7.2 Subsequent safety actions

The ATSB's understanding of the occurrence event and the factors contributing to it evolved over the course of the investigation. Further contributing safety factors and other safety factors were identified and the associated safety actions are set out below.

7.2.1 Intermediate pressure turbine overspeed and burst following failure of drive arm due to internal engine fire

Safety issue

Following the separation of the IP turbine disc from the drive arm, the engine behaved in a manner that differed from the engine manufacturer's modelling and experience with other engines in the Trent family, with the result that the IP turbine disc accelerated to a rotational speed in excess of its design capacity whereupon it burst in a hazardous manner.

Action taken by Rolls-Royce

On 3 December 2010, Rolls-Royce released NMSB RB.211-73-AG639, advising Trent 900 operators of the introduction of a revised standard of engine management software that featured an IP turbine overspeed protection system (IPTOS).

The IPTOS was intended to detect engine conditions with the potential to lead to an IP turbine over speed. In response, IPTOS would shut down the engine before the IP turbine disc reached its critical burst speed. Shaft breaks and disc separation, such as occurred in VH-OQA can occur for mechanical reasons such as component fatigue, an over torque being applied to the shaft or a manufacturing defect, or by localised heating such as from an oil-fed fire. During the course of the investigation into the No.2 engine failure in VH-OQA, the ATSB was provided a detailed summary of the IPTOS protection system, which works on the following logic:

> The first element arms the system, and is based on detecting a prescribed rate of temperature change of turbine cooling air at the front (TCAF) or rear (TCAR) of the IP turbine. Such rates of change indicate that a fire has developed within the engine that may lead to localised heating of the IP turbine disc or shaft.

> Once armed, if an abnormally high rapid rate of compressor deceleration is detected, a shaft break or disc separation is indicated and the EEC (engine electronic controller) will instantly shut off the fuel, open all the bleed valves and close the variable stator vanes.
>
> Flight crew are alerted to an IP shaft failure through a flight deck annunciator alert that raises the message 'ENG FAIL-SHAFT FAILURE'.

Rolls-Royce reported that the engine EEC software upgrade that included the IPTOS functionality was incorporated across the Trent 900 fleet by 6 December 2010.

Action taken by Airbus

On 9 December 2010, in conjunction with the release of the Trent 900 IPTOS as advised in Rolls-Royce NMSB RB.211-73-AG639, Airbus released service bulletin A380-73-8011 to operators of Trent 900 equipped A380 aircraft. This bulletin required the IPTOS to be installed across the Trent 900-equipped fleet.

Action taken by EASA

On 13 December 2010, EASA issued airworthiness directive AD: 2010-0262 in respect of modifying the Trent 900 EEC software by incorporating the IPTOS logic, as detailed in Rolls-Royce NMSB RB.211-73-AG639. The airworthiness directive required all Trent 900 engines to be modified within 10 flight cycles.

A full copy of EASA AD: 2010-0262 is available at:

http://ad.easa.europa.eu/ad/2010-0262

ATSB assessment of Rolls-Royce, Airbus and EASA safety action

The ATSB is satisfied that the action taken by Rolls-Royce, Airbus and EASA adequately addresses the safety issue in respect of the risk of an IP turbine overspeed and burst. Therefore the ATSB makes no recommendation in relation to this issue.

7.2.2 Release of non-conforming oil feed stub pipes into service

Safety issue

Numerous other engines within the Trent 900 fleet were also found to contain a critical reduction in the oil feed stub pipe wall thickness.

Action taken by Rolls-Royce

In December 2010, in response to this safety issue, Rolls-Royce focussed on assessing the oil feed stub pipe counter bore geometries across the Trent 900 engine fleet. Following a stress analysis and numerical modelling of the stub pipe counter bore geometry, a minimum calculated stub pipe wall thickness acceptance limit of 0.5 mm was established in order for engines to remain in service. Any engine with a stub pipe thickness below this limit was removed from service. Wall thicknesses were established across the fleet using either:

- a specialist borescope visual inspection and measurement of the oil feed stub pipe counterbore (NMSB 72-G595)
- examination of a 'replicast' (a rubber-like mould) of the oil feed stub pipe's internal features (Technical Variance 108953)
- a borescope inspection to identify the serial numbers of relevant HP/IP bearing support structures fitted to Trent 900 engines (NMSB 72-643)
- existing manufacturing data.

