mobile gas turbine market in recent years.

The factors driving the growth of this segment are primarily a combination of low degrees of electrification in several developing regions, and rapid population and economic growth in these same areas [2]. In many cases, the demand for electricity grows at a rate which out-paces the ability to install conventional power generation equipment. In these situations, which are normally considered part of the "Fast Power" market, mobile gas turbines provide an attractive solution through a "plug and play" design which enables power dispatch to the electrical grid in a matter of weeks, as opposed to several months or years which are typical for "permanent" forms of power generation technology such as combined cycle power plants.

In many cases, mobile gas turbines are used as a "bridging" power solution, ensuring a reliable supply of rather large generating capacity while more "traditional" power plants can be built and come online.

The Siemens aero-derivative gas turbine portfolio acquired from Rolls-Royce is characterized by technology with high levels of power density and fuel efficiency, and a high degree of modular commonality between different products. These features provided a unique opportunity to develop a new configuration with superior attributes for mobile applications.

The SGT-A45 provides up to 44 MW of electrical output with a gas turbine core sufficiently compact to be packaged in a trailer-mounted configuration meeting the dimensional limits (size and weight) of transportation by road, sea and air.

Such level of power output is significantly higher than any other mobile generator on the market. This means that for larger fast-track power plants utilizing multiple units, fewer SGT-A45 TR units are typically needed than for alternative technologies, with obvious savings in terms of overall investment and complexity of the installation.

In addition, the fuel efficiency of the SGT-A45 is higher than any other mobile gas turbine, reducing operational costs for the end user.

As illustrated by Figure 2 below, the SGT-A45 gas turbine utilizes proven components and Rolls-Royce Aero Engine technology, maintaining a high degree of commonality with gas turbine products with millions of hours accumulated in flight and industrial service.

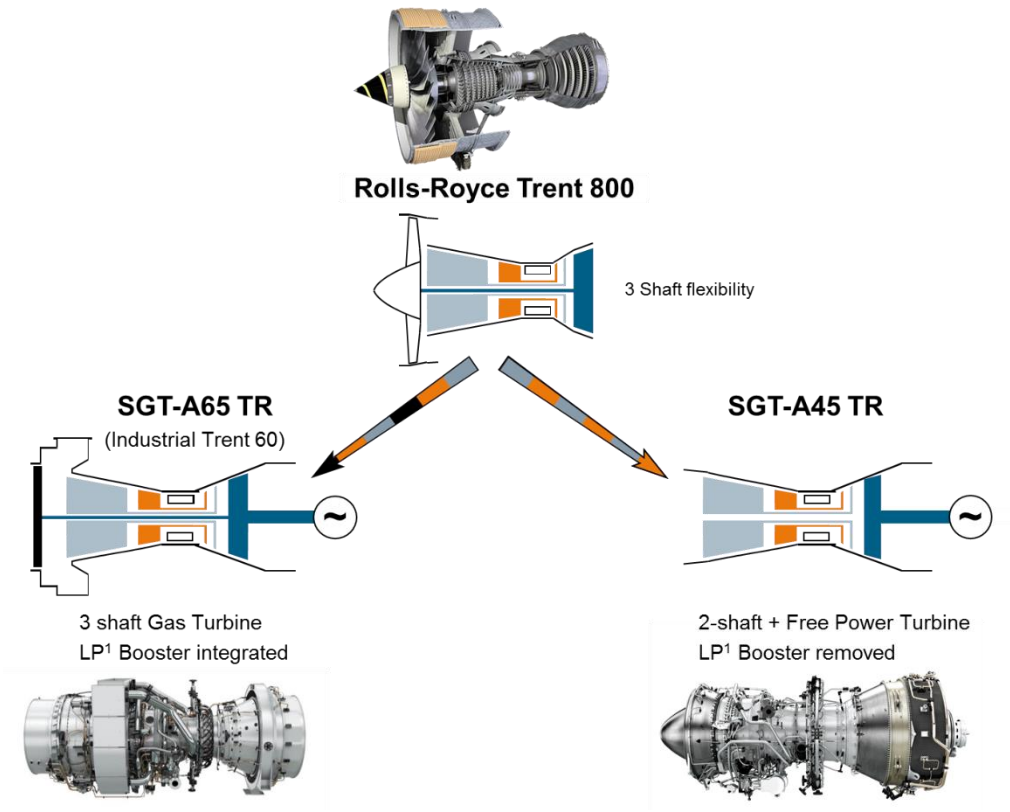

Figure 2: Derivation of the SGT-A45 from proven gas turbine technology.

2 "AGILE" METHODS IN DEVELOPMENT PROGRAM MANAGEMENT

Throughout this development program the team has embodied the agile and lean philosophy of "*re-use*" rather than "*create*". The modular design of the SGT-A65 and the SGT-A35 lend themselves well to the re-use philosophy as many of the structural interfaces are common. Some of the internal rotating components, however, did require new or modified designs. These technical challenges will be discussed in this paper.

The Engine Development Program described in this paper was launched in February of 2016. By the end of September 2016 the Engine Development Program was complete and verified the performance and operability of the SGT-A45 gas turbine.

Throughout the development program, the philosophy has been focused on maintaining a fast paced development cycle while ensuring quality through appropriate management of the technical risks. The principle of agile development is to enable the program to complete small sub sections of the development solution (prototyping), and apply corrections to utilize the learning in the next “sprint”. This prototyping of the solution has then resulted in quicker feedback loop of what worked or what didn’t work.

In this approach, the learning and correction are applied continuously in the development allowing a faster cycle time, while managing the risk levels by breaking down the work scope into smaller packages. The philosophy is that corrections are applied while the development takes place, and before any error can result in costly and time-consuming rework (e.g. once the hardware is built or tested).

