VECTORNAV

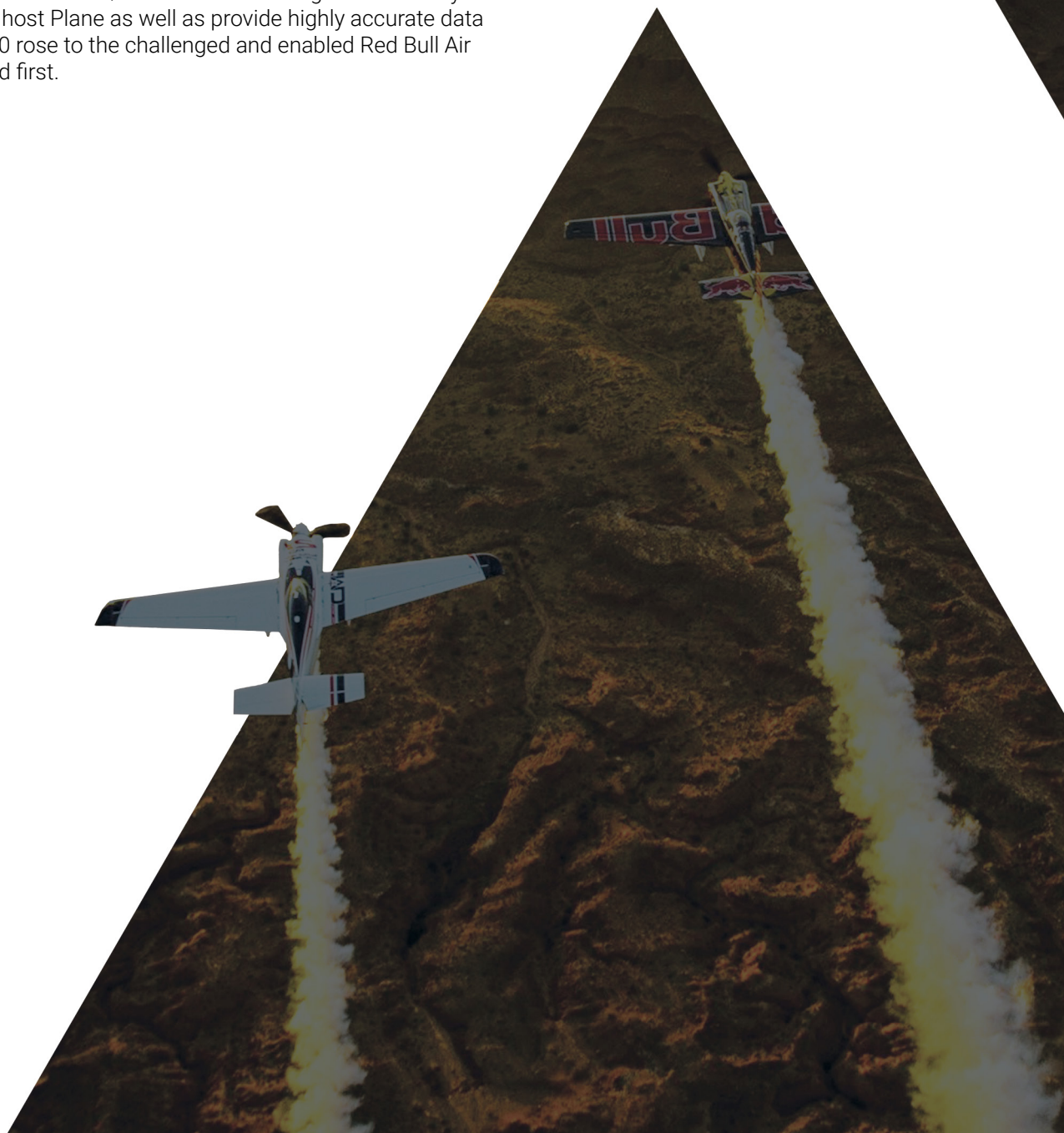
CASE STUDY

RED BULL AIR RACE SEARCH FOR PERFECTION

Aerial Telemetry

VN-300 Dual Antenna GNSS/INS

Red Bull Air Race required a GNSS/INS to drive their augmented reality solution know as the Ghost Plane as well as provide highly accurate data for judging. The VN-300 rose to the challenged and enabled Red Bull Air Race to achieve a world first.



