ROYAL AERONAUTICAL SOCIETY
MANCHESTER BRANCH

NEWSLETTER

November 2020 Edition

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From Your Editor

The RAeS Manchester Branch cordially invites you to the next lecture of the 2020-21 programme on Volcanic Ash and Aviation. For those of you who could not attend the last lecture, Shoaib Syed – Aerospace Engineering student at The University of Manchester - has written an excellent review, available on page 3.

The November Lecture will be delivered by Dr Rory Clarkson, Engineering Associate Fellow at Rolls-Royce, responsible for ensuring engine operation under extreme environmental conditions. He is widely recognised as the global expert on the effects volcanic ash has on gas turbine engines; he has advised regulatory bodies, governments and key military and civil aviation stakeholders across the world on how volcanic ash affects aviation.

Upcoming Lecture:

Volcanic Ash and Aviation

REMOTE LECTURE
Thursday, 19th November 2020, 7:00 pm
Click here to join the lecture via Zoom

Volcanic ash clouds in flight corridors present a significant threat to aircraft operations as the ash particles can cause damage to gas turbine engine components that lead to a reduction of engine performance and compromise flight safety. Volcanic ash particles are hard and abrasive, leading to the erosion of compressor blades and static components by impinging ash particles. The particles have low melting point, and the soft or molten ash particles can lead to clogging and/or corrosion on hot section turbine airfoils and components. Additionally, the fan separates ingested volcanic ash particles from the core stream flow into the bypass flow and therefore influences the mass concentration inside the engine core section, which is most vulnerable and critical for safety.

This talk will present some of the ground-breaking work undertaken to safely reduce the disruption that volcanic ash can cause to aviation.

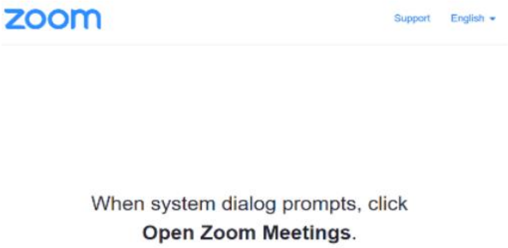
Instructions to join the event on Zoom

Given the importance of organising and holding Branch events for our members under these challenging circumstances, whilst also ensuring the members' health and wellbeing, we are hosting a series of online lectures. You do not need to create a Zoom account before accessing the Lecture link. However, if this is the first time you will be running Zoom on your computer, please allow 5-10 minutes for the software setup. The setup will automatically start upon clicking on the Lecture link and attempting to open Zoom.

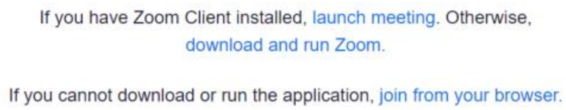
- https://r1.dmtrk.net/4OGU-XVHY-49SAP8-RNY29-1/c.aspx

For those who are not familiar with Zoom, follow these steps to join the RAeS Manchester Branch lecture:

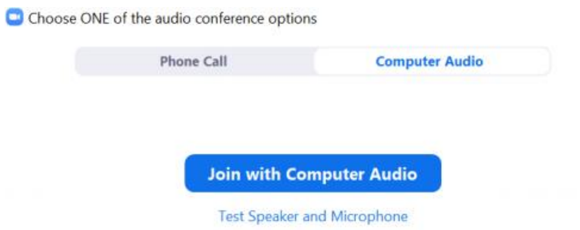
1) Use the access link shown above. Clicking the link will open your internet browser as below:



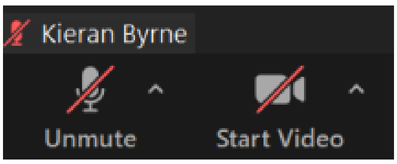
2) Use either the Zoom app or your internet browser to access.



3) On entering the lecture, press the blue button shown, "Join with Computer Audio":

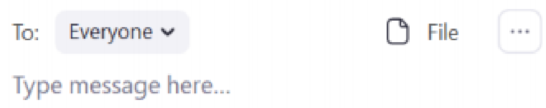


4) Please ensure your microphone and camera are turned off by pressing the buttons so they show the below. The chair of the lecture will do this, but it will assist if all attendees could ensure they do this on joining:



5) During the lecture there will be the possibility to ask questions to the lecturer. These will be presented to the lecturer by the chair of the event. Attendees can ask questions via the "Chat" function as shown. Press this button:

6) Step 5 will open the typing chat function to the right of the screen: in this box, please type your question. The chair will then review these and present as required at the end of the lecture.



