CORRECTED COPY

This is a correction to Partial Grant of Exemption, No. 10964, issued on March 28, 2014. Changes clarify that the exemption was granted to § 33.27(b)(3) and not § 33.27(f)(6) under "The FAA's Analysis" and "The FAA's Decision" sections. The FAA's decision remains the same. Please file this corrected copy with the signed original Partial Grant of Exemption.

Exemption No. 10964

UNITED STATES OF AMERICA
DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
BURLINGTON, MA 01803-5229

In the matter of the petition of **ROLLS-ROYCE PLC** for an exemption from § 33.27(f)(6) of Title 14, Code of Federal Regulations	**Regulatory Docket No. FAA-2013-1049A**

PARTIAL GRANT OF EXEMPTION

By letter dated December 9, 2013, Mr. Iain Park, Airworthiness Specialist, on behalf of Rolls-Royce plc, ML-52, PO Box 31, Derby, DE24 8BJ, England, petitioned the Federal Aviation Administration (FAA) for an exemption from Title 14, Code of Federal Regulations (14 CFR) § 33.27(f)(6), Amendment 33-31. The proposed exemption, if granted, would provide relief from the rotor overspeed provision that prohibits the exclusion of the entire shaft system from loss of load consideration.

The petitioner requests relief from the following regulation:

> **Section 33.27(f)(6), Amendment 33-31**, Turbine, compressor, fan, and turbosupercharger rotor overspeed.
>
> "(f) Failure of a shaft section may be excluded from consideration in determining the highest overspeed that would result from a complete loss of load on a turbine rotor if the applicant:

(6) Does not exclude the entire shaft."

The petitioner supports its request with the following information:

This section quotes the information from the petitioner's request, dated January 21, 2014. The complete petition is available at the Department of Transportation's Federal Docket Management System at http://regulations.gov under Docket No. FAA-2013-1049.

B. Pertinent Section of the Code of Federal Regulations

Rolls-Royce hereby petitions for an exemption from 14 C.F.R. § 33.27(f)(6). This exemption is requested for the HP shaft system only, for the Trent 1000 engine models identified in Section C below.

The pertinent provisions of 14 C.F.R. § 33.27 are:

14 C.F.R. § 33.27 Turbine, compressor, fan, and turbosupercharger rotor overspeed.

(f) Failure of a shaft section may be excluded from consideration in determining the highest overspeed that would result from a complete loss of load on a turbine rotor if the applicant:

(6) Does not exclude the entire shaft.

C. The Exemption Being Sought

Rolls-Royce requests an exemption from 14 C.F.R. § 33.27(f)(6) for the HP shaft system of the following Trent 1000 engine models:

Model	Rating x 1000 lbs.
Trent 1000-K2	74 Hot and High
Trent 1000-J2	74
Trent 1000-L2	70 Hot and High + 24°C Kink point
Trent 1000-D2	70 Hot and High + 20°C Kink point
Trent 1000-C2	70
Trent 1000-G2	67
Trent 1000-A2	64
Trent 1000-H2	58
Trent 1000-E2	53

No exemption is sought for other shaft systems on these, or any other, engine models. The HP shaft system will comply with § 33.27, subject to the granting of the exemption from § 33.27(f)(6) requested herein.

Relief from § 33.27(f)(6) is sought because analysis has failed to show that failure of the HP shaft system can never result in overspeed to burst. The design of the HP shaft system is not amenable to analysis by shaft section. Rolls-Royce therefore seeks an exemption from § 33.27(f)(6) to exclude the entire HP shaft system from consideration in determining the highest overspeed that would result from a complete loss of load on a turbine rotor. However, as demonstrated in Section E below, the level of safety afforded by compliance with § 33.27 for the HP shaft system will be unaffected by the granting of an exemption from § 33.27(f)(6).

In sum, Rolls-Royce is requesting this exemption because compliance with § 33.27 cannot be shown absent an exemption from § 33.27(f)(6). However, compliance can be shown, with at least an equal level of safety to that required to meet § 33.27, if the exemption is granted.

D. Statement of Public Interest

Granting this exemption will promote and serve the public interest because:

- The state-of-the-art engine models (and the HP shaft system) at issue in this petition represent the latest generation of engines and engine technology from the Trent engine family. The Trent line of engines has established an outstanding track record of performance and safety over 41 years and more than 228 million service flight hours. Thus, the engine models and shaft system at issue in this petition are based on proven expertise and in-service-verified design styles and practices. This experience and track record helps to ensure the reliability and safety of the product. As explained further in the points immediately below, the introduction of these engine models into service will generate valuable public benefits.

