Aircraft Wake Vortex Evolution in Ground Proximity and at Cruise Altitude

Applications

As an unavoidable consequence of lift aircraft generate a pair of counter-rotating and long-lived wake vortices that pose a potential risk to following aircraft. The therefore prescribed aircraft separations contribute significantly to capacity restrictions of large airports. But also during cruise severe encounters of wake vortices have been reported. Wake vortex behaviour is largely controlled by the prevailing meteorological conditions and the interaction with the ground. The most important meteorological parameters are wind, wind shear, turbulence, and temperature stratification.

The Deutsche Zentrum für Luft- und Raumfahrt (DLR) develops wake vortex advisory systems for airports [1,2] and en route which aim at optimizing the air traffic with respect to the measured and predicted wake vortex behaviour. As part of such systems simple probabilistic wake vortex prediction models are required that predict wake vortex behaviour accurately, robust, and fast [3]. Highly resolving Large Eddy Simulations (LES) conducted on the HLRB II supercomputer provide valuable insights in the physics of wake vortex behaviour under various environmental conditions. These LES contribute indispensable guidance for the development of the simple wake vortex models.

Figure 1: Wake vortex evolution with crosswind in ground proximity. Green vorticity structures representing the crosswind turbulence are being wrapped around the wake vortices (brown vorticity tubes).

