LINKÖPING UNIVERSITY

Expert Conference: Albatross Flight

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1 Introduction

Albatrosses are the largest seabirds ranging in the Antarctic Ocean and the North Pacific. As sailing to open seas in the Age of Exploration, sailors soon learned that the appearance of albatrosses either meant good sailing winds approaching or the warning signs of storms. Therefore they become associated with good fortune and were considered untouchable; even in times of severe famine on board no bird was to be killed. This gives ground to the myth that killing an albatross brings curse to the ship and its whole crew, as also reflected in Samuel Taylor Coleridge's poem *"The Rime of the Ancient Mariner"* [1].

Besides their great size (the wingspan of the largest albatrosses can reach 3.4m), albatrosses are widely known for their ability to travel very long distances with just an occasional flap of its wings. Once airborne, they can travel for weeks, sometimes up to 500 miles a day without returning to the shore. This is possible by employing specific flight maneuver techniques, such as dynamic and slope soaring [2].

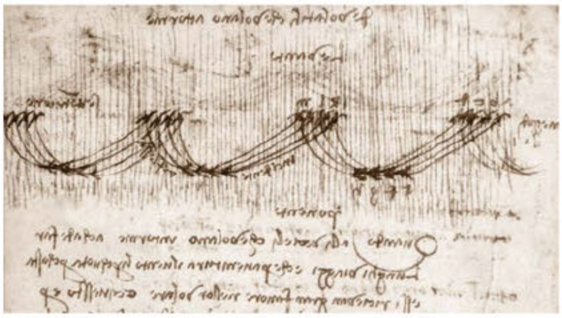

Fig. 1 . Dynamic soaring illustrated by Leonardo da Vinci [3].

As early as in the 15^{th} century, Leonardo da Vinci was the first to document dynamic soaring while studying the flight of birds in order to develop human-powered flying machines. Later at the turn of the 19^{th} and 20^{th} century Lord Rayleigh described how birds gain energy in wind shear layers but also in continuous gradients in wind speed. [3] As we understand today, this is the reason behind albatrosses often flying close to the sea surface, as described in the following chapter.

2 Dynamic Soaring

The velocity boundary layer or "wind sheer field" forms up to about 10 to 20 metres above sea level. Exploiting the dramatic increase in velocity to generate lift, albatrosses fly in a cyclic pattern known as dynamic soaring which allows them to glide just above the sea for a long time spending almost no energy.

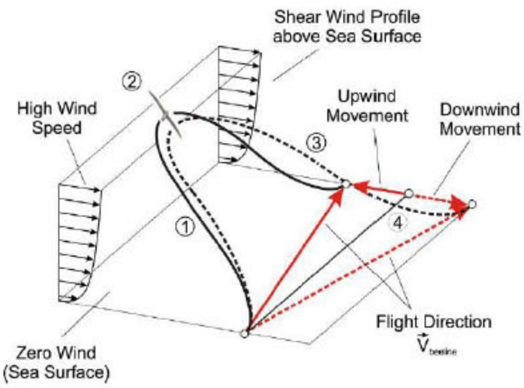

Fig. 2 . Illustration of soaring patterns adapted by albatrosses [4].

Sachs [4] studied the flight and dynamic soaring patterns of albatrosses. He identified four phases, as shown in Figure 2. A windward climb (1), followed by a curve from windward to leeward at peak altitude (2), then a leeward descent (3), and finally a reverse turn (4) close to the sea surface that leads seamlessly into the next cycle of flight. This soaring pattern is known as the Rayleigh cycle. The energy gain needed for flying without flapping their wings is achieved when they change the direction from windward to leeward side. Continuous soaring is then obtained by repeatedly passing high velocity gradient layers above the sea surface and thereby exchanging the gained kinetic to potential energy. Further to dynamic soaring, high speed is achieved with a flight direction transverse to the wind direction. Figure 2 also shows two path cycles, with a net upwind flight (straight line) and a net downwind flight (dotted line). In order to compensate for the lateral displacement of individual soaring cycles they have been observed to fly in alternating soaring cycles.