As shown in Figure 3, the SGT-A45 development was broken down into specific phases, from which agile methodologies such as “scrum cycles” were established. These were then broken down into manageable durations of clear tasks which supported the completion of sub deliverables.

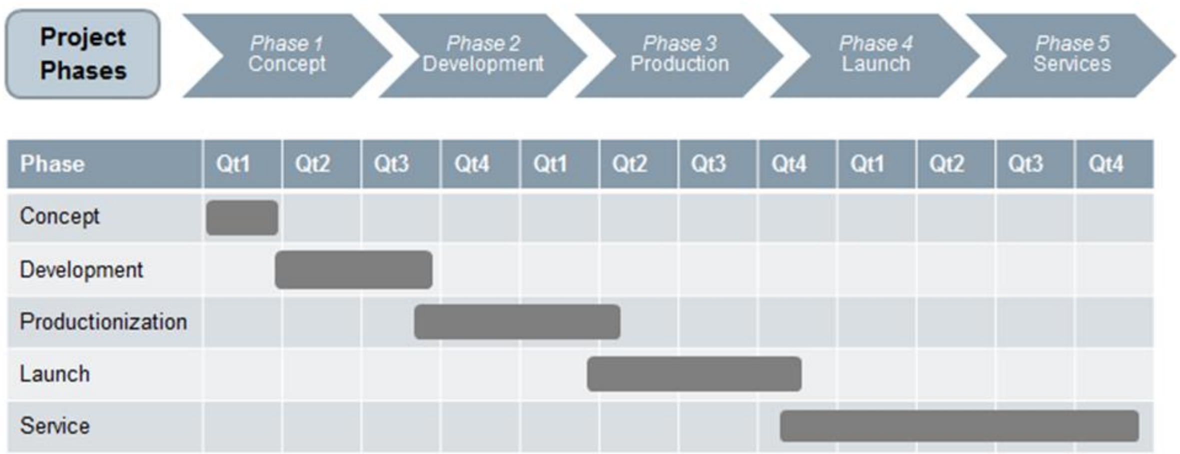

Figure 3: SGT-A45 Development Philosophy

3 GAS TURBINE CORE

The SGT-A45 gas turbine core builds on the successful and trusted legacy of the SGT-A65 (formerly known as Industrial Trent 60). Built with Rolls-Royce Aero Engine technology, both products benefit from many years of continuous technological improvement and over 28 million hours accumulated in flight by the Rolls-Royce Trent 800 aero engine.

As illustrated by Figure 2 in the previous section, the SGT-A45 retains a high degree of commonality with the Rolls-Royce Trent 800, and is a direct derivation of the SGT-A65. So in addition to the pedigree earned in flight, this gas turbine builds on numerous technology references in Industrial Power Generation and the Oil & Gas industry.

The Low Pressure Compressor (LPC), which is mechanically connected to the Low Pressure Turbine in the SGT-A65 (and replaces the aero engine by-pass fan) is eliminated in the SGT-A45 architecture. The Intermediate Pressure (IP) and High Pressure (HP) rotors are left unchanged, and the Low Pressure Turbine becomes a Free Power Turbine (FPT), which is only aerodynamically coupled to the rest of the core engine.

The FPT, which retains a large degree of commonality with the SGT-A45 and the Rolls-Royce Trent 800, is an existing assembly utilized in the Rolls-Royce Marine MT30 gas turbine, and recently introduced into the Industrial RB211 product line as well (now SGT-A35).

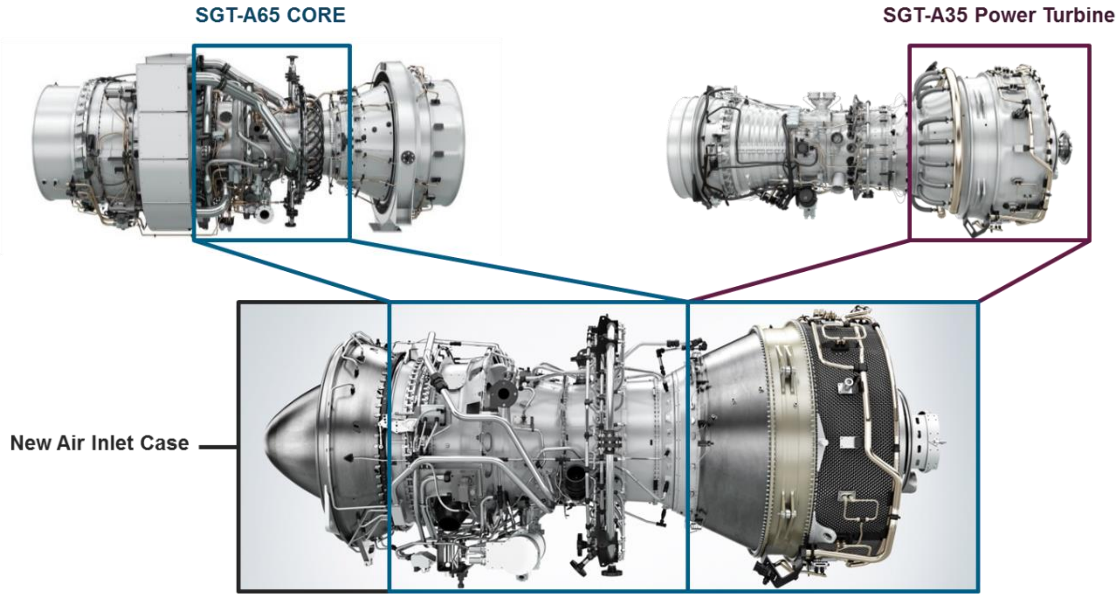

Figure 4: SGT-A45 gas turbine core architecture.

This architecture allows re-using the modular casing interfaces and (see Figure 5 below) the internal design of the existing rotating components and annulus definition.