The borescope inspection technique introduced by NMSB 72-G595 was successful in identifying in-service oil feed stub pipes with reduced wall sections. However, based on the results, the tolerances were not sufficient to provide confidence for accurate service management.

The available manufacturing data was analysed by Rolls-Royce from early December 2010 to calculate the oil feed tube wall thickness in some B-standard HP/IP bearing support structures and all C-standard structures. Rolls-Royce elected to withdraw all of the A-production standard HP/IP bearing support structures due to their manufacturing records being unavailable.

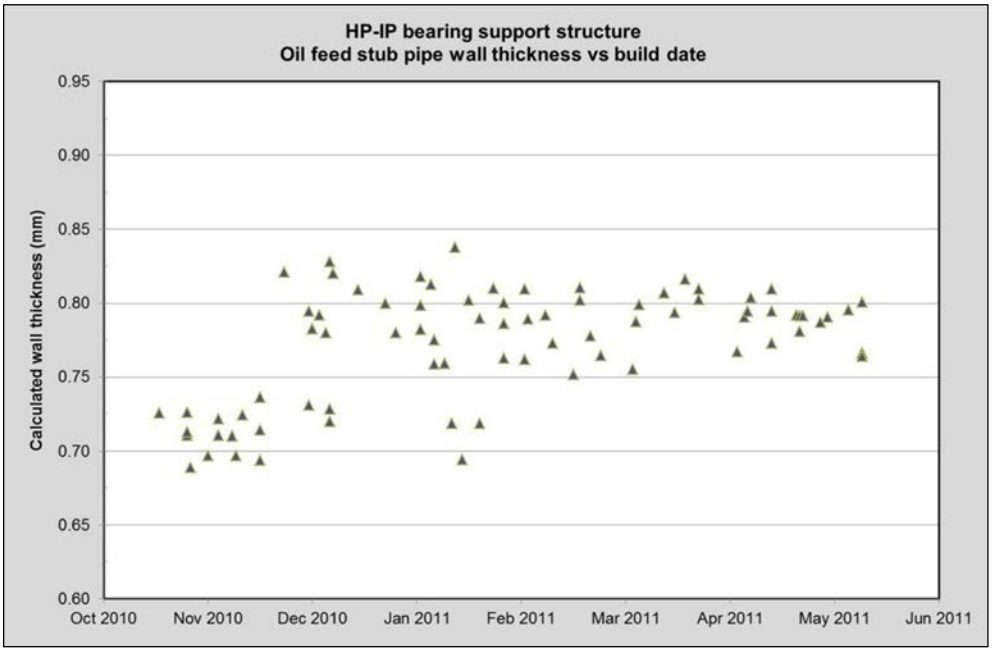
As a result of this action, 40 engines were removed from service having been identified with an oil feed stub pipe wall thickness of less than 0.5 mm. This resulted in the removal from service of the following engines:

- 14 engines with an A-production standard HP/IP bearing support structure
- 23 engines with a B-production standard HP/IP bearing support structure. Of these, five were removed from Qantas-operated A380 aircraft
- Three engines with a C-production standard HP/IP bearing support structure.

Following the occurrence, the stub pipe wall thickness production limit was restricted to 0.70 mm for all newly manufactured engines (Figure 93). The revised limit was introduced in December 2010, along with enhanced techniques for the measurement of critical dimensions within the counter bore region.

Rolls-Royce production data showed that, after the introduction of this revised limit in December 2010, the quality control of the manufacture of the HP/IP bearing support structure at the Hucknall facility had improved (Figure 93).

Figure 93: Production data for the HP/IP bearing support structures that were manufactured at the Hucknall facility



ATSB assessment

The ATSB is satisfied that the action taken by Rolls-Royce adequately addresses this safety issue and therefore makes no recommendation.

