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Airfox Upset Prevention & Recovery Training (UPRT) Flight Simulation with Wake Vortex Encounter Events

Jonathan Pugh[1], Mikhail Goman [1], Nikolay Abramov [1], Gianluca Borghini [2], Ivan De Vissche [3], Géraud Granger [4], Elizabeth Humm [5], Barry Kirwan [3], Diana Moreno-Alarcon [4], Simone Pozzi [5], Frédéric Rooseleer [3]

1. Faculty of Computing, Engineering & Media, De Montfort University Leicester, United Kingdom.
E-mail: jonathan.pugh@dmu.ac.uk; mgoman@dmu.ac.uk; nikolay.abramov@dmu.ac.uk
2. Department of Molecular Medicine, Sapienza University of Rome, Italy.
E-mail: gianluca.borghini@uniroma1.it
3. EUROCONTROL, Centre du Bois des Bordes, Bretigny-sur-Orge, France.
E-mail: ivan.devisscher@wapt.be; barry.kirwan@eurocontrol.int; frederic.rooseleer@eurocontrol.int
4.Safety Management Research Program, École Nationale de l'Aviation Civile (ENAC), France.
E-mail: geraud.granger@enac.fr; diana.moreno-alarcon@enac.fr
5. Deep Blue srl, Rome, Italy.
E-mail: elizabeth.humm@dblue.it; simone.pozzi@dblue.it

A multidisciplinary team of academics, flight safety experts, pilots, flight simulation engineers and human factors specialists adapted the Boeing 737 Next Gen simulator Airfox UPRT at AMST, Ranshofen, Austria to be capable to 'inject' a variable wake vortex encounter (WVE) in cruise flight and measure the effect on a type-rated operating crew. As part of the EU SAFEMODE project (2019-2022), this was used to carry out a validation study for the use of new Air Traffic Control (ATC) cruise wake alerting procedures. Developed at DMU, the flight simulation model for the extended flight envelope allowed continuation of flight simulations in case of onset of high angles of attack and stall conditions following WVE. Along with facilitating the validation of new ATC procedures, the flight data also provided insights into pilot upset prevention and recovery training (UPRT) in the era of recurrent academic and flight training for upset prevention and recovery.

Keywords: flight simulation, pilot training, upset prevention and recovery, wake vortex encounter

1. Introduction

Loss of control in flight (LOC-I) is currently the leading cause of flight accidents and related fatalities, as noted in Boeing (2017). An effective way for avoiding pilot-induced LOC-I events, is implementing UPRT on modern flight simulators equipped with advanced flight simulation models that allow simulating flight conditions in and beyond of stall Fucke et al. (2010); Abramov et al. (2012,?, 2019). The Airfox UPRT flight simulator developed by AMST Systemtechnik, Austria is a dedicated facility for such UPRT training*. The Airfox UPRT flight simulator was used in the EU SAFEMODE research project for a validation study for the use of new Air Traffic Control (ATC) cruise wake alerting procedures, which preliminary results were presented in Rooseleer et al. (2022). This paper presents an analysis of flight simulation data from the SAFEMODE pilot campaign to demonstrate that the Airfox UPRT flight simulator is able to train pilots in critical WVE flight situations, increasing awareness of manual control skills to mitigate against LOC-I. WVE has been the precursor to catastrophic LOC-I on large civil air transport aircraft, with the American Airlines flight 587 incident being one of the most significant examples NTSB (2004). In this case, inappropriate full rudder input, including rudder reversal, was a significant causal factor. Although this incident happened immmediately after departure, in a manual flight control phase that is more familiar to pilots, the risk of WVE in the cruise could be heightened by unfamiliarity with manual

*https://www.amst.co.at/aerospace-medicine/training-simulation-products/airfox/airfox-uprt/

control in this phase and the associated lack of aerodynamic damping. A subsequent WVE with LOC-I which almost resulted in catastrophic loss of the aircraft has also been reported with a Challenger 604 business jet encountering the wake of an Airbus A380 over the Indian Ocean.