Lecture Review: From Comet to Dreamliner, a History of Aircraft Fatigue

When designing an aircraft, it is absolutely crucial that aircraft fatigue, dubbed "the silent killer," is taken into account. It has been given the name because its presence is not always noticed, and the harm is often unseen until it is too late. The de Havilland Comet was a beautiful aircraft, but the three fatal mid-air accidents that it was involved in were both due to aircraft fatigue that led to a structural failure. The Comet fuselage failed around the rear ADF (automatic direction finder) aerial, with fatigue cracks running backwards, as well as forwards and down. The fuselage split along the top centre line, opening outwards and downwards. Hence, it becomes imperative to be cognisant of what aircraft fatigue really is, and how to deal with it.

The metal body of every aeroplane is subject to drastic changes in pressure during every ground to air to ground (GAG) cycle. This means that every time a plane takes off or lands, it inevitably undergoes some wear and tear, which eventually gives way to fatigue failure. Unlike static failure, which occurs when stress exceeds the Ultimate Tensile Strength (UTS) of the material in a single pass, fatigue failure can occur over time even at low levels of stress, because the component seems to get "tired". Aircraft fatigue is a two-stage process. In the first stage, cracks form at the microscopic level due to defects. This creates persistent slip bands that propagate along the maximum shear plane. Stage 2 is crack growth; the crack becomes much larger but is still not visible to the naked eye. This type of crack causes great disruption to the flow of stress across the body of the aircraft, and it propagates along the plane of maximum tension due to the large stress concentration at its tip. It is important to note that not all stage 1 cracks progress on to becoming a stage 2 crack.

In the 19th century, August Wöhler, a German railway engineer, wanted to create unbreakable railway axles, which led him to invent the first fatigue test- the rotating bend test(which has formed the basis for a similar fatigue test used today) and more importantly, the discovery of the concept of "Fatigue Strength", the stress below which an infinite number of loading cycles can be carried out without fatigue failure. In reality, however, it is impossible to have infinite cycles to fatigue failure. He later plotted the log-log relationship between stress and number of cycles to failure. This is called the fatigue life curve.

Each material has a unique fatigue life curve. For instance, the aluminium alloy Al 7075-T6 has a short crack initiation period, and then a long slow predictable crack growth. It is also light, ductile, and flexible, so it has a high fracture toughness and a plastic load redistribution. Such materials are used to make the fuselage, where these properties are desirable. On the other hand, case hardened 300M steel has a very long crack initiation period and then a short and rapid crack growth period, therefore it is strong but brittle (low fracture toughness), more stiff and thus has a poor load redistribution. These properties are better suited for making the undercarriage of an aircraft.

There are three different fatigue design philosophies that are used. The first is safe life- the component survives until the target life and then is either retired or used until it fails. This approach is useful for non-critical components with poor in-service inspections, which do not greatly affect functionality of the whole machine. The next one is *fail-safe*, which means that the component will give early signs of failure before significant damage is caused, such as a pipe in a car's radiator leaking much before it bursts. Such components can survive until that are repaired. The last approach is damage tolerant, which is used in aircraft fuselages. There are cracks and flaws which must be dealt with and fatigue repairs have to be made after regular inspections. This is used with the *fail-safe* approach, so that cracks can be taken care of (often by drilling a small hole to enhance stress redistribution) before they become a major risk for the aircraft.

After the incident with the Comet, it underwent the "Water Torture Test" which involved building a large water tank around the aircraft which simulated the pressure variations that the aircraft would face during a GAG cycle. The plane experienced 3,057 GAG cycles (1,230 real flights and 1,830 simulated by the test) before failure, while the two aircraft which failed mid-flight, Yoke-Peter and Yoke-Uncle experienced 1,290 and 900 cycles to failure, respectively. The fatigue life was then calculated to be between 1,000 and 9,000 GAG cycles, which varies by a factor of 3 due to the varying nature of fatigue failure.