While the re-use of existing components reduces dramatically the scope of new design activities and the associated technical risk, some development and validation activity was still required in order to fully integrate these modules. These included:

- Incorporation of Air Inlet Case (AIC), designed in a previous R&D program;
- Modified Front & Rear Stub Shafts Intermediate Pressure Compressor (IPC);
- Modified locking feature on the Intermediate Pressure Shaft;
- Adjustment of internal cold and hot seals for improved sealing;
- New Externals for Secondary Air System;
- Verification of Performance and Operability;
- Development of Engine Control System;
- Whole engine Testing and validation.

4 GAS TURBINE OVERVIEW

The SGT-A45 re-uses the core engine modular hardware from SGT-A65, with the addition of the AIC and the SGT-A35 Power Turbine. This maintains the philosophy of building the mini-modules (Figure 5) before the stacking and final assembly of the Gas Turbine.

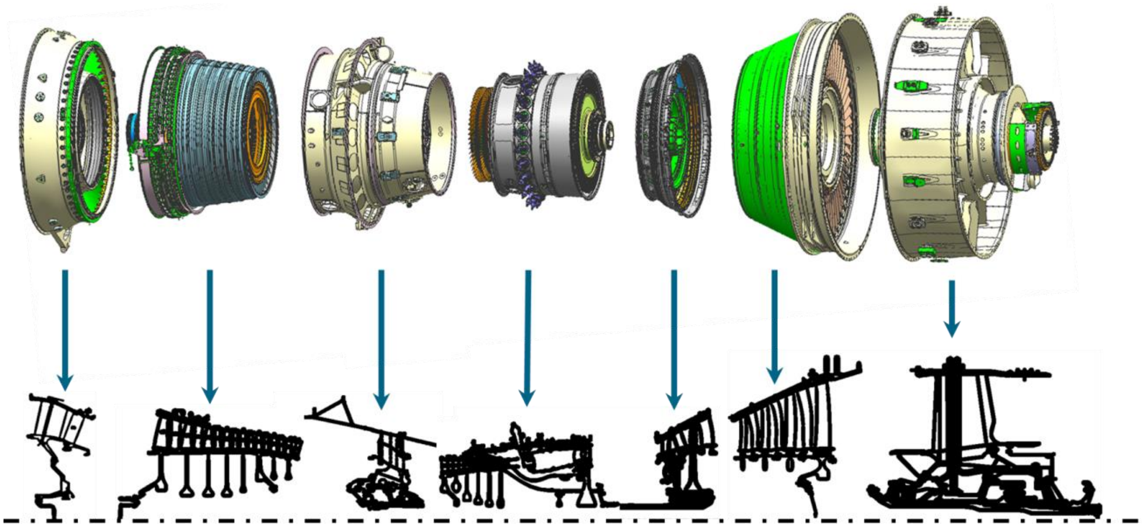

Figure 5: Exploded 3D/2D model of the SGT-A45 gas turbine core

Module 01 – Air Inlet Module, consisting of the air inlet case which holds the pre-swirl vanes, Variable Inlet Guide Vanes (VIGV) and the IPC front bearing structure.

Module 02 – Intermediate Pressure Compressor (IPC) Module, also containing the Intermediate compressor case, two additional stages of Variable Stator Vanes (VSV), stators and IP Discs and blades.

Module 03 – Inter-Case Module, also containing the handling bleed ports, Radial Drive Shaft and axial bearings

Module 04 – High Pressure Compressor (HPC), Turbine and Combustor Module.

Module 05 – Intermediate Pressure Turbine (IPT) module, also containing the rear bearing structure

Module 06 – Gas Turbine Externals, Gearbox and Electric Start Motor (not shown in Figure 5).

Module 07 – Low Pressure Turbine (LPT) Module, containing 4 stages of turbine blades and vanes. As mentioned above, this is the Free Power Turbine (FPT).

Module 08 – Low Pressure Turbine Exhaust Casing, also containing the radial and axial bearing of the Free Power Turbine.

As can be seen in Figure 6, the combustion air is drawn in through the AIC and compressed by the IPC. The combustion air is then drawn through the Module 03 inter-case before being compressed by the HPC. On exit of the HPC the combustion air is at high pressure and temperature, ready to be mixed with fuel from the injectors in the combustion chamber.

The combustion products, at high pressure and very high temperature, expand through the High Pressure Turbine (HPT) and then though the Intermediate Pressure Turbine (IPT). The mechanical work produced by each of these two stages of turbine is transferred to the respective compressor modules (HPC and IPC) through co-axial shafts.

The residual energy in the flow leaving the IPT (still at relatively high temperature and pressure) is converted into mechanical work in the Free Power Turbine, which is not mechanically coupled to a compressor rotor and produces mechanical work to direct-drive a 2-pole electrical generator and deliver the useful output from the gas turbine.