7.2.3 Consultation between manufacturing engineers and design engineers to ensure maintenance of design intent

Safety issue

The engine manufacturer did not require its manufacturing engineers to consult with the design engineers to ensure that design intent would be maintained when introducing manufacturing datums.

Action taken by Rolls-Royce

Rolls-Royce advised the ATSB that:

> In January 2011, a revision to GQP [group quality procedure] 'Manufacturing Technical Package' was issued that provided greater structure and guidance for buy-off [manufacturing acceptance] between design and manufacturing personnel.

ATSB assessment

The ATSB is satisfied that the action taken by Rolls-Royce adequately addresses this safety issue and therefore makes no recommendation.

7.2.4 Use of manufacturing stage drawings for the first article inspection

Safety issue

The procedure for the first article inspection process contained ambiguities that resulted in an interpretation whereby the use of the manufacturing stage drawings was deemed to be acceptable.

Action taken by Rolls-Royce

As part of their ongoing quality assurance activities, Rolls-Royce had previously revised the group quality procedure for first article inspections to explicitly preclude the use of manufacturing stage drawings during the inspection. In addition, Rolls-Royce advised the ATSB that in January 2011:

> A revision to the First Article Inspection (FAI) process was also issued that provided further guidance to personnel if the design intent could not be met.

ATSB assessment

The ATSB is satisfied that the actions taken by Rolls-Royce adequately addresses this safety issue and therefore makes no recommendation.

7.2.5 Culture of acceptance of 'minor' non-conforming components during manufacture at the Rolls-Royce Hucknall facility

Safety issue

A culture existed within the engine manufacturer's Hucknall facility where it was considered acceptable to not declare what manufacturing personnel determined to be minor non-conformances in manufactured components.

Action taken by Rolls-Royce

During the ATSB's investigation, Rolls-Royce advised that, in June 2007, an independent product process audit was conducted at the manufacturer's facility at Hucknall. The audit found that items being produced at Hucknall contained high levels of non-conformance that were not being reported through the existing non-conformance management process.

The manufacturer reported the following safety actions had been taken in response to those audit findings:

> All output from Hucknall [Casings and Structures] (HCAS) was stopped.
>
> Civil and Defence engineering teams were engaged to assess any non-conformance in order to identify anything that could affect fit, form or function.
>
> The CAA were informed of a 'compliance issue at Hucknall'.

All HCAS employees were briefed in July 2007, and again in October/November 2007. The key message to employees was to emphasise the concession process requirement that all non-conformances to the engineering drawings must be identified and assessed.

A major quality investigation (MQI) was raised on 15 August 2007 to investigate systems, processes and behaviours.

These actions were completed in June 2008.

ATSB assessment

The ATSB is satisfied that the action taken by Rolls-Royce adequately addresses this safety issue and therefore makes no recommendation.

7.2.6 Difference between drawing datum and coordinate measuring machine datum

Safety issue

The coordinate measuring machine was programmed to measure the location of the oil feed stub pipe interference bore with respect to the manufacturing datum, instead of the design definition datum as specified on both the design and manufacturing stage drawings.

Action taken by Rolls-Royce

Rolls-Royce advised the ATSB that in July 2008, the design definition and manufacturing stage drawings had been changed to use the inner diameter of oil feed stub pipe as the datum for the oil feed stub pipe counter bore. During March and April 2009 both the manufacturing process and the coordinate measuring machine program were changed to use that revised datum. Use of the original manufacturing datum was discontinued.

ATSB assessment

The ATSB is satisfied that the action taken by Rolls-Royce adequately addresses this safety issue and therefore makes no recommendation.

7.2.7 Expert review of statistical analysis in support of retrospective concessions

Safety issue

The engine manufacturer did not have a requirement for an expert review of statistical analyses used in retrospective concession applications.

Action taken by Rolls-Royce

On 25 May 2011, Rolls-Royce advised the ATSB that a major corrective action, which arose from an internal major quality investigation, was to remove the existing retrospective concession procedures from their quality system, and replace

them with a new Global Process titled *Management of Undeclared Non-Conformance in Delivered Product*.