There are many theories pointing to different reasons for the fatigue failure of the Comet. Some believe it was the iconic square windows that experienced too much stress at the corners, while others say that it was due to the extensive weight savings in the manufacturing of the Comet; the fuselage skin was made of very thin 22 gauge (0.64mm) aluminium, and it wasn't painted not for aesthetics, but because the paint simply weighed too much. Another possibility was that it was rushed into production. Despite this, it was in service for over 48 years (62 years including Nimrod, the military variant) from 1949 up until 1997. This was because in future versions of the plane, ovals windows and thicker 19 gauge 0.9mm aluminium was used, there was reinforcement around apertures, and butt straps were also introduced. Furthermore, the original Ghost engines were replaced with the Rolls Royce Avon engines, which gave twice as much thrust (up to 10,000 lbf). Nonetheless, the real reason for the fatigue failure was a combination of the previously mentioned possibilities. The square windows on the Comet were intentional; the engineers knew about the stress at the corners, and so the original design required the windows to be fitted with Redux bonding glue and drill riveted construction. However, during actual construction, the windows were punch riveted with no bonding! This is much more prone to fatigue failure as it has a steeper fatigue curve. As the makers were worried that America would produce a commercial jetliner before them, they adopted a faster and cheaper manufacturing process which, quite evidently, had its consequences. What they did not know was that the Comet was actually about a decade ahead of its time, as the Boeing 707 flew only in 1957!

So it would be expected that such fatigue failures would be prevented in all future aircrafts, however, several similar incidents have occurred since then, some of which are as follows: Aloha Airlines, Boeing 737, 1998 (the island hopper had experienced many more GAG cycles than its design life), Southwest, Boeing 737, 2009 (fatigue led to cracks on the inner surface of the aircraft's skin), Southwest, Boeing 737, 2011 (there was pre-existing fatigue from a manufacturing error that had recently been repaired), Southwest, Boeing 737-700, April 2018 (fatigue caused a fan blade to fall off). In October 2019, cracks were noticed by around a third of the target life, on the rear spar pickle fork (which connects the fuselage to the wings) on a Boeing 737NG. This highlights that it is necessary to have a design with fatigue accounted for as well as regular checks and maintenance.

In 2011, the Boeing 787 Dreamliner was introduced. The advanced aircraft is primarily made of composite materials, its more fuel efficient and has almost completely electrical flight systems. It has also been criticised for some issues that have showed up in the last few years such as software, engine, and reliability concerns. The wings are highly flexible due to the composite used to make them. Composites are material systems containing two or more phases on a microscopic scale whose properties and performance are superior to the individual constituent materials. There are different types of composites. Engineering polymer composites are structural plastics which may be unreinforced or reinforced with chopped fibres. In uni-directional fibre composites, fibres are very strong in tension and matrix transfers shear loads between fibres. An example of this is timber and carbon fibres embedded in plastic. Reinforced concrete is also an example as steel fibres are embedded in a matrix of concrete. This matrix is strong in compression but week in tension. There is still debate about whether composites are subject to fatigue. The Boeing 787 Dreamliner underwent three years of fatigue testing before production began. Composites can still fail due to matrix cracking, fibre/metrics debonding, fibre cracking, or delamination of matting (this includes BVID- barely visible impact damage, which can be fatal). Moreover, carbon fibre does not show visible signs of surface cracking. The porous nature of composites can collect moisture leading to higher stresses and delamination. Questions are still raised about the durability of composite repairs and the brittleness in a crash. There are also concerns regarding the release of toxic fumes in case of a fire. Modern software such as computer aided design and finite element analysis aid in fatigue design of both traditional and composite aircrafts. After a concept is generated, the aircraft is built, tested, fixed, and only then does production actually begin.

In conclusion, it is interesting to note that the lessons learnt from the Comet were shared liberally across the globe and we have gained substantial knowledge about material behaviour through it. However, with the revolutionary use of new materials in the Dreamliner, the lessons learned will be closely guarded and protected by intellectual property laws. Boeing also offers GoldCare, a comprehensive life–cycle management service, however this is suspected to be a means of revenue generation for the company. Hence, the success of an aircraft is dependent on both engineering as well as the corporate culture.

Shoaib Syed

Reminder: Subscriptions

Our Branch Personal Subscriptions remain as before at £10 per Season with those in full-time education being exempt. Retired members have the choice to continue paying the old subscription fee (£5) if wished. No action is required if you are in full-time education or have made arrangements to pay by standing order. Otherwise, if you are an individual Branch Member and you have not paid your subscription fee, please send your cheque for £10 made out to RAeS Manchester Branch, with your name and address and email on the back, to our treasurer. Alternatively, it is possible to make a bank transfer payment to the following RBS account: sort code 16-14-20, account number 10042916. Please ensure to insert your full name as the reference.

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