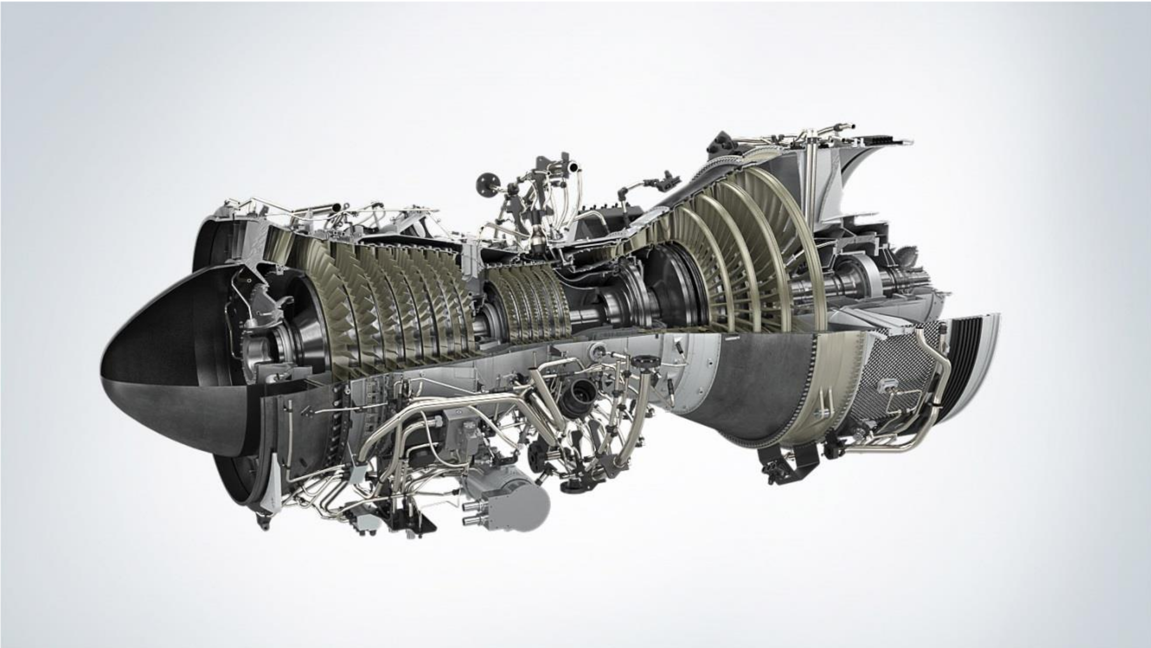

Figure 6: Section cut through of the SGT-A45 gas turbine

As discussed above, the solution for the SGT-A45 gas turbine is focused on the integration of existing hardware. By doing this, the number of new parts introduced was significantly reduced to low complexity parts.

4.1 Air Inlet Case

The SGT-A45 uses steel cast manufacturing technology for the AIC (Figure 7). This module, although cast steel, maintains the aerospace aerodynamic requirements for tolerance and surface finish. This casing is cast before rough machining, and final machining on the Critical to Quality features.

This casing was designed to have the same interface for both inner and outer gas path annulus, and the same bolting pattern to the SGT-A65 IPC case. This allowed the physical mating of the AIC to IPC.

Figure 7: Steps of the Air Inlet Casing design & manufacture.

The main distinctive functional features in the Air Inlet Case are the Pre-Swirl Vanes (PSV). The PSV are required since the SGT-A45 uses an existing compressor designed to operate behind either an aero Trent 800 fan or an industrial SGT-A65 low pressure compressor, both of which have exit swirl. The front stages of the IPC compressor are designed to meet such flow swirl angle with minimal losses. In order to maintain high levels of aerodynamic efficiency, the PSV replicate the swirl angle expected at the entry of the IPC. As a secondary function, the PSV also correct for any swirl deviations created by the package intake housing.

The SGT-A45 Air Inlet Casing design included a study to optimize the number of PSV in order to minimize losses and achieve optimal manufacturability.

Figure 8 compares the loss profile for two designs with 58 or 29 PSV. By optimizing the vane chord at the inner and outer annulus and the inner annuls thickness / chord ratio, the design with 29 PSV realizes an overall adiabatic efficiency increase of 0.16% relative to the datum of 58 PSV.

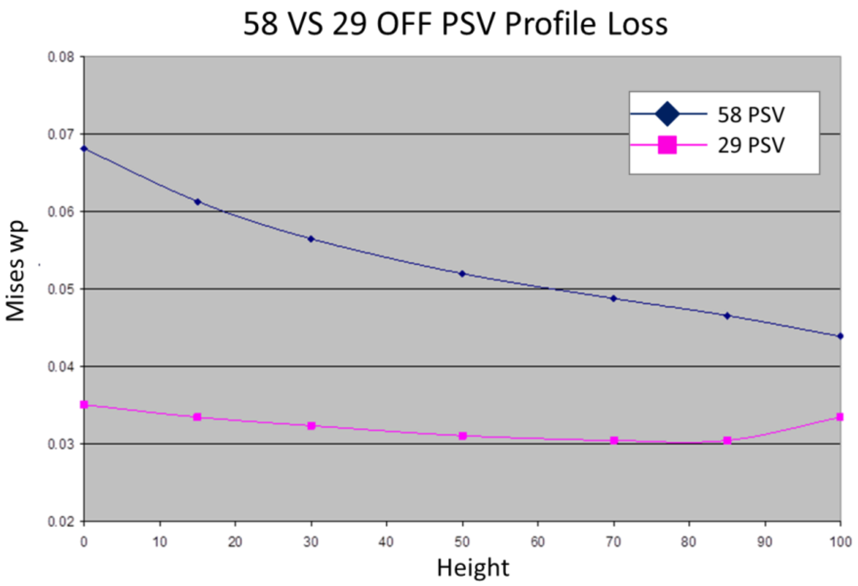

Figure 8: Mises profile loss assessment of 58 & 29 PSV

4.2 Rotatives

For the three rotors of the SGT-A45, some minor modifications were made in order to facilitate the integration of the modules.

1. IPC Front Stub Shaft
2. IPC Rear Stub Shaft
3. IPT Shaft locking feature

In all cases, the solution for these parts relied on machining of the shafts within the existing forgings of either the SGT-A65 or the SGT-A35 (see an example in Figure 9). By doing this, the project was able to reduce the lead time on tooling and manufacturing lead time.