- The granting of the requested exemption will expedite the entry into service of superior engines and engine technology that will enhance the safety and reliability of airline operations, and increase the efficiency of aircraft performance, thereby promoting U.S. economic interests (including those of Boeing, U.S. airlines, and their employees and shareholders) as well as those of the traveling public, while also reducing adverse effects on the environment. All of these enhancements constitute substantial public benefits.

- These state-of-the-art engine models will reduce the operating costs of aircraft, and the airlines that operate them, relative to costs associated with aircraft that are currently in service. Such a reduction in operating costs will benefit U.S. and international airlines, their employees and shareholders.

Moreover, such reduced operating costs provide the opportunity for airlines to offer more and less expensive air service options to the traveling public.

- Certification of state-of-the-art engine models, when operated in the Boeing 787, will reduce fuel burn, thereby reducing harmful emissions such as carbon dioxide (CO^2) and NOx from levels experienced with engines currently in service.

- The Trent 1000 models are installed on the Boeing 787-9 which has customers outside the United States. Sales of the engine contribute to the U.S. economy, support U.S. jobs, and enhance the U.S. balance of trade and gross domestic product—all of which promote the U.S. public interest.

E. Statement of No Adverse Effect on Safety

The FAA's grant of this requested exemption will have no adverse effect on safety. Compliance with § 33.27 is significant for safety purposes because it demonstrates that an engine's rotors will not fail under a varying range of potential operating conditions. The requirements contained in § 33.27(f) are significant for safety because this subsection allows failures of shaft sections to be excluded from the range of conditions considered under § 33.27, but only if a design organization can demonstrate that the risk of such shaft section failures is sufficiently remote. Subsection 33.27(f)(6) does not in itself impose any additional safety requirement. Clearly, if risk of failure of the whole shaft system is considered and shown to be at least as remote as is acceptable for "shaft sections," then the overall level of safety must be at least equal to circumstances in which only "shaft sections" are considered, as provided for under § 33.27(f). Subsection 33.27(f)(6) was included in Section 33.27 based on a history of failures associated with conventional shaft systems, which raised doubt about the ability of design organizations to fully assess the potential failure modes (and failure rate) of an entire shaft system. However, for the HP shaft system of the Trent 1000 (and indeed for other Rolls-Royce modern 3 shaft engines), this analysis can be carried out with high fidelity because:

1. The HP shaft system design utilized across the Trent engine family differs significantly from conventional shaft systems. For example, it features no bearings or oil system components, has high stiffness and significant clearance relative to other shafts; consequently, the threats associated with the features of a conventional shaft do not apply. A Failure Mode and Effect Analysis has determined that there are no known or potential environmental threats to the integrity of the HP shaft system components that could lead to a loss of load failure.

2. In order to ensure a high level of integrity, the special controls applied to the torque-transmitting components (i.e., the HP Compressor Rear Drum and the HP Turbine disc of the HP shaft system) are of a higher standard than those of many

other shaft systems in the past. These mandated controls address, but are not limited to:

- Material specifications;
- Material properties (e.g., low cycle fatigue, high cycle fatigue, creep);
- Manufacturing induced anomalies;
- Service induced damage tolerance assessment;
- Safe life mandatory inspections; and
- Mandatory cycle life limitation.

3. The theoretical assessment of points 1) and 2) above is supported by the service experience of the Rolls-Royce three shaft family of engines, all of which incorporate the same design style for the HP shaft system as the Trent 1000 engine models that are the subject of this petition. Over the course of more than 228 million service flight hours, there have been no failures of the HP shaft system torque path on the Trent family of engines. This performance reflects an extremely remote potential failure rate of less than 3.1 x 10-9 failures per flight hour.

In sum, there is ample evidence that analysis of the complete HP shaft system on the Trent 1000 models at issue achieves the level of fidelity required for failures of shaft sections under § 33.27(f). Therefore, the level of safety under the requested exemption will be at least equal to that otherwise provided by § 33.27, thereby assuring that no adverse effect on safety will result from a grant of the requested exemption.

F. Summary for Federal Register

In accordance with § 11.81(f), Rolls-Royce offers the following summary suitable for publication in the Federal Register.

