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Wake vortex encounter severity for rotorcraft in final approach

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Abstract

The Advisory Council for Aeronautics Research in Europe (ACARE) predicts that European air traffic may nearly triple by 2020. The growth in air traffic is already an increasing problem with capacity at some airports becoming limited due to congestion. This could be alleviated by providing additional passenger capacity at hubs through the introduction of rotorcraft using new IFR procedures and operating simultaneously but independently of the fixed-wing traffic. These Simultaneous Non-Interfering Operations (SNIOps) will be enabled by a 'reconfiguration' of the airspace, taking advantage of new navigational and air traffic management systems. SNIOp's raise critical safety questions for rotorcraft wake vortex encounters (WVE's) and will require consideration of the longitudinal and lateral aircraft separation and the locations of the rotorcraft FATO's (Final Approach and Take-Off areas). This paper presents analysis from work carried out as part of the Framework 6 project 'OPTIMAL' including the development of predictive methodology and analysis for rotorcraft WVE's, using a severity rating scale. In particular, scenarios are considered where the rotorcraft is following precision glideslopes of up to 12° in both good and degraded visual conditions. Handling qualities criteria have already been found to be well suited to investigating severity of an encounter. Within this framework, draft boundaries are proposed for assessing the severity of an encounter. Furthermore, the results have shown a pilot may be able to recover from an encounter, but the question of whether the required navigational precision would be compromised and a go-around required is also addressed.

Keywords: Rotorcraft; Vortex; Safety

1. Introduction: OPTIMAL

The OPTIMAL project is part of the European Commission's Framework 6 Programme. It is an Integrated Project (IP) covering a wide range of technical areas through a consortium of 24 partners. The OPTIMAL project is an air-ground cooperative program that is aiming to define and validate innovative approach and landing procedures for fixed and rotary wing aircraft in a pre-operational environment (website: www.optimal.isdefe.es).

The need for these developments is identified by ICAO forecasts of 5% growth per annum of world air traffic (www.icao.int). Based on recent experience this estimate is likely to be conservative for the European theatre of operations. Taking into account the variations in growth in the types of traffic (i.e. commuter over long-haul), ACARE's Vision 2020 [3] is expecting European air traffic to potentially triple over the 2002–2020 timeframe. The impact of this will be increased airport congestion and the associated safety, efficiency and environmental effects unless additional measures are taken.

In response, it is proposed that a re-design of the airspace structure, division, categorisation and the Air Traffic Management (ATM) procedures, exploiting improved aircraft performance and new navigation technologies/capabilities, be undertaken. From this, four key aspects for European commercial air operations will be addressed: capacity, efficiency, safety, and reduced noise exposure.

Overall, the expected outcomes of the OPTIMAL project will be a validated set of approach and landing procedures, support systems and technologies achievable from 2010 as one part of a first step to the ACARE 2020 vision.

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Nomenclature

$\dot{p}, \dot{q}, \dot{r}$	Roll, pitch and yawing body-axes angular accelerations (rad/s^2 or deg/s^2)
a_x, a_y, a_z	X, Y, Z body-axis accelerations (m/s^2 or ft/s^2)
ACP	Aerodynamic Computation Point
ACARE	Advisory Council for Aeronautics Research in Europe
AGL	Above Ground Level (m or ft)
ATM	Air Traffic Management
B	Vortex generating aircraft wingspan (m or ft)
BVI	Blade Vortex Interaction
c.g.	Centre of gravity
C_D	Drag coefficient
C_L	Lift coefficient
C_M	Pitching moment coefficient
DVE	Degraded Visual Environment
FATO	Final Approach and Take-Off area
g	Acceleration due to gravity (m/s^2 or ft/s^2)
GVE	Good Visual Environment
H_{lat}	FATO distance from runway/taxiway (m or ft)
HQR	Handling Qualities Rating
ICAO	International Civil Aviation Organisation
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IP	Integrated Project
LIDAR	Light Detection And Ranging system
M	Aircraft mass (kg or slugs)
MDH	Minimum Decision Height
MTE	Mission Task Element
MTOW	Maximum Take-Off Weight
OFE	Operational Flight Envelope
r	Radial position in vortex (m or ft)
r_c	Vortex core radius (m or ft)
RVR	Runway Visual Range
RNP	Require Navigational Precision
s	Non-dimensional scaling parameter of initial vortex spacing
SNIOps	Simultaneous Non-Interfering Operations
SAS	Stability Augmentation System
V_c	Vortex core tangential velocity (m/s or ft/s)
V_{MINI}	Minimum speed for IFR flight (kts)
VMC	Visual Meteorological Conditions
VSR	Vortex Severity Rating
V_T	Vortex tangential velocity (m/s or ft/s)
Vx	Body X-axis velocity (m/s or ft/s)
XI	Inertial X position (m or ft)
YI	Inertial Y position (m or ft)
ZI	Inertial Z position (m or ft)
Γ_0	Average vortex circulation (m^2/s or ft^2/s)
γ_h	Rotorcraft horizontal flightpath angle (deg)
Γ_r	Vortex circulation at a radial position r (m^2/s or ft^2/s)
ρ	Density of air (kg/m^3 or slugs/ft^3)

2. New rotorcraft procedures

The University of Liverpool has been working within the OPTIMAL work package that is developing new rotorcraft procedures, paying special attention to the context of airports allowing Simultaneous Non-Interfering (SNI), IFR (Instrument Flight Rules) rotorcraft operations. The new SNI procedures for rotorcraft are aimed at incorporating steep and/or curved and segmented trajectories. The benefit of these is the smaller noise footprints resulting from the higher altitudes of flights over population zones adjacent to airports and it is also known that the BVI noise emissions of rotorcraft are lower in steep approaches (greater than 6°). Important for the development of future SNI operations are the safety issues associated with interactions between rotorcraft and fixed-wing wake vortices in these new scenarios.

The University of Liverpool is contributing to the project by building upon research in the modelling and simulation of rotorcraft vortex wake encounters. It is developing methods that will eventually allow the definition of the safety boundaries in terms of where rotorcraft SNI operations can take place and for defining the flight envelopes for different rotorcraft types. Important factors for such a study will include the wind speed, direction and meteorological conditions, the vortex generating aircraft (e.g., Airbus 310, Boeing 737), the encountering rotorcraft type and the rotorcraft's trajectory (approach, hover, take-off).

3. Wake vortices: Their characteristics and risks

Wake vortices are generated by the lifting surfaces of an aircraft. Typically, the vortices that are shed by the wing along its span eventually roll-up to form two counter-rotating vortices of swirling air. The strength of the vortices, Γ_0, is directly linked to the lift (C_L) generated by the wing and is related to the wake generating aircraft's weight through the following relationship:

$$\Gamma_0 = \frac{Mg}{\rho s B V} \tag{1}$$

Clearly, the heavier the aircraft, the stronger the circulation Γ_0. The correlation of the circulation with the velocity flow-field can be seen through the 'Dispersion' model for a vortex [19]. This model expresses the tangential velocity, V_T, as function of the local circulation Γ, the radial location, r and the vortex core radius, r_c.

$$V_T = \frac{\Gamma r}{2\pi(r^2 + r_c^2)} \tag{2}$$

As Eq. (2) shows, the tangential velocity is directly proportional to the circulation and thus to the aircraft weight via Eq. (1).

These parameters can be used to describe the basic characteristics of vortices and Table 1 shows some best fit parameters of vortices for current commercial transport aircraft. Also included are parameters for an alternative vortex model known as