Air Accident Investigation Unit Ireland

FACTUAL REPORT

SERIOUS INCIDENT
Boeing 767-322ER, N675UA
Shanwick Oceanic Airspace

28 March 2022

An Roinn Iompair
Department of Transport

Foreword

This safety investigation is exclusively of a technical nature and the Final Report reflects the determination of the AAIU regarding the circumstances of this occurrence and its probable causes.

In accordance with the provisions of Annex 13[1] to the Convention on International Civil Aviation, Regulation (EU) No 996/2010[2] and Statutory Instrument No. 460 of 2009[3], safety investigations are in no case concerned with apportioning blame or liability. They are independent of, separate from and without prejudice to any judicial or administrative proceedings to apportion blame or liability. The sole objective of this safety investigation and Final Report is the prevention of accidents and incidents.

Accordingly, it is inappropriate that AAIU Reports should be used to assign fault or blame or determine liability, since neither the safety investigation nor the reporting process has been undertaken for that purpose.

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[1] **Annex 13**: International Civil Aviation Organization (ICAO), Annex 13, Aircraft Accident and Incident Investigation.
[2] **Regulation (EU) No 996/2010** of the European Parliament and of the Council of 20 October 2010 on the investigation and prevention of accidents and incidents in civil aviation.
[3] **Statutory Instrument (SI) No. 460 of 2009**: Air Navigation (Notification and Investigation of Accidents, Serious Incidents and Incidents) Regulations 2009.

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In accordance with Annex 13 to the Convention on International Civil Aviation, Regulation (EU) No 996/2010 and the provisions of SI No. 460 of 2009, the Chief Inspector of Air Accidents, on 28 March 2022, appointed Kevin O'Ceallaigh as the Investigator-in-Charge to carry out an Investigation into this Serious Incident and prepare a Report. For operational reasons, Kate Fitzgerald was subsequently appointed Investigator-in-Charge.

Aircraft Type and Registration:	**Boeing 767-322ER, N675UA**	
No. and Type of Engines:	**2 x PW4000-94**	
Aircraft Serial Number:	**29243**	
Year of Manufacture:	**2000**	
Date and Time (UTC)[4]:	**28 March 2022 @ 07:50 hrs**	
Location:	**53°30'N 025°00'W, 583 NM west-northwest of Shannon Airport (EINN), Ireland**	
Type of Operation:	**Commercial Air Transport**	
Persons on Board:	**Crew – 10**	**Passengers – 116**
Injuries:	**Crew – Nil**	**Passengers – Nil**
Nature of Damage:	**Substantial (engine), minor (horizontal stabiliser)**	
Commander's Licence:	**Airline Transport Pilot (ATP) Certificate, issued by the Federal Aviation Administration (FAA) of the USA**	
Commander's Age:	**54 years**	
Commander's Flying Experience:	**16,000 hours, of which 7,171 were on type**	
Notification Source:	**Shannon Air Traffic Control**	
Information Source:	**AAIU Report Form submitted by the Pilot** **AAIU Field Investigation**	

[4] **UTC**: Co-ordinated Universal Time. All times in this report are quoted in UTC unless otherwise stated; local time at Shannon Airport was UTC +1 hour on the date of the occurrence.

SYNOPSIS

During the cruise phase of a scheduled passenger flight between Newark and Zurich, the right engine of the Boeing 767-322ER aircraft surged several times. Due to abnormal indications on several engine instruments, the Flight Crew believed that the engine had been severely damaged. They completed the '*Severe Damage*' checklist and shut down the engine. The Flight Crew made a MAYDAY transmission and diverted to the nearest suitable airport which was Shannon (EINN). The aircraft landed safely and was escorted to a parking stand by the Shannon Airport Fire and Rescue Services. The passengers and crew disembarked normally, and no injuries were reported to the Investigation. There was no fire.

NOTIFICATION AND RESPONSE

Shannon Air Traffic Control notified the AAIU shortly after this occurrence. Two Inspectors of Air Accidents deployed to EINN and commenced an investigation.