Introduction

Created in 2003, the Red Bull Air Race World Championship features the world's best race pilots in a pure motorsport competition that combines speed, precision and skill. Using nimble and lightweight racing planes, pilots hit speeds of 370 km/h (230 mph) while enduring forces of up to 12 g as they navigate a low-level slalom track marked by 25-meter-high, air-filled pylons (Air Gates). Pilots incur time penalties for hitting pylons, incorrectly passing through the Air Gates or exceeding 10 g for more than 0.6 seconds, among several other competition constraints.

Pilots race one at a time and mere fractions of a second separate field, so it can be difficult for viewers to compare the performance of each pilot. With the help of its suppliers Red Bull Air Race invented a completely unique augmented reality (AR) solution known as the Ghost Plane, which displays in real-time the trajectory of prior pilots' runs for real-time comparison. The Ghost Plane is driven by onboard telemetry data gathered during flight. In order for a pilot's run to be accurately represented by the Ghost Plane, the onboard telemetry system has to accurately track position, velocity and attitude (yaw, pitch and roll) through high-dynamic maneuvers and in challenging environmental conditions.

Francois Le Vot of France performs during qualifying day at the second round of the Red Bull. Air Race World Championship in Cannes, France on April 21, 2018. // Predrag Vuckovic / Red Bull Content Pool

COMPANY PROFILE

Since it was officially launched in 2003, the Red Bull Air Race World Championship has become globally recognized as the most exhilarating motorsport series on the planet. The Red Bull Air Race World Championship is an international series of races where pilots navigate the most agile and streamlined race planes through an aerial racetrack featuring air-filled pylons. Each pilot aims to complete the race track in the fastest possible time incurring as few penalties as possible. Devised by the Red Bull sport think-tank, the initial goal was to create the most advanced aerial challenge the world has ever seen; what they achieved far exceeded their original expectations.

APPLICATION

Aerial Telemetry

VECTORNAV PRODUCT

VN-300 Dual Antenna GNSS/INS

Challenges

Racetracks in the Red Bull Air Race place significant challenges not only on pilot and plane but also the onboard telemetry system. While every racetrack layout is different, they each consist of:

- A Start/Finish gate,
- Three or four air gates through which pilots are required to fly straight and level through,
- A chicane, which consists of three pylons that pilots need to bank around, and
- A Vertical Turning Maneuver (VTM), which requires pilots pass through a gate and turn 180 degrees to reverse course as quickly and efficiently as possible without exceeding the g limit.

Each plane is fitted with several GNSS receivers to track the plane's position and velocity through the track. To accurately determine position and velocity, GNSS receivers require direct Line of Sight (LOS) visibility to at least 4 satellites to measure the distance signals have travelled from each satellite. The dynamic maneuvers made during the race (such as the chicane, in which pilots bank the plane side-to-side reaching angular rates of 400°/sec,) rapidly changes which satellites the GNSS receiver can track, which typically results in a loss of position fix.

To further increase the challenge for the telemetry systems races are commonly held over water, which is particularly effective at reflecting GNSS signals, in turn creating significant multipath errors at low altitudes. Multipath errors occur when instead of tracking the direct LOS signal from the satellite a GNSS receiver tracks the reflected signal, which results in position and velocity errors.

The Vertical Turning Maneuver is arguably the most challenging maneuver in the race. The VTM is an aerobatic maneuver wherein the pilot performs a 5/8 loop to an inverted 45° line, followed by a 1⁄2 roll to flat and level flight. During this maneuver the plane can experience 300°/sec angular rates and 12 g accelerations. GNSS tracking is typically lost when the plane is rolled or inverted as the antennas no longer point to the sky.