The global process was developed to ensure an improved and more consistent approach across the company when it is identified that parts containing undeclared and non-conforming features have been released to the customer for entry into service. The global process included a technical review by a statistic expert.

The global process was incorporated into the engine manufacturer's quality management system on 4 July 2011.

ATSB assessment

The ATSB is satisfied that the action taken by Rolls-Royce adequately addresses this safety issue and therefore makes no recommendation.

7.2.8 Chief Engineer and Business Quality Director review of retrospective concessions

Safety issue

The engine manufacturer's process for retrospective concessions did not specify when in the process the Chief Engineer and Business Quality Director approvals were to be obtained. Having them as the final approval in the process resulted in an increased probability that the fleet-wide risk assessment would not occur.

Action by Rolls-Royce

On 25 May 2011, Rolls-Royce advised the ATSB that a major corrective action, which arose from an internal major quality investigation, was to remove the existing retrospective concession procedures from their quality system, and replace them with a new Global Process titled *Management of Undeclared Non-Conformance in Delivered Product*.

The global process was developed to ensure an improved and more consistent approach across the company when it is identified that parts containing undeclared and non-conforming features have been released to the customer for entry into service. The global process requires the Chief Engineer and the Business Quality Director to be involved in the process at a much earlier stage to ensure that the fleet-wide risk assessment is conducted.

The global process was incorporated into the engine manufacturer's quality management system on 4 July 2011.

Additionally, Rolls-Royce carried out an independent audit and review of the retrospective concession activity for the 2009 to 2011 period. The review revealed that only 7 out of 138 retrospective concessions that had been raised within the Civil Large Engine business unit were compliant with the engine manufacturer's procedures.

All non-compliant retrospective concessions that had been raised since 2009 were subsequently identified and revalidated by the appropriate Chief Engineer and Business Quality Director. Other than the retrospective concession regarding the

misalignment of the oil feed stub pipe counter bores, no safety concerns were identified and no in-service activity required.

ATSB assessment

The ATSB is satisfied that the actions taken by Rolls-Royce adequately addresses this safety issue and therefore makes no recommendation.

7.2.9 Reporting of significant non-conformances to the quality review board

Safety issue

The engine manufacturer's group quality procedures did not provide any guidance on how manufacturing personnel were to determine the significance of a non-conformance, from a quality assurance perspective.

Action taken by Rolls-Royce

On 25 May 2011, Rolls-Royce advised the ATSB that a major corrective action, which arose from an internal major quality investigation, was to remove the existing retrospective concession procedures from their quality system, and replace them with a new Global Process titled *Management of Undeclared Non-Conformance in Delivered Product*.

The global process was developed to ensure an improved and more consistent approach across the company when it is identified that parts containing undeclared and non-conforming features have been released to the customer for entry into service. The global process includes involvement of quality assurance personnel from the initiation of the process through to its completion.

The global process was incorporated into the engine manufacturer's quality management system on 4 July 2011.

ATSB assessment

The ATSB is satisfied that the action taken by Rolls-Royce adequately addresses this safety issue and therefore makes no recommendation.

7.2.10 Classification of the HP/IP bearing support assembly

Safety issue

The manufacturer's classification, relating to the criticality of failure, of the HP/IP bearing support assembly was inappropriate for the effects of a fire within the buffer space and hence, the requirement for an appropriate level of process control was not communicated to the manufacturing staff.

Action taken by Rolls-Royce

In February 2012, Rolls-Royce advised the ATSB of the initiation of a major quality investigation into Trent 900 failure modes effects and criticality analysis

(FMECA) inaccuracies. That investigation was commenced after it was identified that the potential for an IP turbine disc failure was not reflected in the Trent 900 FMECA certification documentation as a hazardous event. Safety action by Rolls-Royce included:

> ...the Trent 900 FMECAs have been reviewed and updated in light of the QF32 event. The Oil System and Transmissions FMECAs have now been updated.

The manufacturer advised that as a result of the review of the FMECA, it had reclassified the HP/IP bearing support from 'unclassified' to 'reliability sensitive'. This change in classification would require the appropriate level of process control.