1. FACTUAL INFORMATION

1.1 History of Flight

Following the occurrence, the aircraft Flight Crew provided statements to the Investigation detailing their recollection of the event. This information, combined with data from the Flight Data Recorder was used to develop this history of flight.

The aircraft departed Newark Liberty International Airport (KEWR) at 03:35 hrs, five hours behind schedule due to an earlier aircraft change. The aircraft's intended destination was Zurich (LSZH) and there were 116 passengers and 10 crew on board.

The first four hours of the of the flight were uneventful. There were four pilots assigned to the flight; the Commander (Captain), two International Relief Officers (IRO)[5] and an Operational Experience (OE)[6] Pilot. The Commander and OE Pilot operated the aircraft for the first part of the flight whilst the two IROs rested. When it was time for the pilots to rotate duty, the IROs returned to the flight deck where the Commander and OE Pilot carried out a handover before leaving the flight deck for a scheduled crew rest break.

Less than 30 minutes later, at a time of approximately 07:50 hrs and a few minutes after a step climb to FL370[7], the right engine surged[8] several times. The two IROs identified the affected engine, and in accordance with the '*Engine limit or surge or stall*' checklist, reduced the power of that engine to idle to minimise any further surges and associated vibration.

[5] **IRO:** International Relief Officer. Additional pilot(s) required by regulation when a flight exceeds a specified scheduled duration to facilitate crew rest breaks.
[6] **OE Pilot:** refers to a first officer who is accumulating operational experience on the flight. Operational experience must be acquired in a pilot duty position under the supervision of a check pilot. In this occurrence, the captain was the check pilot.
[7] **FL370**: A three-digit representation of aircraft altitude (37,000 ft in this case) referenced to standard pressure (1013.25 hPa).
[8] **Surge:** An instantaneous breakdown of airflow through the engine that is caused when the pressure rise demanded from the compressor is higher than the compressor blades can sustain. This can induce a reversal of the airflow through the engine, a loud 'bang' and a loss of thrust.

The IROs initiated a descent to an appropriate single-engine altitude and established a five nautical mile (NM) offset[9] to the right and parallel to their current track to avoid conflicting with other traffic.

The resting pilots heard the engine surge and returned to the flight deck. The IROs briefed the Commander on the situation. At this point, the N1[10] display for the affected engine was blank, the Exhaust Gas Temperature (EGT) was high and that there was a slight smell of burning in the flight deck. The four pilots determined that the engine was severely damaged and that the '*Severe Damage'* checklist was required. This was carried out by the two IRO pilots and included securing the affected engine and pulling the fire switch[11] for that engine.

The Commander then took control of the aircraft and completed the diversion checklist. The Commander also notified Shanwick Radio, made a MAYDAY transmission, requested a lower altitude, squawked 7700[12], switched on the external aircraft lights, adjusted the TCAS[13] setting, made a radio call on the designated emergency frequency (121.5 MHz) and called the Operator's dispatch centre to discuss potential alternate airports.

At that time the nearest suitable airport was identified as EINN and the Operator provided the Flight Crew with the latest available weather and landing information for EINN. The Commander updated the Flight Management Computer for a diversion to EINN, briefed the Cabin Crew and made an announcement to the passengers. The Commander decided that the most experienced First Officer (IRO1) would sit in the right seat, fulfilling the role of Pilot Monitoring for the remainder of the flight.

As the aircraft approached the west coast of Ireland, the Commander requested and was cleared for a descent to FL200 to avoid icing and to stay in Visual Meteorological Conditions. The Flight Crew received clearance for an ILS[14] approach to Runway (RWY) 06 from Shannon Approach Control. A one-engine inoperative approach was performed and the aircraft landed without further incident at approximately 09:43 hrs. The Airport Fire and Rescue Service met the aircraft and escorted it to stand.

