ALUMNI STORIES

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PROF PAUL D WILLIAMS, LINCOLN 1995, BALLIOL 1999

Atmospheric turbulence research leads to smoother, safer, and cleaner flights

This article tells the story of how we took some basic academic research, dating from my student days at Oxford 20 years ago, and applied it to achieve real-world impacts via improved aviation turbulence forecasts. Atmospheric turbulence is the leading cause of injuries to air travellers and flight attendants. Rough air probably costs the global aviation sector around one billion dollars annually. Furthermore, we know that climate change is causing at least some kinds of turbulence to strengthen.

To help reduce turbulence encounters, we have developed an award-winning turbulence forecasting algorithm, which is now being used operationally by the US National Weather Service. Every day, our algorithm is used in flight planning by commercial and private pilots, flight dispatchers, and air-traffic controllers. To date, our algorithm has improved the comfort, safety, and environmental impact of air travel on billions of passenger journeys, and that figure is growing by several million passenger journeys every day.

But turbulence was not on my mind when I arrived in Oxford for my MPhys degree (Lincoln College, 1995–99), nor even during my graduate studies in the sub-department of Atmospheric, Oceanic and Planetary Physics (Balliol 1999–2003). What was occupying my thoughts during my DPhil, supervised by Peter Read and Tom Haine, was a physical theory for the generation of gravity waves in the atmosphere. These waves can produce clear-air turbulence, which is hazardous to aviation because it is invisible and undetectable by on-board radar.

It was only several years after graduating that I set out to develop the gravity wave theory into a practical turbulence forecasting algorithm. I achieved this by collaborating with John Knox (University of Georgia, USA) and Don McCann (McCann Aviation Weather Research, Inc., USA). Our forecasting method works by analysing the atmospheric wind field and using a set of equations to identify the regions where the geostrophic balance (between the Coriolis force and the horizontal pressure gradient force) is breaking down. The subsequent loss of balance generates gravity waves, leading to shear instabilities and the production of turbulence.

INITIAL TESTS

After I left Oxford to take up my position at the University of Reading, we conducted some initial tests on the accuracy of our forecasting algorithm, with promising results. At that time, the US Federal Government's goals for aviation turbulence forecasting were not being achieved, either by automated systems or experienced human forecasters, but our algorithm came tantalisingly close. We published our results in 2008, concluding that 'major improvements in clear-air turbulence forecasting could result if the methods presented herein become operational'.

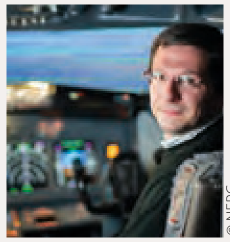
It is crucial that we improve turbulence forecasts, because rough air has long plagued the global aviation sector. Tens of thousands of aircraft annually encounter turbulence strong enough to throw unsecured objects and people around inside the cabin. On scheduled commercial flights involving large airliners, official statistics indicate that several hundred passengers and flight attendants are injured every year, but we know this is just the tip of the iceberg and the real injury rate is probably in the thousands. A typical airline loses 7,000 working days annually due to flight attendants being injured by turbulence and unable to work. On smaller planes, turbulence causes around 40 fatalities each year in the USA alone.

At its worst, turbulence can cause structural damage to aircraft. For example, a plane flying over Colorado on 9 December 1992 encountered extreme clear-air turbulence, which tore off about six metres of its left wing and one of its four engines. For all the above reasons, turbulence is the underlying cause of many people's fear of flying. This fear reportedly affects up to 40% of the population, and it is classified as a specific phobia in the Diagnostic and Statistical Manual of Mental Disorders. Most people find it generally unpleasant and uncomfortable to be randomly buffeted up and down by turbulence, but for the unfortunate sufferers of aviophobia, even light turbulence can be extremely distressing.