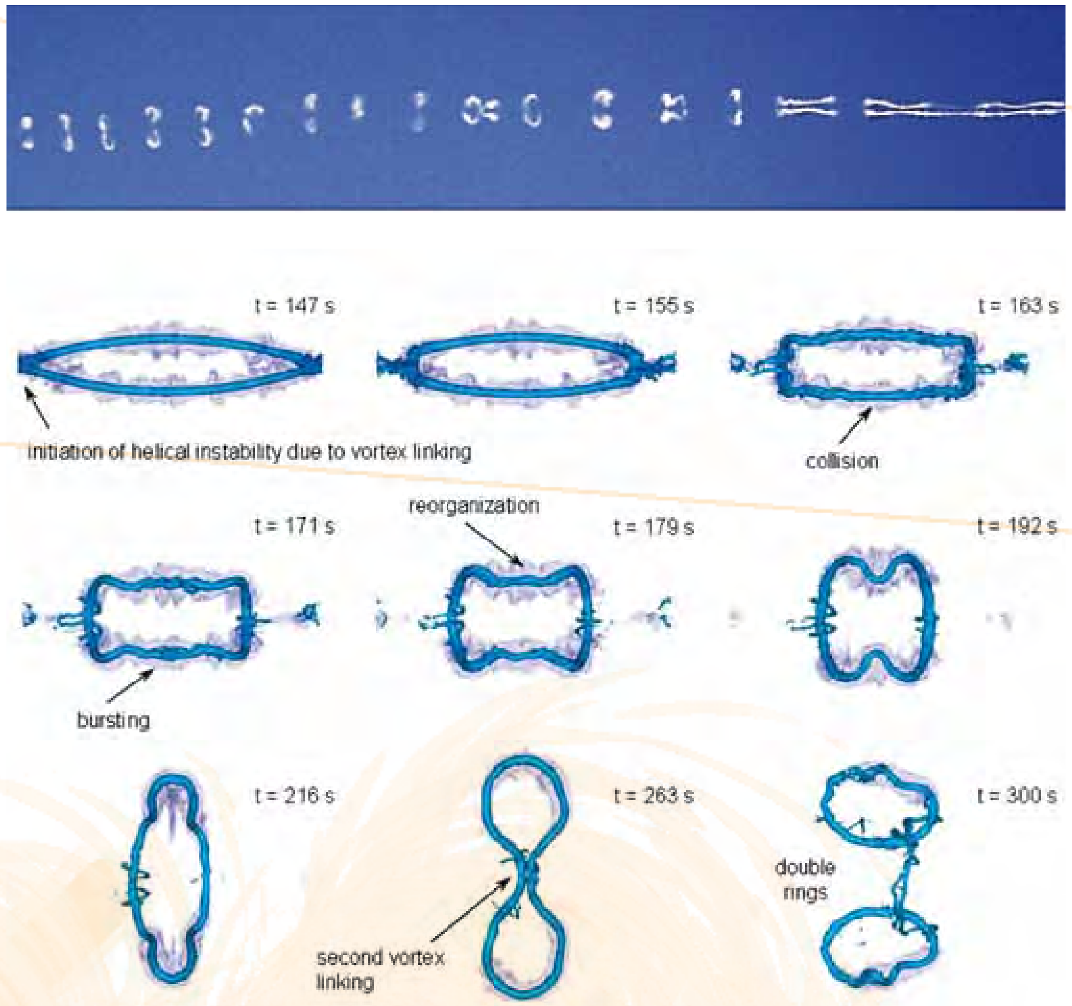

Figure 2: Above: Photo of various stages of vortex rings; flight direction from left to right (photo Sven Lüke, November 16, 2006, 8:53, http://www.4elements-earth.de). Below: LES of vortex ring formation in neutrally stratified and weakly turbulent environment.

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A particular risk prevails during final approach, where the vortices can not descend below the flight path, but tend to rebound due to the interaction with the ground [4]. Moreover, the possibilities of the pilot to counteract the imposed rolling moment are restricted due to the low height of the aircraft above ground. Figure 1 shows a snapshot of the interaction of the primary wake vortices (brown) with the turbulent structures generated by the crosswind at the ground surface (green). Several phenomena are visualized in Figure 1: The turbulent streaks generated by the crosswind at the ground surface are wrapped around the primary wake vortices. During this process the streaks are intensified by vortex stretching and establish the so-called secondary vorticity structures. At the same time relatively strong vorticity sheets (brown) are generated at the ground surface. About 20 seconds later these vorticity sheets detach from the ground and start rotating around the primary vortices. Under unfavourable crosswind conditions the rebounding wake vortices may hover over the runway directly in the flight corridor of a landing aircraft.

At cruise altitude winds may be strong but the prevailing turbulence typically is very weak. At these altitudes stable temperature stratification (inversion) typically limits wake vortex lifetimes to a maximum of about 3 mins. Figure 2 depicts wake vortex evolution in a neutrally stratified weakly turbulent environment where long-lived wake vortex rings may form. The vortex rings feature intriguing phenomena both visible in the photograph (above) and in the LES (below): After linking of the vortex pair an elongated vortex ring is established and helical instabilities propagate along the vortices. Later bone-shaped vortex rings transform into the shape of an "8" followed by a double ring phase [5].

Investigations of wake vortex evolution at cruise altitude are not only relevant for passenger safety and comfort but possibly have also significant relevance for the contribution of aviation to global warming. Ice crystals from the exhaust jets may develop contrails or even induced cirrus clouds (contrail cirrus) that modify the radiation budget of the atmosphere [6].

The LES are conducted using MGLET, which is a Finite Volume solver for the incompressible Navier-Stokes equations [7]. The numerical experiments have been conducted typically in a Cartesian grid with 1 m resolution and domain sizes of 400 × 512 × 512 m³. Larger grid sizes and higher resolutions also with adapted grid spacing have been employed in order to better resolve the vortex cores and the surface boundary layer or to realize large turbulent length scales of the ambient flow. For the simulations up to 1,024 processors on the HLRB II have been used.