[9] **Five mile offset:** This is an established procedure for aircraft flying in oceanic airspace that may need to descend but may not be able to contact air traffic control for clearance to descend. The aircraft departs from the cleared oceanic track to a parallel track 5 NM away for descent. This ensures separation between the affected aircraft and other aircraft that may be flying on the same oceanic track at a lower flight level.

[10] **N1:** The speed of the engine low pressure shaft expressed as a percentage. Similarly, the term N2 refers to the speed of the engine high pressure shaft expressed as a percentage.

[11] **Fire Switch:** Also known as a fire handle on other aircraft types.

[12] **Squawk 7700:** A transponder emergency code that alerts air traffic control that an aircraft has an emergency, although the emergency may not always require immediate assistance.

[13] **TCAS:** Traffic Collision Avoidance System.

[14] **ILS:** Instrument Landing System.

1.2 Injuries to Persons

No injuries were reported to the Investigation.

1.3 Damage to Aircraft

The aircraft's right engine was substantially damaged (**Section 1.8**). The horizontal stabiliser sustained minor damage due to the impact of a low-pressure turbine blade that had been ejected from the exhaust of the right engine (**Photo No. 1**). The right engine containment system remained intact.

Photo No. 1: Turbine blade impact with horizontal stabiliser

1.4 Other Damage

No other damage was reported to the Investigation.

1.5 Personnel Information

The Flight Crew of the aircraft consisted of the Commander, two IROs, and one OE Pilot.

Each pilot held a valid ATP Certificate issued by the Federal Aviation Administration (FAA) of the USA and current first-class medical certificates.

1.5.1 Flying Experience

The Flight Crew's Flying Experience is outlined in **Table No.1**.

	Commander	IRO 1	IRO 2	OE Pilot
Total all types (hrs):	16,000	14,600	10,200	6,000
Total on type (hrs):	7,171	3,216	2,513	21
Last 90 days (hrs):	158	110	150	21
Last 28 days (hrs):	78	67	53	21
Last 24 hours (hrs):	0	0	0	0

Table No. 1: Crew Flying Experience

1.6 Aircraft Information

The aircraft, a Boeing 767-322ER, was manufactured in 2000. The aircraft's Certificate of Airworthiness was issued on 28 July 2000[15]. At the time of the occurrence the aircraft had accumulated a total of 75,453 hrs. Two Pratt and Whitney PW4000-94 engines were installed. The occurrence engine had accumulated 97,839 hours / 14,881 cycles since new.

1.7 Recorded Data

1.7.1 Flight Data Recorder

The aircraft's Digital Flight Data Recorder (DFDR) could record 25 hours of data. After the occurrence, the data was downloaded and analysed. The data from the subject flight showed that while flying at FL370, there were four surges in the aircraft's right (No. 2) engine over approximately three minutes. This resulted in a drop in fuel flow, EPR[16] and combustion chamber pressure. The data also showed increases in Engine No. 2 EGT, N2 and that the N1 signal became erroneous after the first surge. The engine N1 vibration signal was lost after the first surge; during the fourth surge, the EGT exceeded the maximum temperature limit by 10 degrees Celsius for 5 seconds. The data shows that the affected engine was shutdown 200 seconds after the first surge.

1.7.2 Cockpit Voice Recorder

The aircraft's Cockpit Voice Recorder (CVR) records two hours of data. In this case, the engine failure occurred when the aircraft was at 53°30'N 025°00'W (583 NM west-northwest of EINN) and approximately two hours away from a suitable diversion airport. Therefore, the recording of the occurrence had been overwritten by the time the recorder was de-powered after landing. The Investigation notes that new regulation is under development to mandate a significantly longer recording time for cockpit voice recorders, reducing the risk of recordings being overwritten.

[15] An FAA-issued Certificate of Airworthiness remains valid as long as the aircraft meets its approved type design, is in a condition for safe operation, and maintenance, preventative maintenance, and alterations are performed in accordance with the prescribed standards.

[16] **EPR:** Engine Pressure Ratio. The ratio of engine exhaust total pressure to engine intake total pressure.

