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FIRE MODEL SMOKES OUT SECRETS OF DOOMED SWISSAIR FLIGHT 111

New tool enters armoury of crash investigation

The advanced computational fire model, SMARTFIRE, developed by scientists at the University of Greenwich in London, has been used to reconstruct the final tragic minutes of the doomed Swissair flight 111 from New York to Geneva that crashed off the coast of Nova Scotia in September 1998 with the loss of all 229 people on board. The report of the official investigation released today by the Transportation Safety Board of Canada (TSB) acknowledges the important contribution made by SMARTFIRE in 'helping to develop better insight into and understanding of the fire,' which is believed to have caused the disaster (see notes).

"This is the first time a fire model has been used in an official air crash investigation and the results underline the formidable capability the technology offers crash investigators," says Professor Ed Galea, Director of the Fire Safety Engineering Group of the University of Greenwich. "The rigours of such a complex simulation have only just entered the scope of fire modelling, and SMARTFIRE is one of the few fire models in the world able to handle the complex curved geometry of the aircraft fuselage and the cabling, ducting and other utilities in the above-ceiling voids."

Fire models such as SMARTFIRE use Computational Fluid Dynamics to simulate the spread of fire and combustion products in enclosed spaces. In the case of the Swissair MD-11 the cockpit and surrounding voids were defined by a mesh of 250,000 cells, in which the environmental conditions were calculated for each second of the unfolding disaster. The challenges of the complex geometry were compounded by the complex properties of the materials involved, their behaviour on combustion, and by the dynamic pre-fire airflow conditions. This complexity made Swissair Flight 111 one of the most challenging simulations ever undertaken by any fire model. The modelling capability worked in concert with laboratory-based fire experiments that provided specific data needed to ensure the robustness of the simulation.

Using the model the University of Greenwich team were able to confirm that the fire scenario proposed by the TSB was consistent with the evidence, a conclusion that would otherwise have required the staging of prohibitively expensive full-scale fire tests. The model was also used to investigate where the fire may have started and demonstrated how the developing fire affected airflow within the cockpit area and the spread of fire and smoke. In this way the model helped investigators resolve one of the big unanswered questions of the disaster – why, given that the fire was in the ceiling cavity above their heads, the Swissair pilots initially thought they were facing a problem with the air-conditioning system:

“We conducted detailed airflow testing and fire modelling which showed that most of the odours and smoke produced by this creeping fire would be either drawn away from the cockpit into the avionics compartment below the cockpit and dumped overboard or drawn rearwards…” explains Vic Gerden, the lead investigator for the TSB. “This airflow pattern would have helped to conceal the presence of the fire and deprived the pilots of additional cues thereby supporting their initial belief that the odour in the cockpit was related to air-conditioning and that they had time to prepare for the pre-cautionary landing.”

“The availability of advanced fire models like SMARTFIRE heralds a new era in fire safety analysis – the era of Computational Fire Engineering,” adds Professor Galea, who also modelled the Manchester B-737 disaster for the UK Civil Aviation Authority in the late 1980s. “Investigators can now have a high degree of confidence that what they are seeing unfolding on their computer screens is an accurate representation of what may have happened. In effect they have a virtual laboratory in which they can revisit the disaster time and time again, probing the likely causes and testing the wider ramifications of their recommendations."

The official investigation of the Swissair 111 crash lasted four and one half years and turned into one of the most challenging and onerous crash investigations ever undertaken.

"The sheer complexity of the investigation and the number of variables involved made a compelling case to use fire modelling," says John Garstang, Fire & Explosion Chairperson of the TSB investigative team. "We chose SMARTFIRE and the University of Greenwich because of the model's sophistication and the fire modelling expertise of the Fire Safety Engineering Group, particularly their experience in the aviation sector. We have now licensed the software and intend to explore further its capabilities for accident investigation."

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NOTES FOR EDITORS (refer to www.tsb.gc.ca 1998 Air Report Number A98H0003)

The Swissair 111 Disaster
At 20.18 eastern daylight savings time on 2 September 1998 Swissair Flight 111, an MD-11 aircraft, departed JFK Airport in New York, en route to Geneva, Switzerland. On board were 215 passengers and 14 crewmembers. Approximately 53 minutes into the flight the flight crew smelled an abnormal odour in the cockpit. Their attention was then drawn to an unspecified area behind and above them and they began to investigate the source. Whatever they saw initially was shortly thereafter no longer perceived to be visible. They agreed that the origin of the anomaly was the air conditioning system. When they assessed that what they had seen or were now seeing was definitely smoke, they decided to divert. They initially began a turn toward Boston; however, when air traffic services mentioned Halifax, Nova Scotia, as an alternative airport, they changed the destination to the Halifax International Airport. As they were preparing to land they were unaware that the fire was spreading above the ceiling in the front area of the aircraft. About 13 minutes after the abnormal odour was detected, the aircraft's flight data recorder recorded a rapid succession of aircraft systems-related failures. The flight crew declared an emergency and indicated a need to land immediately. About one minute later radio communications and secondary radar contact with the aircraft were lost and the flight recorders stopped functioning. About five and a half minutes after that, the MD-11 crashed into the ocean about five nautical miles southwest of Peggy's Cove, Nova Scotia, Canada with the loss of all 229 on-board.