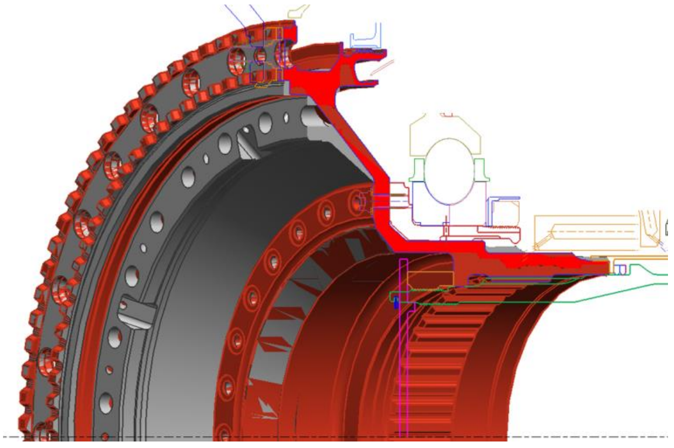

Figure 9: IPC Rear Stub shaft Overlay: Existing geometry (Grey) Vs New Geometry (Red)

During the development it was also clear that the existing SGT-A65 IPT shaft geometry would be suitable, with slight modification for the internal locking feature. The SGT-A45 has, again, reused existing forgings (Figure 10) and modified the machining to change the geometry from an internal shaft locking arrangement to a more traditional castellated nut arrangement.

Figure 10: IPT Shaft Overlay: Existing geometry (Green) Vs New Geometry (Violet)

As the rotative hardware is manufactured out of existing material and used in SGT-A65 operating conditions, it was possible to read across the validity of existing mechanical integrity analysis. In only a few specific components and systems was additional detailed analysis required. All analysis was completed based on a Functional Design Definition (FDD) for component simulated duty and mission cycles.

4.3 Gas turbine externals

The majority of externals for the SGT-A45 are new hardware designs. Considering the type of components (mostly tubes) and low level of technical risk and complexity, most of the components for the development test vehicle were bent on-site as prototypes directly from 3D models. By doing this the development team was able to drastically reduce the cycle time for design, manufacture and build. Also the errors in externals were found earlier in the development cycle and rectified quickly.

The externals were separated into the three groups.

1. Electrical and fuel systems components (Figure 11), which with the exception of some minor changes are largely common with the SGT-A65.

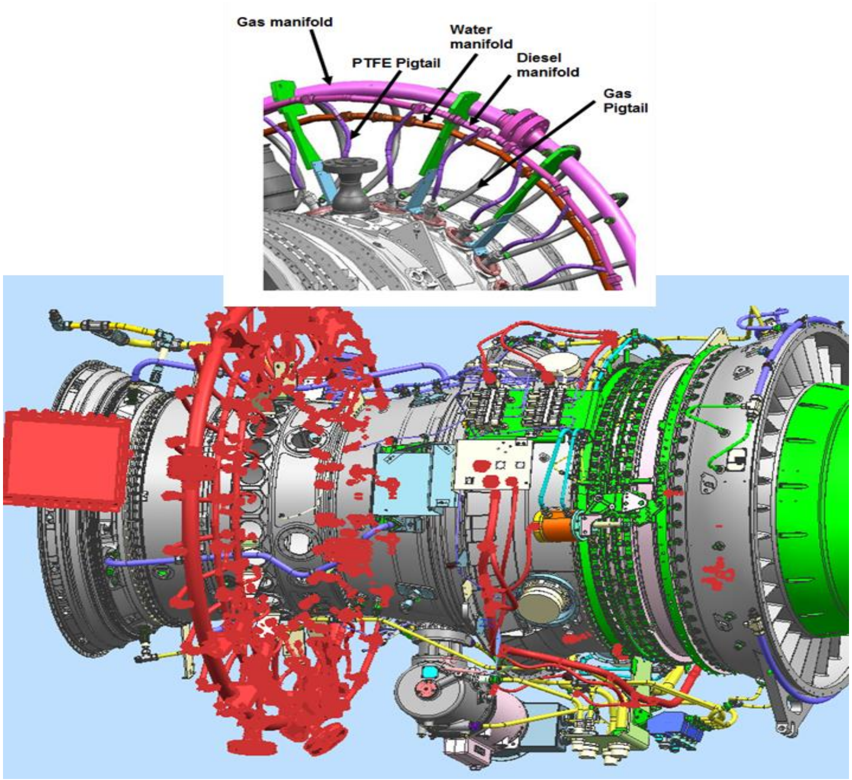

Figure 11: Fuel and Electrical systems.

2. For the Oil System, the solution relied on reusing SGT-A65 oil pipes (9 pipes) and modifying the geometry – be it length, routing or end fitting type. The interface plate to the package skid was reduced in overall length to improve clearance in the package. The chip detectors were also relocated for ease of accessibility. Unlike the SGT-A65, the SGT-A45 utilizes an off-engine lube oil pump (in duplex arrangement) located in the package skid. As such, the lube oil scavenge lines were re-routed and the Qualitative Debris Monitoring (QDM) re-positioned (Figure 12).