CLIMATE CHANGE

But there's another chapter to this story. Turbulence also has consequences for the environment, by causing excessive fuel consumption and CO_2 emissions. Up to two-thirds of flights deviate from the most fuel-efficient altitude due to turbulence. This wastes fuel – up to 160 million gallons annually in the USA – and it also contributes to climate change through 1.5 million tonnes of unnecessary CO_2 emissions annually. At a time when we're all concerned about lowering aviation's carbon footprint, improving turbulence forecasts may be a relatively easy way to help make flying greener.

Furthermore, climate change is expected to make turbulence much worse in future. In particular, our published projections indicate that there will be several hundred per cent more clear-air turbulence globally by 2050–80. The increase occurs because climate change strengthens the vertical wind shear in the jet stream at flight cruising altitudes – and our recent *Nature* paper shows that the shear has already increased by 15% in the North Atlantic region since satellites began monitoring the jet stream in the 1970s. These findings underline the increasingly urgent need to develop better aviation turbulence forecasting techniques.



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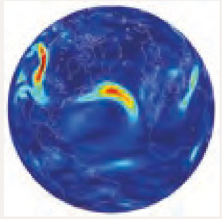
Paul Williams in the cockpit of an aircraft, with the weather radar on the flight deck visible in the background.

@DrPaulDWilliams



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A patch of clear-air turbulence in the jet stream over the North Atlantic Ocean, calculated using supercomputer simulations of the global atmospheric circulation.

AT A TIME WHEN WE'RE ALL CONCERNED ABOUT LOWERING AVIATION'S CARBON FOOTPRINT, IMPROVING TURBULENCE FORECASTS MAY BE A RELATIVELY EASY WAY TO HELP MAKE FLYING GREENER.

The operational challenges associated with turbulence are compounded by the projected future growth of the aviation sector. Historically, global air traffic (measured in passenger-kilometres) has experienced an average long-term growth rate of 5% per year, which corresponds to a doubling period of about 14 years. According to Boeing's market outlook, this trend is expected to continue for at least the next 20 years. Accurate turbulence forecasts are needed to ensure the efficient use of airspace in our increasingly crowded skies.

SMOOTHER JOURNEYS AHEAD

Future passenger growth coupled with climate change will lead to more turbulence encounters, all other things being equal. Therefore, it is good news for air travellers that our improved turbulence forecasting algorithm is now being used operationally by the Aviation Weather Center (AWC) in the National Weather Service (NWS), which is the US equivalent of the Met Office. The turbulence forecasts are freely available via an official US government website (www.aviationweather.gov/turbulence/gtg). They forecast turbulence up to 18 hours ahead, updated hourly. Our algorithm is the latest in a basket of diagnostics that are optimally combined to produce the final published forecast.

Every day since 20 October 2015, turbulence forecasts made with our algorithm have been used in flight planning by commercial and private pilots, flight dispatchers, and air-traffic controllers. The aviation sector is benefitting from advance knowledge of the locations of turbulence, with greater accuracy than ever before, allowing flight routes through smooth air to be planned. The United States was a natural place to test and roll out the algorithm, because it has arguably the most extensive air transportation network in the world. On an average day in the US, 2.6 million people fly on a scheduled passenger service. To date, therefore, our algorithm has improved the comfort and safety of air travel on nearly four billion passenger journeys.

Our turbulence forecasting algorithm has won several awards recently, including £5,000 in the Natural Environment Research Council (NERC) Impact Awards last year. But the real prize is the knowledge that the algorithm is making a difference to people's lives every day. In the time it has taken you to read this article, thousands of passengers have taken to the skies and are benefitting from our research. It is the perfect and somewhat unexpected culmination of a DPhil research project that began in earnest at Oxford 20 years ago.

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Paul Williams at Heathrow Airport, as a British Airways aircraft departs through partly cloudy skies.