The subsequent investigation revealed fire damage in the ceiling area concentrated forward of, and several metres aft of, the rear cockpit wall. It was determined that the fire most likely started from an electrical arcing event that occurred above the ceiling on the right side of the cockpit near the cockpit rear wall. The TSB concluded that an arc found on a segment of the in-flight entertainment network (IFEN) electrical cable in this area was likely associated with the fire initiation event. The TSB also concluded that it is likely that one or more additional wires were involved in the lead arcing event, and that the additional wire or wires could have been either IFEN or aircraft wires. Therefore, it could not be concluded that the known arcing event on the IFEN cable located in the area where the fire most likely originated was by itself the lead event. The arcing event ignited the flammable cover material on nearby metallized polyethylene terephthalate (MPET) thermal acoustic insulation blankets. These blankets were used extensively in the fuselage to insulate and reduce noise from entering the cabin. MPET was found by the investigation to be capable of igniting from a spark or electrical arc. Tests also indicated that another blanket cover material used in the aircraft (MPVF) could be ignited once sufficiently preheated. Other materials in the area of the fire damage were also found to be combustible.

Reconstruction of the wreckage showed that the pattern of the fire was very complex and it was decided that the effects of numerous variables needed to be explored in a series of different fire scenarios. For this the investigation team enlisted the fire-specific Computational Fluid Dynamics (CFD) software, SMARTFIRE, of the Fire Safety Engineering Group of the University of Greenwich to study both the possible pre-fire airflow patterns and the post ignition fire and smoke spread scenarios. All the simulations were undertaken by the Fire Safety Engineering Group in close liaison with TSB investigators. The pre-fire airflow CFD analysis was based to a large extent on data collected by the TSB during MD-11 airflow flight tests. Using the SMARTFIRE software, CFD fire field modelling techniques were then applied to the pre-fire airflow patterns to initiate a fire at a pre-selected location. Possible fire and smoke spread scenarios were studied and the TSB investigators took the CFD results into consideration as part of their fire investigation.

The technical challenges of modelling Swissair 111
The geometrical data defining the complex aircraft geometry and components was specified by a three dimensional CAD model which was constructed during the course of the investigation and was subsequently imported into the meshing software. The complex computational mesh used to define the volume of the aircraft in the fire analysis was then generated over a period of time using an iterative approach.

"This was necessary because of the vastly varying length scales that were needed to represent the various important components present within the enclosure," explains Dr Fuchen Jia of the Fire Safety Engineering Group, who developed the SMARTFIRE models of Swissair Flight 111. "Using this approach, it was possible to achieve stable and converged predictions for all the scenarios investigated. The CFD analysis of the various scenarios was also undertaken in an iterative fashion. This approach provided information regarding the relative importance of various components and most importantly revealed their relative impact on the complex flow structures present within the cockpit and upper ceiling area."

"This analysis has highlighted the great care that must be taken to ensure that key components of the geometry - those that will exert great influence on the nature of the predictions - must be adequately represented, no matter what their size or shape," adds Dr Mayur Patel, a senior member of the FSEG investigative team. "A further factor critical to our success was being able to import accurate data on the materials involved. This includes both fundamental material properties and the behaviour of the material when ignited."

The Fire Safety Engineering Group (FSEG) of the University of Greenwich

The Fire Safety Engineering Group at the University of Greenwich won the contract to model Swissair 111 in a competitive bid in 2002. The group is recognised as a world leader in fire simulation, fire model development and evacuation modelling. Founded by Prof. Galea in 1986, it has expanded into one of the largest university-based groups in the world - a team of 25 focusing on the development of Computational Fire Engineering tools for the simulation of evacuation, non-emergency circulation of people, combustion, fire/smoke spread, structural response to fire and fire suppression. As well as aviation application areas include buildings, shipping and rail.

In 2002 the group's contribution to public safety was recognised with the Queen's Anniversary Prize, the highest academic honour in the UK, and in 2001, the group won the prestigious British Computer Society IT award for the development of its software.

FSEG Software

FSEG has developed two leading CFE software products – the fire model, SMARTFIRE, used in the simulation of Swissair Flight 111, and the evacuation and crowd circulation model, EXODUS, which has also been used extensively in aviation applications.

SMARTFIRE

The fire field model, SMARTFIRE, is an open architecture CFD environment written in C++. It has four major components: a CFD numerical engine, Graphical User Interfaces, an automated meshing tool and an Intelligent Control System. As a specialist fire model, its CFD engine has many additional physics features, including an six-flux radiation mode, a multiple ray radiation model, provision for heat transfer through walls, a volumetric heat release model or gaseous combustion model (using the eddy dissipation model) to represent fires, smoke modelling and turbulence (using a two equation K-Epsilon closure with buoyancy modifications). Within SMARTFIRE the user can define a range of scalar variables, which can be used to represent the transport of products such as toxic gases and smoke.

SMARTFIRE uses three-dimensional unstructured meshes, enabling complex irregular geometries to be meshed without the recourse of cruder methods such as the stepped regular meshes or body-fitted meshes. The code uses the SIMPLE algorithm and can solve turbulent or laminar flow problems under transient or steady state conditions.

The software has been under development since 1992 and is now used in twelve countries, worldwide.

EXODUS

The EXODUS suite of evacuation software uses complex interacting sub-models - including human behaviour and smoke toxicity - to simulate evacuations from buildings, aircraft and ships. Design engineers and safety regulators in 22 countries are using buildingEXODUS to improve the evacuation performance of a wide range of buildings - from cinemas to airports, hospitals to schools. Notable applications include the Dusseldorf airport redevelopment, the Greenwich Millennium Dome and the Sydney Olympic Stadium. The aircraft evacuation version, air EXODUS, has been used by the world's leading aircraft manufacturers, including Airbus and Boeing to improve the safety performance of aircraft, ranging from regional jets to the Airbus A380 SuperJumbo. A shipping model, maritimeEXODUS, has recently been introduced and is being used in maritime applications, including the next generation of Royal Navy aircraft carriers.