Besides dynamic soaring, albatrosses also exploit upward force components generated when the wind is redirected by steep objects or waves, and thereby gain height. This phenomena is called slope soaring.

3 Dynamic soaring applied to aircrafts

3.1 Similarities with an albatross

As described by Lord Reyleigh, albatrosses are even able to soar upwind by harvesting wind energy for wind speeds above 3 m/s. There is also a potential for using the same maneuver with an Unmanned Aerial Vehicle (UAV), however, they should be able to soar above the sea level and quickly change course relative to wind. This is a slightly different soaring method than that of an albatross, who wanders only in a certain direction, rarely changing its course.

Another distinctive difference between an albatross and a UAV flying like an albatross would be in minimum closeness to the surface. Ocean waves are much smaller than ridges or cliffs of mountains, which would imply that an albatross must fly very close to the sea surface to extract the wind energy more efficiently. The same dangerously close maneuver would be expected from a UAV, and while flying close and even grazing the surface with its wingtips is not a problem for an albatross, for a UAV it would mean certain destruction. That kind of maneuverability could perhaps be duplicated by a sophisticated autopilot.

3.2 Glider velocities in practice

In his paper, Richardson [5] claims that gliders flying over mountain ridges reached speeds about 10 times of the wind speed blowing over the ridge. For a cruise speed of about 25 m/s, a lift to drag ratio of 30 was estimated for the tested glider. While the Rayleigh cycle, described earlier in the chapter 2, predicts that for wind speeds of at least 5 m/s, a maximum achievable speed would be about 9.5 times the wind speed in the upper layer, the field measured value comes in quite a close agreement with the theoretical maximum value. Another interesting observation in those field measurements was that of the accelerometer, which recorded peak accelerations of about 100 g's.

The fastest way to cover a certain distance over sea surface by the method of dynamic soaring for a UAV would be along diagonal lines relative to wind direction. This is because a transverse velocity vector and windward velocity vector can be exploited, which would give maximum velocity, as shown in Figure 3.

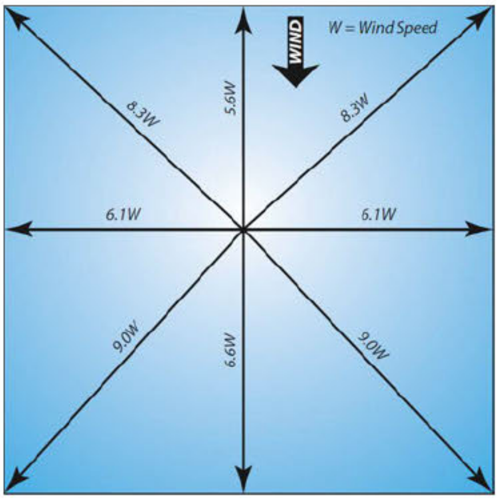

Fig. 3 . UAV travel velocity polar diagram showing maximum theoretical velocities obtainable by dynamic soaring relative to wind direction [5].

The following expression shows the relation between the UAV's or albatross' velocity and wind speed for the optimum loop period:

$$V_{\max} = \frac{(V/V_z)_{\max}}{\pi} \cdot W$$

where $V_{\max}$ is the maximum achievable velocity, W is the wind speed, and $(V/V_z)_{\max}$ represents values of the glide ratio. For L/D values $\gg 1$, the glide ratio is closely equal to lift/drag (L/D) ratio.

This relation can be used to predict the maximum theoretical cruising velocity for a given wind speed, or a minimum required wind speed for a certain cruising velocity.

4 Discussion

Dynamic soaring employed by albatrosses is a highly efficient technique to gain energy from wind conditions, and is also one of the main techniques adopted for remote controlled aircrafts.

The application of albatross-like flight technique was investigated in detail by Richardson [5], as he considered the possible development of a robotic albatross UAV that could soar over the ocean using dynamic soaring like an albatross. The robotic UAV would be faster considering its superior strength and better aerodynamic performance. Some uses for such a device would be search and rescue, environmental monitoring, weather monitoring, and surveillance.

For building such an aircraft, structural stability should be considered for long range flight, and an autopilot for close surface maneuvering.

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