1.8 Engine Investigation

Following the occurrence, the right engine was removed from the aircraft and shipped to an approved maintenance facility for teardown and examination. Initial examinations identified that the engine's No. 1 bearing[17] was heavily distressed and the No. 1 oil pressure tube of the engine had fractured. There was also rotor clashing[18] evidenced by damage to the low-pressure turbine blade trailing edges and the corresponding stator vane leading edges. Metallic debris was also found in the engine's main oil filter.

1.8.1 No.1 Bearing Distress

Teardown of the right engine No. 1 bearing assembly revealed that multiple parts within the assembly had sustained significant damage. There was evidence of overheating and some of the rolling elements had been compressed and had lost their spherical profile (**Photo No. 2**).

Photo No. 2: Engine No. 1 Bearing post Occurrence (*Courtesy of Engine Manufacturer*)

A metallurgical analysis of the disassembled bearing components indicated likely spalling[19] on the bearing outer race. Examination of debris found in the main oil filter determined it to be bearing material. The Engine Manufacturer deemed it likely that spalling was also present on the inner race of the bearing; however, due to the level of damage on the bearing it was not possible to confirm this.

The Engine Manufacturer recommended an overhaul of the No. 1 bearing every 20,000 hours/5,000 cycles. The Operator informed the Investigation that the time since overhaul of the No 1 bearing for this engine was 4,518 hours / 702 cycles. The Engine Manufacturer reviewed the procedures used for the overhaul and confirmed that they were consistent with recommended practice.

[17] **No.1 Bearing:** The bearing near the front part of the engine, which in this case is designed to manage the axial and radial loads generated by the engine low-pressure system.
[18] **Rotor clashing:** This is when rotating hardware (compressors and turbines) within the engine makes contact with static hardware during operation.
[19] **Spalling:** The loss of small pieces of material as a result of subsurface or surface-initiated fatigue.

The aircraft maintenance schedule included an inspection of the engine magnetic chip detectors every 850 aircraft operating hours. The magnetic chip detectors for the right engine had been checked 150 hours prior to the occurrence and were found to be clear.

1.8.2 Oil Tube Failure

Metallurgical analysis of the fractured No. 1 oil tube did not identify any material or manufacturing abnormalities. Analysis of the fracture surface indicated that the oil tube failed in High Cycle Fatigue (HCF)[20]. **Photo No. 3** shows the location of the oil tube fracture.

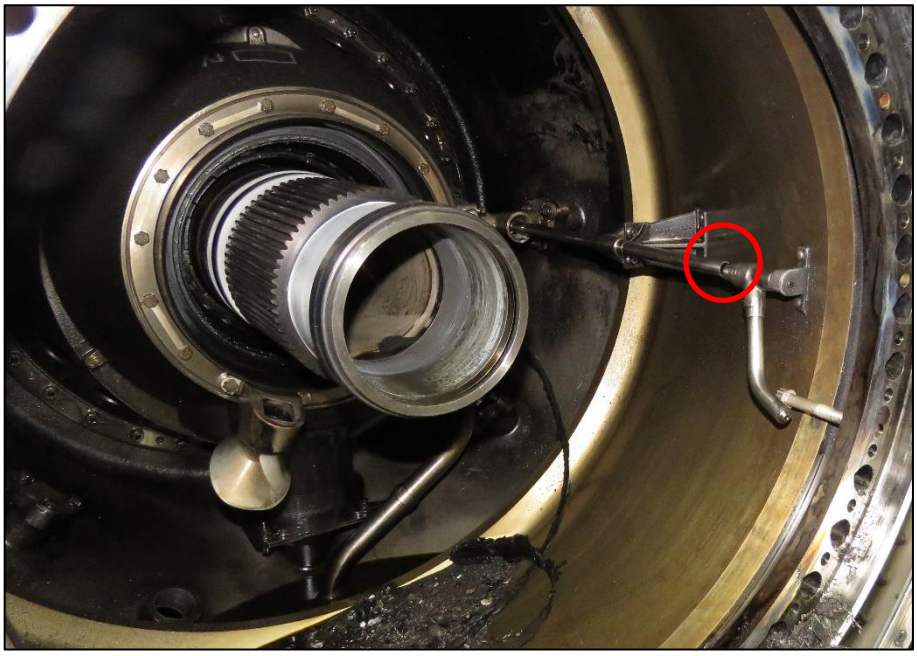

Photo No. 3: Location of oil tube fracture indicated by red circle (*courtesy of Operator*)