UPRT guidance for pilots has been produced and updated by ICAO (2017) and enhanced UPRT initial and recurrent training has been mandated by national regulators in reponse to high-profile accidents where LOC-I has been a significant causal factor, notably Air France flight 447 and Colgan flight 3407 BEA (2012); NTSB (2010).

Latest developments in aircraft manufacturer Standard Operating Procedures (SOPs) are integrating Threat & Error Management (TEM) Moriarty (2015); Merritt and Klinect (2006) into briefings in all phases of flight to identify and mitigate threats, including LOC-I.

2. Flight Simulator for LOC-I

The AIRFOX UPRT flight simulator at AMST-Systemtechnik GmbH, Ranshofen, Austria is a novel and cost-effective solution for Upset Prevention and Recovery Training and simulation studies of Loss-Of-Control In-flight (LOC-I) situations. The flight simulator has a full replica cockpit for Being 737NG and the unique flight simulation model for the extended flight envelop covering the stall and post-stall flight regimes. The implemented class-specific out-of-the-envelope flight simulation model was developed on the principles of objective compliance with the aircraft flight performance, stability and control characteristics in the normal flight envelope and was subjectively validated by a number of experienced line and test pilots. In the out-of-envelope region the model was blended with the aerodynamic model, developed during the FP7 EU SUPRA project specially for the extended flight envelope covering stall and beyond stall regions Abramov et al. (2012, 2019). The SUPRA model is currently used for UPRT pilot training on the DESDEMONA centrifuge flight simulator in the Netherlands** . Wake vortex disturbances in the form of time dependences of the increments of aerodynamic forces and moments acting on the aircraft were provided by Airbus for nine different scenarios for the aircraft crossing a disturbed atmospheric region corresponding to mild, medium and severe impacts. The simulated wake vortex disturbance was fine-tuned during preliminary simulator details, flown by type-rated airline safety-officer pilots. The fine tuning involved the selection of existing simulated turbulence from the Instructor Operating Station (IOS) of the Airfox UPRT simulator.

3. Flight Simulation Results with WVE

The SafeMode Airfox UPRT WVE study represents an extremely rare research opportunity; the ability to study a cross-section of type-rated airline captains and first officers in a specialized but realistic (in terms of airline operations) simulator. Such studies would be both prohibitively expensive to most research institutions and the coordination required for roster release of pilots from commercial operations would be extremely complex. Manufacturers and ATOs would have access to such research but, in many cases, the data becomes commercially sensitive and subject to non-disclosure and commercial proprietary-data considerations.

The flight data, including pilot input to flight controls and aircraft systems, were retrieved by AMST Austria in the form of binary data and were analysed using proprietary software developed by AMST and DMU. Specific data makers were used in the evaluation of new ATC procedures, after further analysis by EUROCONTROL. These flight data were used in conjunction with pilot EEG data, eye tracking data and Bedford workload-scale analysis to support the recommendation of ATC wake-alerting procedures Rooseleer et al. (2022).

The full flight data results of the study are one part of an ongoing major study at DMU into optimal upset recovery techniques and the use of

**https://www.amst.co.at/civil-aviation/flight-simulation-training-devices/desdemona/

extended flight simulation in UPRT training.

Figs. 1, 2 and 3 show an example of the time histories of aircraft parameters, pilot inputs, and WVE disturbances in the form of increments to the rolling, pitching, and yawing aerodynamic moments obtained from Airfox UPRT flight simulations for a severe wake vortex encounter and no ATC alert.