Applications

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CLUES
on how we got to be here

Among mankind's oldest and most fundamental questions are "Where do we come from?" and "How did our earth come into being?". From the dawn of civilization our ancestors have contemplated these mysteries with often beautiful creation myths. Today we know that our earth is a small planet in the solar system, and our sun is one of the few hundreds of billions of stars in the Milky Way and the Milky Way is one of a countless number of galaxies in the universe. Our Milky Way is a spiral galaxy which together with another spiral galaxy of approximately the same mass (the Andromeda galaxy or "M31") forms the main members of the so-called Local Group of galaxies. The third largest member of this group is a somewhat smaller spiral galaxy (called the Triangulum Galaxy or "M33"). In total the Local Group comprises more than 30 galaxies which are distributed in a sphere of about 10 million light-years across centred between Andromeda and Milky Way. At a distance of around 50 million light years from the Milky Way, sits a huge cluster of galaxies (the Virgo cluster) which comprises more than 1,000 member galaxies. This cluster forms the heart of the Local Supercluster which is the most massive structure in the Local Universe. The Local Universe is a tiny fraction of the observable universe, the radius of which is larger than 13 billion light years; yet the special environment around the Milky Way is also the best-known part of the whole universe.

Applications

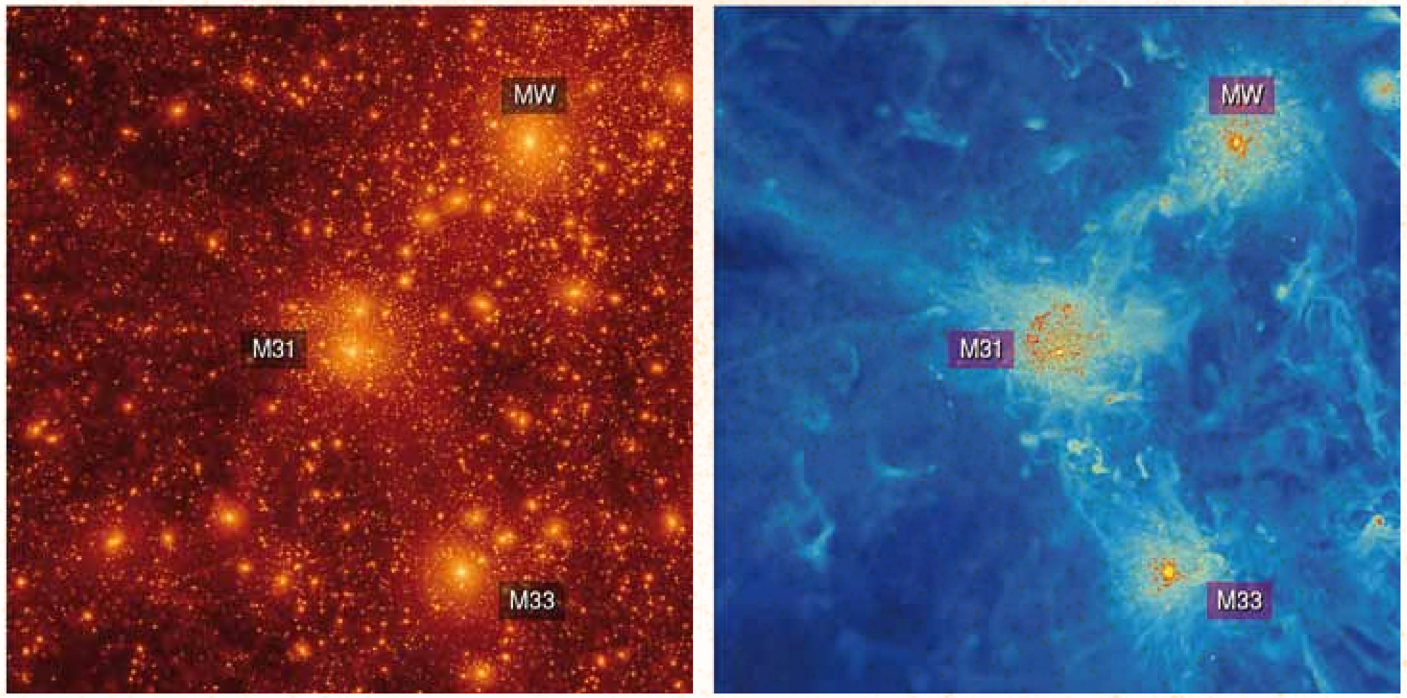

Figure 1: Dark Matter (left) and gas (right) distribution in the Local Group