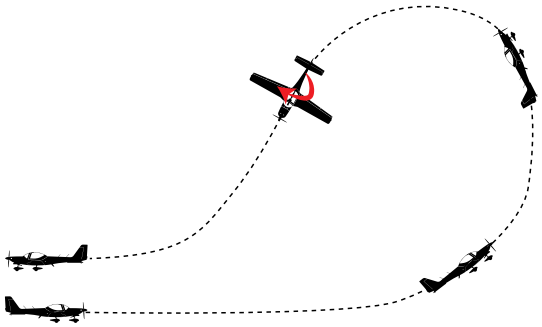


Figure 1: Vertical-Turning Maneuver (VTM).

Figure 2 shows position tracks from two laps of the 2018 Red Bull Air Race in Cannes, France, as reported from three different sources:

- The filtered VN-300 GNSS/INS solution (**Blue**)
- The VN-300 GNSS receivers (**Green**)
- A Survey Grade Multi-Frequency (L1/L2), Multi-Constellation Receiver (**Orange**)

In Figure 2 you can see the effects of multipath error: as the aircraft goes inverted in the VTM, the Survey Grade GNSS receiver loses its position fix as there are no valid GNSS signals. The VN-300 GNSS receiver continues to maintain a fix, but is now tracking the reflected signal. Notice that the VN-300 GNSS trace (green) continues to climb as the aircraft descends towards the gate. This is because the reflected signal range is getting shorter, which is equivalent to an increase in altitude when tracking direct LOS.

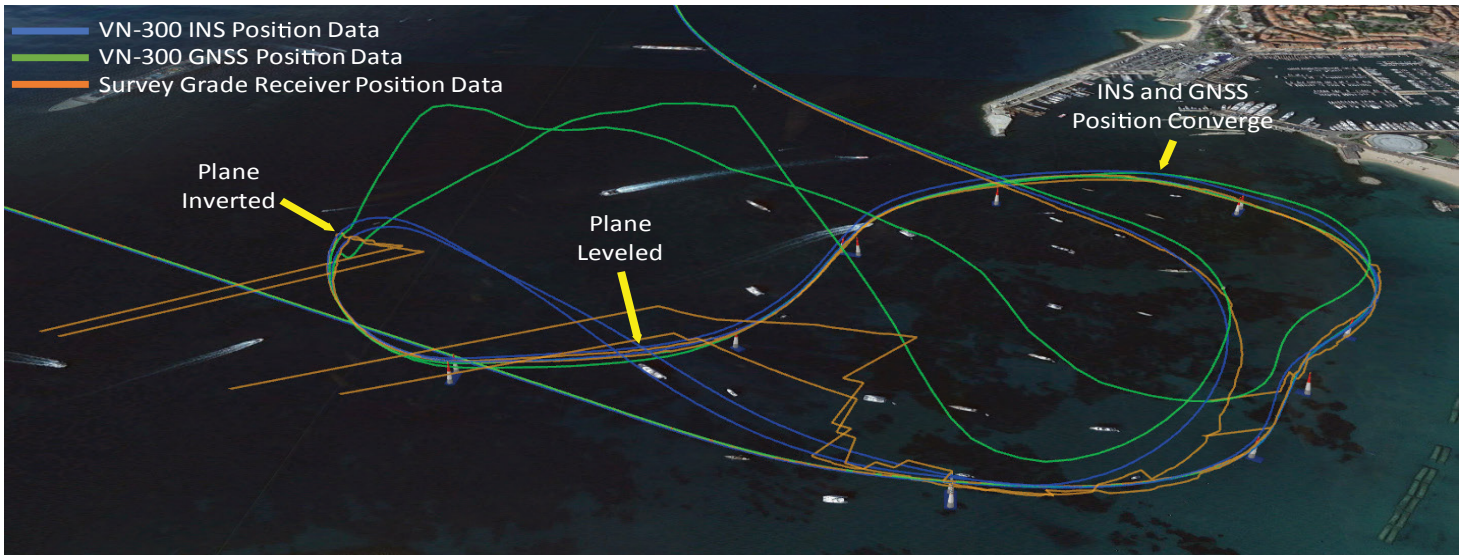


Figure 2: Position traces of GNSS (Green), INS (Blue), and Survey Grade (Orange) data from the onboard telemetry system

Francois Le Vot of France performs during the finals at the second round of the Red Bull Air Race World Championship at Kazan, Russia on June 16, 2019. //Mihai Stetcu/Red Bull Content Pool.