Airplane response to the WVE is quite significant. The angle of attack $\alpha_{max} \approx 12°$, the sideslip angle $|\beta_{max}| \approx 6°$, the bank angle $|\phi_{max}| \approx 42°$, and the pitch angle $\theta_{max} = 10°$ (Fig.1). Pilot control inputs in pitch and roll channels, X_θ and X_ϕ, aerodynamic disturbances due to WVE, L_{WV}, M_{WV}, N_{WV}, and load factors, n_Z, n_Y with March number variation are shown in Fig.2. The pedal control has not been used in this case.

In Fig. 3, we see that the pilot subject has used significant rudder input (in excess of 0.25 units, where full deflection is normalized to 1). This was unexpected in recovery from a WVE, and was contributory to the AA587 incident. In the study, there were only a few instances of this.

4. UPRT training

Commercial and Airline-Transport pilot UPRT training is divided into initial and recurrent phases, with both academic and operational flying training syllabi. An example of the academic works available for pilot briefing and self-briefing is the 'Airplane Upset Prevention and Recovery Training Aid' (AUPRTA), published by the International Civil Aviation Organization (ICAO), a specialized agency of the United Nations ICAO (2017). Academic training provided by Approved Training Organizations (ATO) is frequently based on AUPRTA and is used both in theoretical instruction and in briefing/de-briefing of operational training for on-aircraft and simulated UPRT training details. On-aircraft UPRT training involves the use of a dedicated aerobatic aircraft on which the instructor and student can practice departure from controlled flight, and recovery from deliberately induced upsets. National civil air transport regulators, such as the United Kingdom Civil Aviation Authority (CAA), mandate when academic and operational training is to be delivered. Invariably,

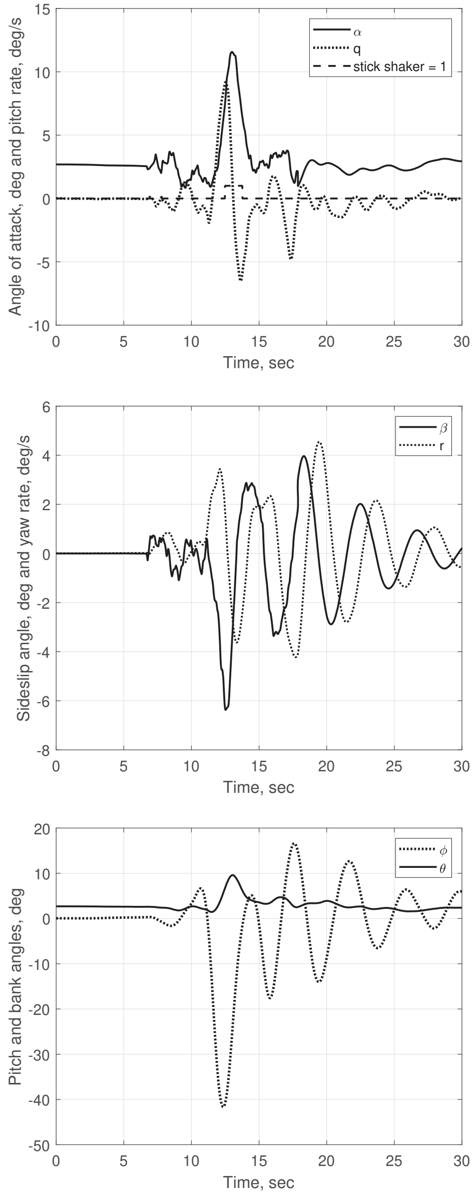

Fig. 1. Flight simulation data (set A).

there is an initial requirement for on-aircraft training before initial pilot licence issue, or the issue of a first commercial aircraft type-rating. The 'Part-FCL 745.A Advanced Upset Prevention and Recovery' training course is one such academic and operational flying course. Once a Commercial or Airline-Transport pilot has been employed on