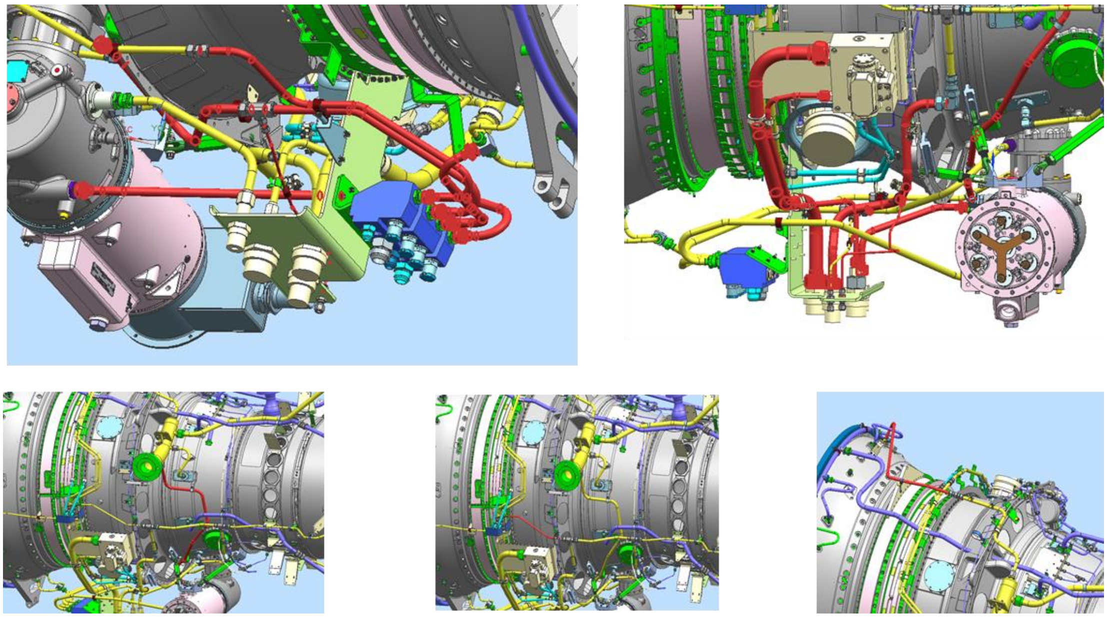

Figure 12: Oil system externals.

3. Air system externals. In this case, the differences between the SGT-A45 and the SGT-A65 are greater, mostly because of the elimination of the LPC and the LPT conversion to Free Power Turbine requiring different provisions for thrust load management.

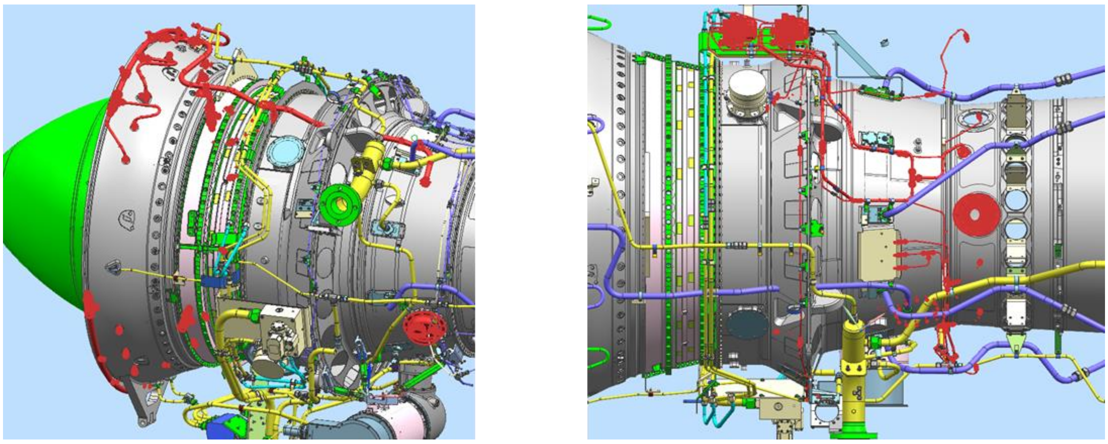

Figure 13: Air system externals.

4.4 Performance and Operability

Figure 14 and Figure 15 show the electrical power output and efficiency of the SGT-A45 gas turbine in simple cycle, at 50 Hz and 60 Hz respectively.

The data curves also show the effect of optional water injection in the combustion chamber. This is primarily used for NO_x emissions control; however it also results in significant power augmentation, especially in hot climate conditions.

Performance of the SGT-A45 has been optimized for high ambient temperatures, taking into consideration that the primary markets for mobile gas turbines are located in warm climates and other gas turbines suffer from a rapid reduction of power output as the ambient temperature increases.

For the SGT-A45, the retention of power output in hot ambient conditions is remarkably good. Particularly, in 50 Hz operation the SGT-A45 gas turbine retains at 30 °C about 96% of its ISO power output. When water injection is used, the power output is approximately constant all the way up to the proximity of 40 °C.

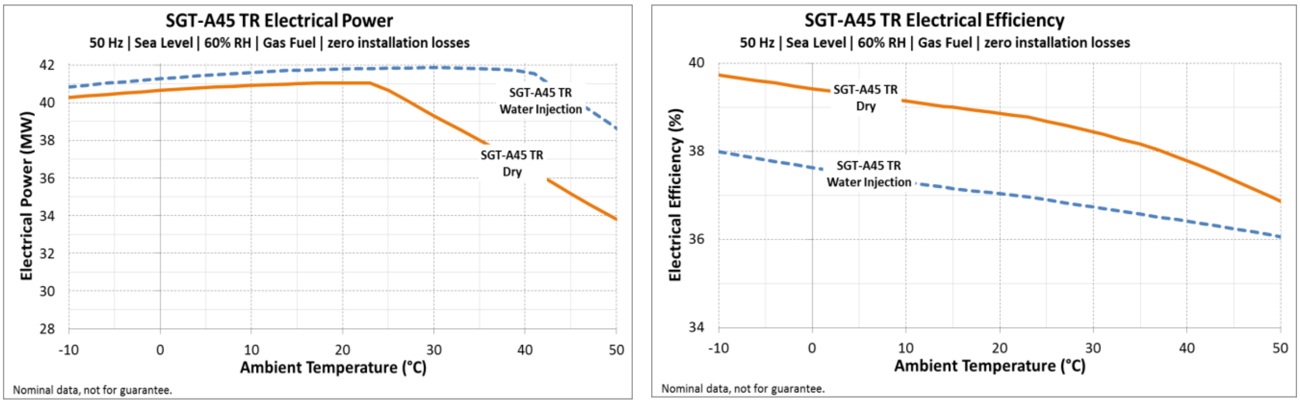

Figure 14: 50 Hz Power and efficiency of the SGT-A45 vs. ambient temperature. Nominal data, not for guarantee.