NICK ARMSTRONG MA CPHYS MINSTP, WADHAM 1979–82

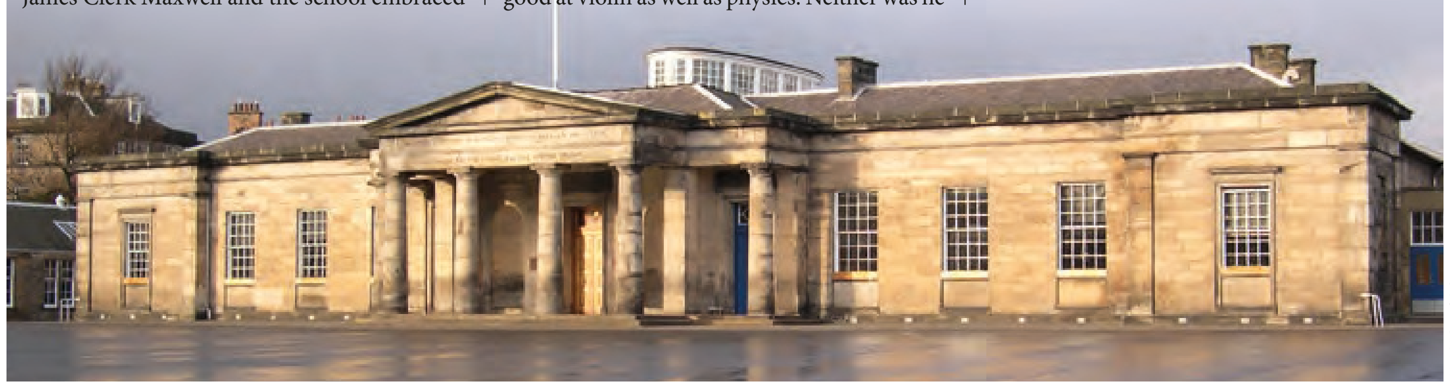
Wadham's Scottish Physics Cycle

My first-year tutor in Physics at Wadham made a distinct impression on me. His name was Don Edmonds and he was relaxed, friendly, approachable and with no distinct accent to bely his roots (unlike mine!) His enjoyment of physics was obvious and I remember he spent a lot of time working on cobwebs simply because he thought it was fun. He had a standard saying for solving problems: 'Turn the handle and out pops the answer.' I personally found it didn't actually always work for me! But at least the saying always stayed with me and because of it, I've regularly thought about him.

A few years after graduating, I also switched into teaching and eventually moved to Edinburgh to become the Head of Physics at the Edinburgh Academy. This school is the Alma Mater of James Clerk Maxwell and the school embraced his legacy. It felt like an appropriate place for a physicist to be. Very shortly after moving, my wife recounted a conversation she had had that day with another lady at a toddler group when they were alternately sending the kids down the chute (that's what a slide is called in Scotland!) In the type of 'part sentence' conversation with which only adults looking after kids can identify, it was discovered that the lady was Don Edmonds' daughter. Her two older boys attended the Academy and I got to teach them both. We loved the story.

However, in my first year of teaching there, another student came immediately to attention. The A level class had some smart students in it and one in fact went on to work for NASA. It was another though, that stood out from the rest – simply for being an extremely intelligent and studious young man. This didn't make him an introvert. In fact, I remember him being very good at violin as well as physics. Neither was he 'cocky'. He knew he was good but he didn't show off. We both knew he could easily have put me on the spot asking me questions in class that I couldn't answer but he was far too polite to ever do so. He represented Britain in the World Physics Olympiad in Iceland and came 15th. I remember always marking his homework first so that I knew I had the right answer before I marked the rest and it was a shame, I didn't get to find out what happened to him after Further Education.

Keeping in touch with Wadham and its Alumni has many benefits. One of them has been that through the Wadham College Gazette, for example, I discovered that this exceptional pupil, Martin Shotter, had become a Physics tutor at Wadham. For me, this has completed a cycle of personal connections to impressive Scottish physicists having links with Wadham. I shall always keep in touch!



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