The Engine Manufacturer carried out a modal analysis[21] for the No.1 oil supply tube. This showed that the frequency response of a No.1 bearing with a defect in the inner race could excite the first (fundamental) frequency mode of the oil tube. In addition, the fracture of the oil tube was found to be in the location where the stress due to the fundamental frequency mode wave form was greatest.

1.8.3 Compressors and Turbines

Following the bearing failure, the low-pressure rotor shifted aft causing a loss of compressor axial position, leading to clashing between rotor blades and stator vanes. The low-pressure compressor and turbines sustained damage including blade tip fractures, trailing edge fractures and rub/smearing damage in various locations.

[20] **High Cycle Fatigue:** A type of fatigue where the initiation and propagation of cracks is caused by cycling loads, generally in the elastic range. Component failure occurs after a high number of cycles.
[21] **Modal Analysis:** An analysis of the resonant frequencies of components, either individually or as part of a system.

1.8.4 Engine Investigation Summary

The Engine Manufacturer considered that the most likely sequence of events was:

1. No.1 Bearing distress caused by spalling in the outer, and likely spalling in the inner race (the exact cause of the spalling could not be determined).
2. No.1 oil supply tube fractured in high cycle fatigue, due to vibration in its first fundamental frequency range.
3. Inadequate lubrication to No. 1 bearing caused by No. 1 oil supply tube fracture.
4. No. 1 Bearing oil starvation and overheating, leading to raceway and ball wear.
5. Aft axial shift of low-pressure shaft causing rotor clashing.
6. Multiple engine surges.
7. Impact of released turbine blade on horizontal stabiliser.
8. Engine in-flight shutdown actioned by the Flight Crew.

Appendix No. 1 shows relevant parameters recorded by the Flight Data Recorder.

1.9 Meteorological Information

Met Éireann, the Irish meteorological service, was asked to provide details of the weather conditions prevailing at 53°30'N 025°00'W, between 35,000-37,000ft on 28th March 2022 at approximately 08:00 hrs UTC. *Met Éireann* advised the Investigation that there was very limited observational data available for this location, so they provided information based on World Area Forecast Centre (WAFC) forecast charts and modelled forecast data which was analysed against observed radiosonde[22] data from Valentia. Details from the report received are reproduced in **Table No. 2**.

Meteorological Situation:	A low-pressure system to the south of Greenland with associated fronts in the mid-Atlantic were moving eastwards.
Wind:	Westerly 30-40 knots east of the front backing southerly 20-35 knots through the front.
Cloud:	No significant cloud.
Temperature/Dew Point:	-53/-75 degrees Celsius
Ambient Pressure:	250 hectoPascals (hPa).
Other Comments:	There was a front in the vicinity of the area of interest, but frontal cloud and associated hazards were at lower levels. WAFC charts highlighted moderate turbulence and moderate icing risk up to FL190. No PIREPs[23] or AIREPs[24] in the vicinity.

Table No. 2: Estimated weather conditions prevailing at 53°30'N 025°00'W between 35,000 and 37,000 feet at the time of the occurrence

[22] **Radiosonde:** Small, expendable measurement instrument package, normally suspended beneath a weather balloon.
[23] **PIREP:** Pilot Report.
[24] **AIREP:** Aircraft Report.

The FDR also recorded the ambient conditions during the flight. The conditions at the time of the occurrence are shown in **Table No. 3**.