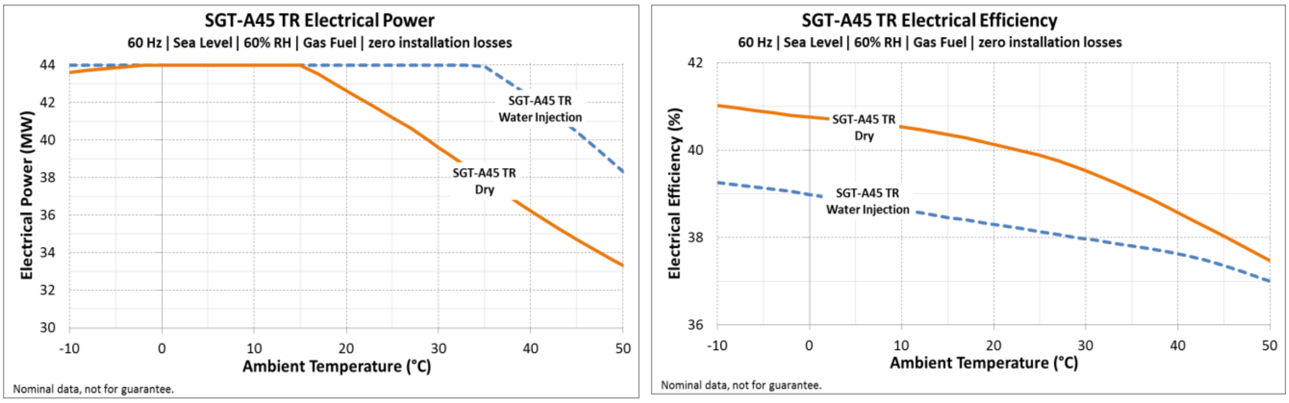

Figure 15: 60 Hz Power and efficiency of the SGT-A45 vs. ambient temperature. Nominal data, not for guarantee.

4.5 Testing and Validation

The first SGT-A45 gas turbine was assembled and tested at the end of 2016 at the Siemens facility in Montréal, Canada (Figure 16).

During the development testing the gas turbine was taken through a comprehensive plan of testing in order to verify the key product attributes and pre-test predictions.

Figure 16: SGT-A45 gas turbine – development test vehicle.

The test plan consisted of several manoeuvres (Figure 17), including the following:

1. Performance Curve (Gas & Liquid - Dry/Wet – 50 & 60Hz)
2. Load Acceptance / Rejection (Gas & Liquid - Dry/Wet – 50 & 60Hz)
3. Speed Controller response (50 & 60Hz)
4. Steady-State fuel map for speed controller
5. Fast Acceleration / Deceleration ramping
6. Rotor dynamic validation
7. Air system and thrust piston validation
8. Oil system validation
9. Emission mapping and combustion rumble measurement
10. Combustion stability with water injection

During the testing a range of instrumentation was connected to the gas turbine. This was in addition to the standard Engine Control System (ECS) parameters and Test Bed instrumentation. The test specific instrumentation was in excess of 400 parameters. This captured static and close coupled pressures, surface, fluid and air temperatures and dynamic responses.

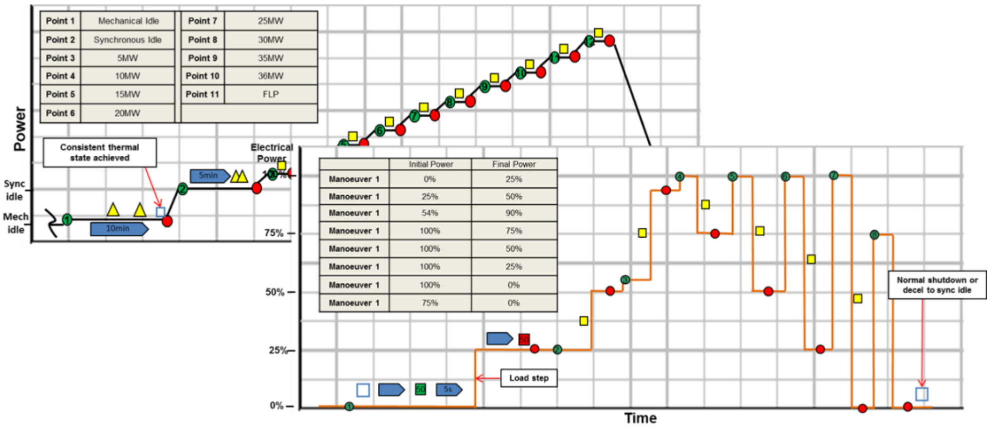

Figure 17: Typical test manoeuvre

5 PACKAGE DESIGN SGT-A45 MOBILE UNIT

The SGT-A45 mobile unit is a site assembly of three highly standardized main modules, factory-built and permanently integrated onto road-ready trailers. With this approach, the gas turbine and its associated ancillary systems can be built and fully pre-commissioned at the factory, thus minimizing the scope of site activities.

This drastically reduces the duration of the installation and commissioning schedule, which can be completed in only 2 weeks at a site prepared to provide the necessary connections.

The three trailer-mounted modules are identified in Figure 18 below. The design features of the SGT-A45 mobile unit are described in greater detail in other publications [2].