Petitioner: Rolls-Royce plc

Section of 14 C.F.R. Affected: 14 C.F.R. § 33.27(f)(6)

Description of Relief Sought:

Rolls-Royce requests an exemption from 14 C.F.R. § 33.27(f)(6) to be applied to Rolls-Royce Trent1000 engine, models Trent 1000-A2, Trent 1000-C2, Trent 1000-D2, Trent 1000-E2, Trent 1000-G2, Trent 1000-H2, Trent 1000-J2, Trent 1000-K2, and Trent 1000-L2. Rolls-Royce seeks to exclude the entire HP shaft system from consideration in determining the highest overspeed that would result from a complete loss of load on a turbine rotor.

G. Additional Supporting Information

EASA Certification requirements CS-E 840 and CS-E 850 are similar requirements to those of § 33.27. The Trent 1000 engine models at issue have been certified by EASA under Type Certificate E.036 issue 4, which was released on September 10, 2013. To meet the requirements of CS-E 840 and CS-3 850, EASA granted an Equivalent Safety Finding. The evidence provided to support this Equivalent Safety Finding was similar to that provided in this petition for exemption. The Equivalent Safety Finding was accepted by EASA on August 27, 2013.

H. Privileges of this Exemption Outside the United States

Per 14 C.F.R. § 11.81(h), Rolls-Royce requests that the privileges of this exemption be extended outside the United States. This extension of privileges is necessary for operations based within foreign countries having bilateral agreements with the United States accepting FAA 14 C.F.R. Part 33 as their airworthiness standards for transport category aircraft. The Trent 1000 is intended for the global marketplace, with customers based in countries utilizing the U.S. airworthiness standards.

I. Good Cause Exists to Issue the Exemption without Notice and Comment

Pursuant to 14 C.F.R. § 11.87, Rolls-Royce requests that this petition be processed without publication in the Federal Register for notice and comment, as may otherwise be required. Rolls-Royce believes that good cause exists to not delay this action because: a) granting of this petition will not set a precedent; b) the relief requested is effectively identical an Equivalent Safety Finding previously accepted by EASA (c) delaying the action would adversely affect Rolls-Royce because the Trent 1000 engine models covered by this petition are currently undergoing cross-validation with the FAA, the timing of which is aimed at meeting Boeing requirements for entry into service of the Boeing 787-9, and significant delays in engine validation would impact the Boeing program; and (d) this petition is timely filed.

Federal Register Publication

The FAA determined that the petition for exemption may set a precedent and identical exemptions had not been previously granted. Therefore, per 14 CFR 11.87, publishing in the Federal Register for public comment was necessary. A summary of the petition was published in the Federal Register on February 26, 2014 (79 FR 10868). One supportive comment was received from The Boeing Company.

The FAA's Analysis

14 CFR 33.27 specifies that when determining the maximum overspeed condition applicable to each rotor, the failure of the component or system that is most critical must have margin to burst of more than 5 % of rotor terminal speed, i.e., the speed resulting from a loss of load event. Section 33.27(f)(6) prohibits exclusion of the entire shaft for a loss of load failure. The

petitioner, Rolls-Royce plc, has petitioned for exemption to § 33.27(f)(6) for the high-pressure (HP) shaft system. Our review of the petitioner's petition, supporting data, and the requirement we imposed indicated that what we granted the petitioner was not an exemption to § 33.27(f)(6), but to § 33.27(b)(3). Section 33.27(b)(3) requires a rotor burst margin be greater than 5 % of rotor terminal speed.

The FAA has reviewed the data provided by Rolls-Royce and concludes granting this petition for the Trent 1000-A2, C2, D2, G2, J2, K2 and L2 engine models, subject to the condition that the HP disc burst speed is greater than 100 % rotor terminal speed due to HP shaft system failure, has no adverse effect on safety and is in the public interest.

Effect on Safety

The FAA requires that engine models under this partial exemption have disc burst margins greater than 100 % rotor terminal speed due to HP shaft system failure.

The FAA has not had a request for relief from 14 CFR 33.27(f)(6) previously. When the rule was promulgated, the assumption was that if an HP turbine loss of load occurred, the HP compressor would surge and stall, ensuring the energy in the system was low enough to preclude disc burst. For this petition, Rolls-Royce provided data showing that if an HP shaft failure occurred, the HP turbine disc burst speed would be less than the 105 % of the terminal speed required by the regulation. Rolls-Royce provided their justification to show that an HP shaft system failure is not expected to occur.