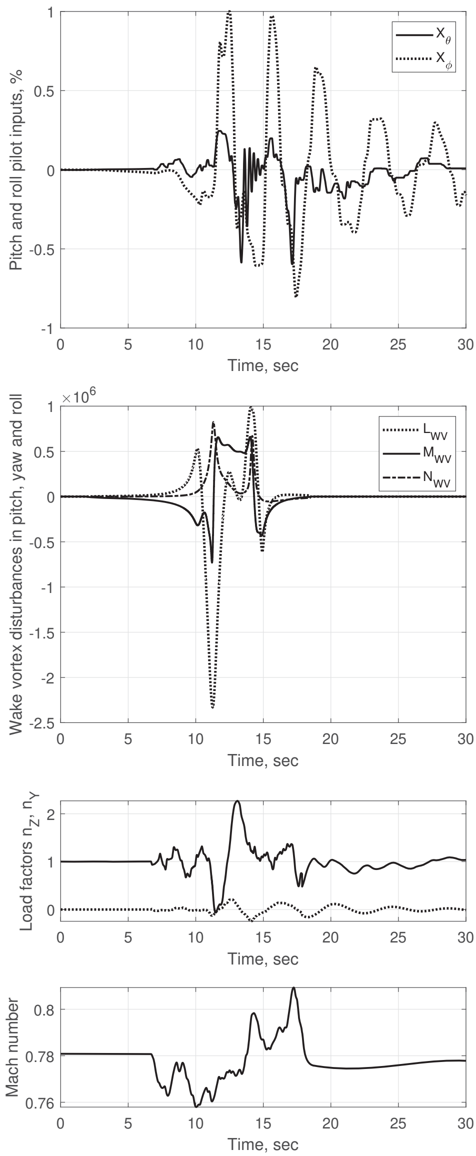

Fig. 2. Flight simulation data (set B).

their first commercial aircraft type, there is usually no further mandated on-aircraft UPRT training. Recurrent training is then academic and synthetic-flight (simulator) only for the remainder of their flying career.

On-aircraft UPRT training has the obvious advantage of realistically representing the onset to an upset, departure from controlled flight, and

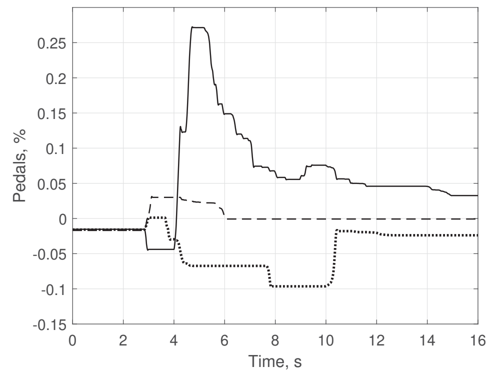

Fig. 3. Examples of the use of pedals during WVE pilot control.

realistic flight dynamics during recovery to controlled flight; the realism is specific to that aircraft type, although it may share common characteristics with other types. This realism extends to the danger involved, both perceived and actual, in failure to recover controlled flight. Human factors (HF) phenomena, such as those related to the physiological and neurological effects of the sympathetic and parasympathetic nervous systems, may supervene to affect pilot performance under such conditions, particularly where it is a novel experience for the pilot under training. This has been referred to, both in flight training and pilot human factors courses, as 'Startle and Surprise' or 'Fight, Flight, Freeze'. The extent to which these HF phenomena affect pilot performance will depend on individual experience, personality and perception of danger in a way that is complex and also variable, even within a given individual.

On-aircraft training also has the advantage of allowing the student to practice the recovery repeatedly until they gain a level of familiarity with recovery techniques. Recovery may be taught in a simplified set of procedures, such as 'push, roll, power', in which the wing is briefly unloaded, wings are rolled level, and power (or thrust) is used in recovering controlled flight. Such simplified techniques may have significant commonality with the stall recovery techniques of commercial aircraft types.