Static Temperature:	-52.02 degrees Celsius
Total Air Temperature:	-22.75 degrees Celsius
Total air pressure:	334 hPa
Wind Velocity:	25 knots at 248.6° magnetic

Table No. 3: Ambient conditions recorded by the FDR at the times of the occurrence

1.10 Other Similar Occurrences

The PW4000-94 engine type entered service in 1987, and on the date of this occurrence the total engine fleet had accumulated approximately 138 million flying hours and 29.4 million flight cycles. The Engine Manufacturer reviewed the complete fleet history for spalling of the No. 1 bearing on the engine type and informed the Investigation that there were 40 events, six of which resulted in an engine In-Flight Shutdown (IFSD) of the affected engine. Three of the IFSD (including the subject occurrence) resulted in secondary damage to the No. 1 oil tube. The Engine Manufacturer carried out a risk analysis of this event including consideration of the ETOPS[25] requirements that are applicable in this case. It determined that the risk to the in-service engine fleet was acceptable with the current maintenance actions, and that no further mitigating actions were required.

2. AAIU COMMENT

In this occurrence, the right (No. 2) engine surged multiple times whilst the aircraft was in the cruise phase of a transatlantic flight. The Flight Crew immediately identified the affected engine, reduced the engine power of that engine to idle and commenced a descent. The two other pilots, one of whom was the Commander, were taking scheduled crew rest at the time of the engine surges but returned to the flight deck immediately when they became aware of the problem. The four pilots then reviewed the situation together. They determined that the '*severe damage*' checklist was applicable and worked through this checklist, which included shutting down and securing the affected engine. The Commander then resumed control of the aircraft and asked the most experienced of the other three Pilots to sit in the right seat and fulfil the role of pilot monitoring for the approach and landing. The diversion checklist was completed, and the aircraft diverted to EINN where a single-engine landing was performed. The aircraft was met by the Aircraft Fire and Rescue Services and taxied to stand without assistance.

Detailed analysis carried out by the Engine Manufacturer determined that the surges were the result of a sequence of events initiated by distress in the No. 1 bearing of the right engine. The bearing outer race showed evidence of spalling. The Engine Manufacturer deemed it likely

[25] **ETOPS:** Extended Twin-Engine Operation permits operation for turbine-engine-powered aircraft with two engines during which a portion of a flight is conducted beyond a specified time from an adequate airport. In order to maintain a level of safety consistent with the overall safety level achieved by modern aircraft, it is necessary for ETOPS certified aircraft to have an acceptably low risk of significant loss of power/thrust.

that spalling had also occurred in the inner race; however, secondary damage meant that this could not be definitively proven.

The distress to the No. 1 bearing caused it to vibrate at a frequency that was in the range of the first fundamental mode of the bearing oil supply tube. The associated resonance caused failure of the oil supply tube in high cycle fatigue. The No. 1 bearing subsequently failed due to oil starvation and overheating. The failure of the No. 1 bearing allowed the low-pressure rotor to move axially causing rotor clashing. This caused significant damage to the engine. The engine then surged four times. One of the turbine blades that was subsequently ejected from the engine impacted with the horizontal stabiliser causing minor damage.

The subject bearing had been overhauled 4,518 hours / 702 cycles prior to the occurrence which was within the Engine Manufacturer's recommended timeframe and using procedures that were consistent with the Engine Manufacturer's recommended practice. Scheduled examination of the engine magnetic chip detector 150 hours prior to the occurrence did not contain any bearing material.

The Engine Manufacturer reviewed the occurrences of IFSD due to bearing spallation in the fleet of PW4000 engines. It determined that the current fleet risk is acceptable and that no new mitigations were required.