Rolls-Royce presented a Failure Modes and Effects Analysis (FMEA) assessing the known potential failure modes of the HP shaft system environment. The FMEA Rolls-Royce submitted identified no hazardous concerns.

Rolls-Royce provided data to show that the Trent 1000 engine models are consistent with their experience on similar three-shaft engine designs, including stress margins. The HP shaft system is comprised of two life-limited parts, and is simple relative to the intermediate- and low-pressure shaft systems. Rolls-Royce reported they never had a failure of the HP shaft system within their family of three-shaft engine designs.

Rolls-Royce has shown that the Trent 1000 engine design is sufficiently similar to the design of other Rolls-Royce three-shaft engine designs. Therefore, the 244 million flight-hours service experience accrued by similar engines is applicable to this petition. Since Rolls-Royce reports no known failures of the HP shaft system, Rolls-Royce estimates the predicted failure rate is 2.87×10^{-9} per engine flight hour[1] for the HP shaft system.

[1] Rolls-Royce's petition for exemption initially used 3.1×10^{-9} as its predicted failure rate, based on engine flight hours through October 2012. Rolls-Royce updated the predicted failure rate to 2.87×10^{-9} based on engine flight hours through December 31, 2013.

Section 33.27 requires the applicant to assume failure of the entire shaft system and evaluate the resulting disc speeds. Rolls-Royce presented terminal speed estimates showing that on seven of the nine Trent 1000 engine models listed in the petition for exemption, the HP disc would have less than the 105 % terminal speed required by 14 CFR 33.27, if a shaft failure occurred. Rolls-Royce provided sufficient information to show their terminal speed prediction methodology is validated.

Rolls-Royce provided their justification to show that an HP shaft system failure is not expected to occur. The FAA reviewed their data and disagrees. We concluded that it is impossible to know all potential failure modes of the HP shaft system or to show that no failure will occur during the life of the engine by using past experience.

The FAA has determined, as part of Rolls-Royce's petition, that allowing disc burst speed to be less than 100 % rotor terminal speed could result in a hazardous condition. Therefore, to ensure that safety is not adversely affected because of an HP shaft failure, the HP turbine disc burst speed must be greater than the terminal speed. Further, we also determined that the data (field experience, design similarity, FMEA, and terminal speed methodology) Rolls-Royce provided is sufficient to reduce from the 105 % terminal speed requirement of 14 CFR 33.27 without adversely affecting safety.

Based on what the petitioner demonstrated in its supporting package and the requirement we imposed, an exemption to § 33.27(f)(6) is not applicable. Rather, the petitioner's request is a petition for exemption to § 33.27(b)(3), and the requirement that rotor burst margin be greater than 5 % of rotor terminal speed. Therefore, we interpret the petitioner's request as a request for exemption to § 33.27(b)(3).

In consideration of the above, the FAA concludes that granting this petition in part will not adversely affect safety, provided Rolls-Royce shows the HP disc burst speed is greater than 100 % rotor terminal speed due to HP shaft system failure.

Public Interest

The partial grant of the requested exemption will permit entry into service of the Trent 1000-A2, C2, D2, G2, J2, K2 and L2 engine models. We agree the proposed engine models will provide economic and environmental benefits to the public. Therefore, the FAA concludes that a partial grant of this petition is in the public interest.

The FAA's Decision

In consideration of the foregoing, I find that a partial grant of exemption will not adversely affect the level of safety provided by the regulations and is in the public interest. Therefore, pursuant to the authority contained in 49 U.S.C. §§ 106(f), 40113 and 44701, delegated to me by the Administrator, the petitioner, Rolls-Royce plc, is hereby granted a partial exemption from 14 CFR 33.27(b)(3) to the extent necessary to allow the type certification of Rolls-Royce Trent 1000-A2, C2, D2, G2, J2, K2 and L2 engine models, subject to the condition listed below:

Rolls-Royce must show for each of the listed Trent 1000 engine models that the HP disc burst speed is greater than 100 % rotor terminal speed due to HP shaft system failure.

Rolls-Royce also requested exemption for the Trent 1000-H2 and E2 engine models. However, these models meet the 105 % rotor terminal speed requirement of 14 CFR 33.27. As they already meet the rule, no exemption is necessary; therefore, the exemption is not granted for the Trent 1000-H2 and E2 engine models.

Issued in Burlington, Massachusetts, on February 19, 2015.

\\SIGNED\\
Colleen D'Alessandro
Assistant Manager, Engine and Propeller Directorate
Aircraft Certification Service