Simulated flight UPRT training has the disadvantage of only being able to provide limited motion cuing of flight dynamics, particularly where g-forces would be experienced for protracted periods on-aircraft. The DESDEMONA centrifugal simulator partially addresses this disparity, but the consequences of failure to recover in DESDEMONA are completely different to failure on-aircraft. Whilst simulated flight has the advantage of placing the student pilot in the familiar surroundings of their own flight-deck, this disparity in potential failure outcomes has led to a perception of simulated flight being an unavoidably limited tool in UPRT training.

There is a paradox in this perception of the limitations of simulated UPRT training, associated with the preparation and delivery of training details. On-aircraft training is usually delivered in visual meteorological conditions (VMC), during the day, with an instructor and student who are expecting to induce upsets and who are accordingly briefed in the correct recovery technique. They are likely to be in a moderate state of arousal, as defined by the Yerkes-Dobson law, with a relatively high level of potential performance being expected. Colgan Air Flight 3407 and Air France 447 occured at night, in Instrument Meteorological Conditions (IMC), when pilot fatigue may also have been a significant factor, BEA (2012); NTSB (2010). There is therefore a potentially large disparity in initial conditions between crews in training and those conducting airline operations. Exposing airline pilots to unexpected UPRT training on commercial aircraft types, in a similar manner to commercial flight test, is obviously impossible. A question therefore arises as to the potential benefits of UPRT training in commercial simulators, available to ATOs, and how to conduct this training to maximum positive effect. The risk of negative confirmation of skills has been an ever-present effect in the delivery of simulated UPRT training, with an emphasis on avoidance of the onset of an upset.

Belcastro et al. (2014) identify several causal and contributing factors which can be precursors to LOC-I. They categorize these as *i) Adverse onboard conditions; ii) External hazards and disturbances; and iii) Abnormal dynamics and vehicle upsets*. Many of the examples given within these three headings fit the common framework of threats and errors that can be highlighted in line oriented Safety Audits (LOSA) or in operational use of TEM. With many of the precursors to LOC-I being of a highly complex nature on modern commercial transport aircraft, as in the case of AF447, there may be considerable benefit in using simulated flight to integrate analysis of TEM, in the context of LOC-I, into UPRT simulator details. HF prescursors, being no less complex, may also feature in simulator details, which are more line-oriented in their focus than on-aircraft UPRT training details. The fact that many simulator details are held during unsociable hours and even during the Window Of Circadian Low (WOCL), may also be a significant human factor, although not necessarily a desirable one for maximal training benefit.

5. Conclusions & Recommendations

Qualitatively, the WVE upsets that the pilot subjects were exposed to in this study were of a large magnitude, relative to typical line operations, with notable subjective observation of startle, particularly at the first encounter, when crews were still unaware of the purpose of the study.

During manually flown recovery, large fluctuations in angle of attack were recorded, with instances of stick-shaker activation, heralding the potential onset of stall. Although no crews lost control and entered the extended flight envelope regime of the AMST Airfox flight dynamical model, there was the potential for this to occur and a larger survey could have resulted in flight into the extended envelope, requiring stall recovery.

Further investigation is required to understand the effect of the recoveries in which significant rudder input was used. This is a discouraged technique ICAO (2017) and the factors behind this response are worthy of further investigation, given that it has been a significant causal factor in catastrophic failure in the departure flight phase NTSB (2004). It is important to note that this only occurred in a very small fraction of flown recoveries. This highlights the value of the method of flight data capture. If it were not for this objective and quantitative capture of flight control input, the rudder input could be indistinguishable from the overall subjective or objective evaluation of aircraft response.

The flight data output are currently the subject of a major ongoing DMU study into the optimal use of UPRT recovery techniques. This study aims to integrate Threat and Error Management (TEM) into a simulator trial, using the smaller Airfox DISO disorientation simulator, based at DMU's Leicester UK campus. Using DMU's synergy of large civil aircraft flying instruction experience and extended flight envelope simulation design experience, there will be a focus on exploring the practical benefits of further integration of LOC-I precursor threats, such as those explored in Belcastro et al. (2014), into UPRT flight simulator training details.

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