- END -

3. Appendix No. 1 – Plot of relevant FDR Data

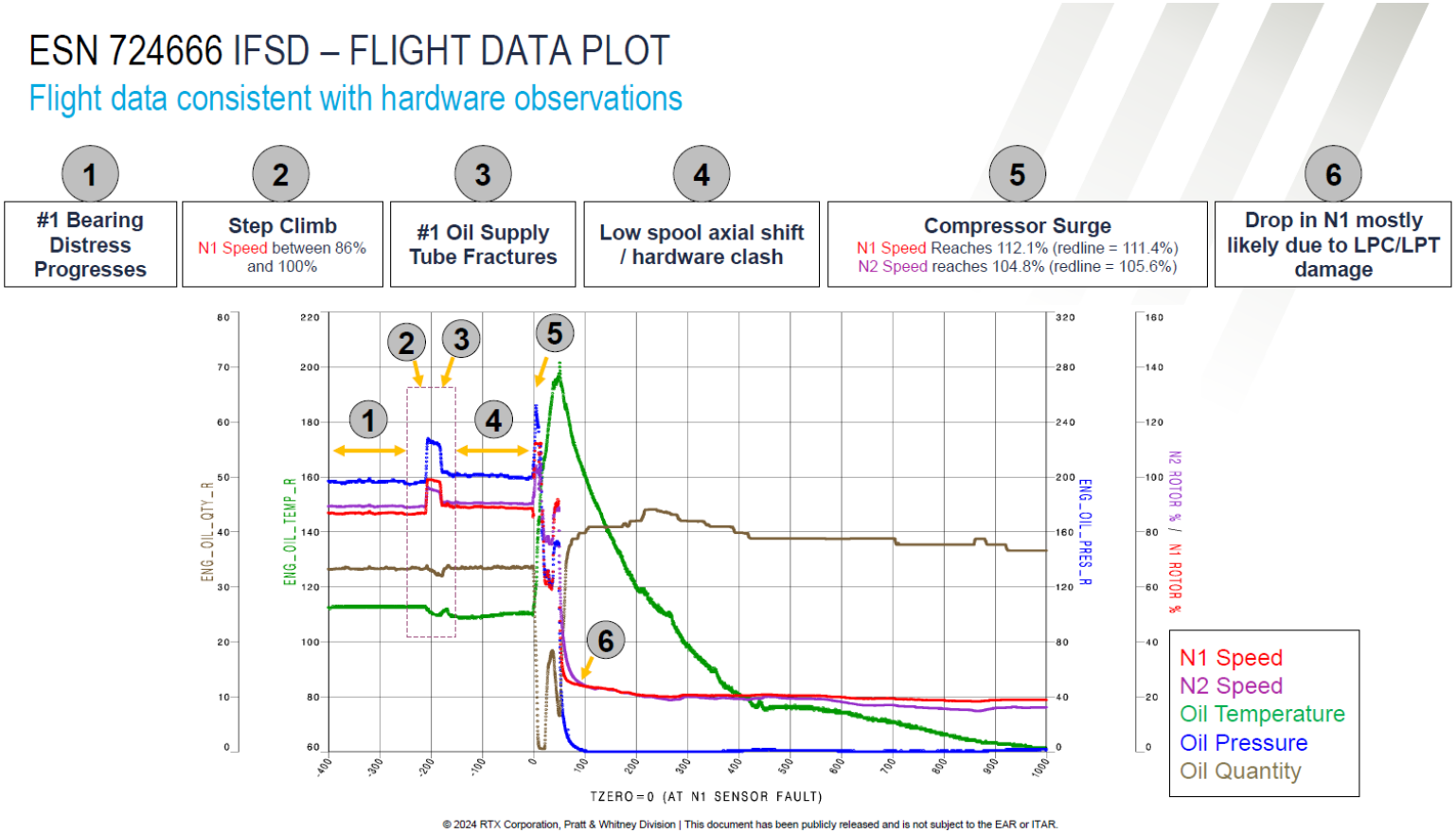

Figure No. 1: Relevant parameters recorded during failure progression (Produced by Engine Manufacturer)
NOTE: LPC denotes Low Pressure Compressor, LPT denotes Low Pressure Turbine

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Produced by the Air Accident Investigation Unit

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