ATSB assessment

The ATSB is satisfied that the action taken by Rolls-Royce adequately addresses this safety issue and therefore makes no recommendation.

7.2.11 Landing distance calculation at aircraft weights below the A380 maximum landing weight

Safety issue

The calculation method in the aircraft manufacturer's landing distance performance application was overly conservative and this could prevent the calculation of a valid landing distance at weights below the maximum landing weight with multiple system failures.

Action taken by Airbus

On the 28 September 2011, in response to this safety issue, Airbus advised the ATSB of the following safety action:

> Airbus has developed a product improvement with the in-flight landing distance application OIS 2B+, available to A380 Operators 4 October 2011 with SB A380-46-8046, that ensures consistency of computation results whatever the landing weight,
>
> Airbus has informed all A380 Operators at March 2011 Flight Safety Conference and at May 2011 Performance and Operations Conference.
>
> A further product improvement will be introduced with future OIS standards planned to be available by the third quarter of 2013 that will optimize performance calculation and therefore improve consistency of in-flight landing distance prediction to actual aircraft capability.

ATSB assessment

The ATSB is satisfied that the action taken by Airbus adequately addresses this safety issue and therefore makes no recommendation.

7.2.12 Airframe certification standards in the case of an uncontained engine rotor failure

Safety issue

The evolution of the current advisory material relating to the minimisation of hazards resulting from uncontained engine rotor failures was based on service experience, including accident investigation findings. The damage to Airbus A380-842 VH-OQA exceeded the modelling used in the UERF safety analysis and, therefore, represents an opportunity to incorporate any lessons learned from this accident into the advisory material.

Action taken by ATSB

As a result of the identified safety issue, coincident with the release of this investigation report, the ATSB has issued the following safety recommendations to the European Aviation Safety Agency and the United States Federal Aviation Administration.

ATSB safety recommendation AO-2010-089-SR-039

The Australian Transport Safety Bureau recommends that the European Aviation Safety Agency, in cooperation with the US Federal Aviation Administration, review the damage sustained by Airbus A380-842, VH-OQA following the uncontained engine rotor failure overhead Batam Island, Indonesia, to incorporate any lessons learned from this accident into the advisory material.

ATSB safety recommendation AO-2010-089-SR-040

The Australian Transport Safety Bureau recommends that the US Federal Aviation Administration, in cooperation with the European Aviation Safety Agency, review the damage sustained by Airbus A380-842, VH-OQA following the uncontained engine rotor failure overhead Batam Island, Indonesia, to incorporate any lessons learned from this accident into the advisory material

7.3 Proactive actions

7.3.1 Action taken by Airbus

Although not specifically associated with any of the safety issues identified by the ATSB investigation, Airbus advised on 9 March 2013 of the following software enhancements for the A380 aircraft.

Trim tank availability

A software upgrade to the A380 ECAM was released to all A380 operators via Service Bulletin A380-42-8022 on 25 April 2013. The upgrade further emphasises the status and availability of fuel trim tank services.

Operator compliance with the service bulletin was ‘recommended’ by Airbus.

Electrical generation and distribution

Airbus' analysis of the available data after the occurrence established that when the aircraft electrical system (feeder cables) were damaged from the liberated engine debris, the No. 2 generator line contactor (GLC2) physically opened in order to isolate the Primary Electrical Power Distribution Center (PEPDC) from potential damage (that is, from short circuits or current spikes). Airbus advised the ATSB that the associated current monitoring system onboard the aircraft had actually detected that the GLC2 remained in a closed position, even though the contacts had physically opened.

Airbus advised the ATSB that in the first-quarter of 2014, software enhancements will be available for the A380 electrical generation, distribution and monitoring system. The introduction of a revised software, 'GGPCU Standard-18', is intended to enhance the capabilities of the of the aircraft electrical system. The software is designed to monitor the electrical current at the feeder block to which each GLC is connected (as close to the GLC as possible), such that even in the hypothetical situation of a short-circuit:

- residual current from the VFG will no longer affect the monitoring of the GLC, with reliable detection of the GLC in the open or closed state
- recovery of the associated AC BUS bar will no longer be prevented.