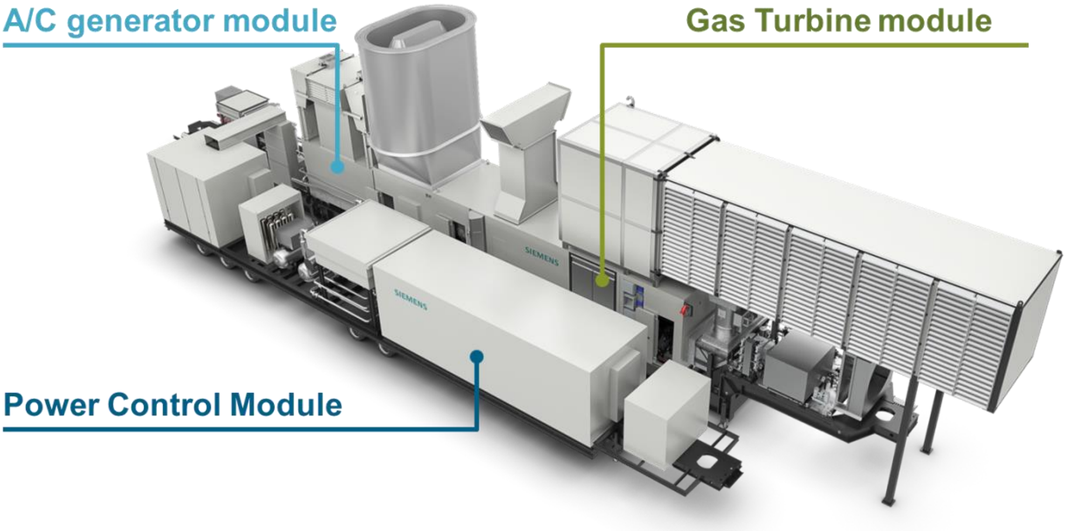

Figure 18: Layout of the SGT-A45 TR mobile unit.

6 KEY PRODUCT FEATURES SGT-A45 MOBILE UNIT

The development program described in this paper has validated the product specifications listed in Table 1 below.

Table 1: Product specifications for the SGT-A45 mobile unit.

Specification	50 Hz		60 Hz	
	15° C	30° C	15° C	30° C
Electrical power (ISO, dry)	41.0 MW(e)	39.3 MW(e)	44.0 MW(e)	39.6 MW(e)
Electrical efficiency (ISO, dry)	39.0%	38.4%	40.4%	39.5%
Fuel type	Dual (gas & liquid)			
Low emissions option	Water injection			
Low emissions – gas fuel	25 vppm NO_x			
Low emissions – liquid fuel	42 vppm NO_x			
Turbine speed	3,000 rpm		3,600 rpm	
Pressure ratio	27.7 : 1	26.7 : 1	27.9 : 1	25.8 : 1
Exhaust gas flow	127 kg/s	120 kg/s	126 kg/s	116 kg/s
Exhaust gas temperature	477° C	501° C	483° C	498° C

As mentioned in some of the previous sections, the SGT-A45 mobile unit achieves differentiation primarily through its performance, which is superior to all other mobile gas turbine offerings in the market.

The higher power output enables significant capital savings for the end user, especially where the provision of large blocks of generating capacity is required on a fast-track basis. Fewer SGT-A45 units are typically needed than for alternative technologies, with obvious savings in the $/kW of the complete power plant. The installation time of only 2 weeks minimizes the construction costs.

In operation, the higher fuel efficiency of the SGT-A45 mobile unit compared to other mobile gas turbines results in significant fuel cost savings and reduced greenhouse gas emissions.

7 CONCLUSIONS

This paper has focused on the specific challenges of the development program of the SGT-A45 Gas Turbine. It has also discussed the key risks that were overcome during the design and the testing phases. Overall the development program is testament to the ingenuity of the Siemens Power Generation Team to develop a new product line from concept November 2015 to product launch March 2017.

The gas turbine's aero-derivative design builds on the proven pedigree of Rolls-Royce Aero Engine technology and the legacy of the SGT-A65 (Industrial Trent 60), and has been validated through a comprehensive test program. The core engine is capable of operating in a mobile package designed for 2-weeks installation, however due to the modularization of the gas turbine core it will also be possible to utilize this configuration in other applications in future.

The performance of the SGT-A45 mobile unit is superior to all other mobile gas turbines in the market, offering significant cost savings potential.

Thanks to these and other features, the SGT-A45 mobile unit is positioned to offer outstanding value creation potential in Fast Power applications, accelerating electrification and fueling economic growth in multiple areas of the world.

REFERENCES

[1] E G Hooper. "Emerging Trends in Distributed Generation"; *Proceedings of POWER-GEN Europe*, Cologne, Germany, June 2017.

[2] C Balestrino. "Siemens introduces the SGT-A45 mobile gas turbine with superior performance". *Proceedings of POWER-GEN Asia,* Bangkok, Thailand, September 2017.

[3] Siemens. (2017). Press Release. Retrieved from Siemens AG: 1. https://www.siemens.com/press/pool/de/feature/2017/power-gas/2017-03-aeroderivative-gas-turbine/datasheet-sgt-a45-tr-e.pdf

DISCLAIMER

This document contains statements related to our future business and financial performance and future events or developments involving Siemens that may constitute forward-looking statements. These statements may be identified by words such as “expect,” “look forward to,” “anticipate” “intend,” “plan,” “believe,” “seek,” “estimate,” “will,” “project” or words of similar meaning. We may also make forward-looking statements in other reports, in presentations, in material delivered to shareholders and in press releases. In addition, our representatives may from time to time make oral forward-looking statements. Such statements are based on the current expectations and certain assumptions of Siemens’ management, of which many are beyond Siemens’ control. These are subject to a number of risks, uncertainties and factors, including, but not limited to those described in disclosures, in particular in the chapter Risks in Siemens’ Annual Report. Should one or more of these risks or uncertainties materialize, or should underlying expectations not occur or assumptions prove incorrect, actual results, performance or achievements of Siemens may (negatively or positively) vary materially from those described explicitly or implicitly in the relevant forward-looking statement. Siemens neither intends, nor assumes any obligation, to update or revise these forward-looking statements in light of developments which differ from those anticipated.