Challenges Continued

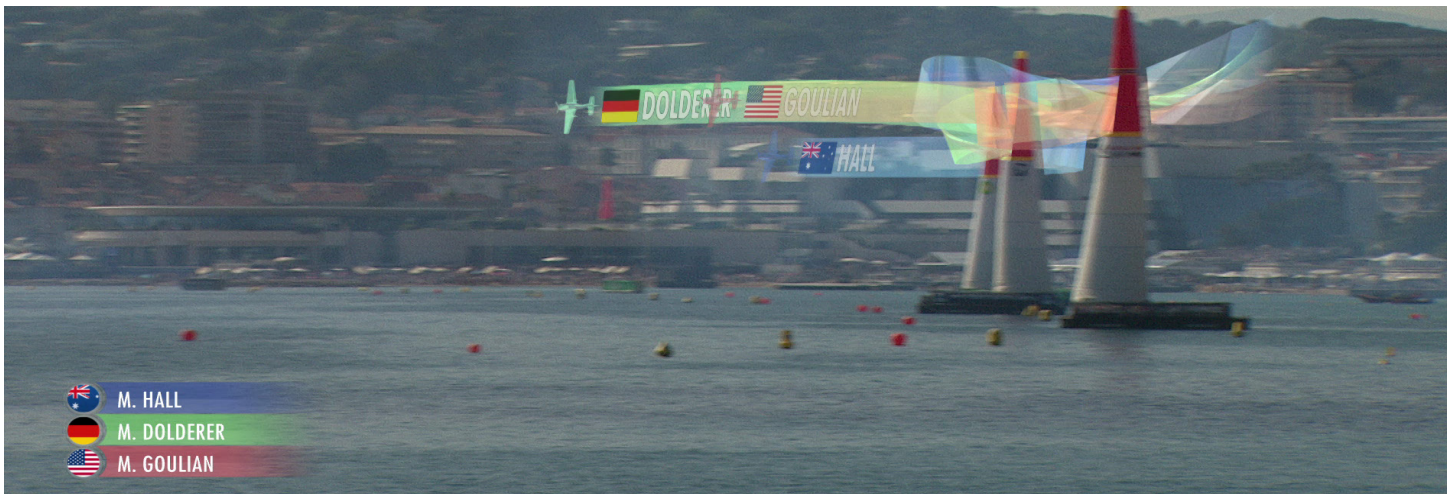
If the telemetry system were solely reliant on GNSS receivers the Ghost Plane footage would not be possible. Instead Red Bull Air Race turned to a GNSS/INS system, which couples gyroscope and accelerometer data to propagate position and velocity estimates during poor or total loss of GNSS measurements through maneuvers such as the VTM. A GNSS/INS offers the added benefit of providing much more accurate yaw, pitch and roll estimates, which enables a much more accurate Ghost Plane representation.

However, not all GNSS/INS systems are created equal. Red Bull Air Race found that many GNSS/INS systems were not able to effectively estimate position and velocity during these VTMs. The position data from these systems drastically diverged from the actual trajectory and resulted in unreliable or entirely unusable telemetry data for the Ghost Plane representation. One product however was able to track position through these flights and VTM's: VectorNav's VN-300 GNSS/INS. Alvaro Navas, Sport Technical Manager at Red Bull Air Race, stated: "We tested a variety of GNSS/INS systems and they all suffered through these maneuvers, only the VN-300 proved equal to the task."

How VectorNav Helped

The VN-300 is a MEMS-based Dual GNSS/INS that combines two GNSS receivers with a 9-axis IMU (3-axis gyroscopes, accelerometers and magnetometers). It couples acceleration and angular rates from the IMU with position and velocity data from the GNSS receiver using a quaternion based Extended Kalman Filter (EKF). Many other INS products in the market implement EKF filters, however, what sets the VN-300 apart from the rest are the proprietary algorithms developed by VectorNav that work in conjunction with the state estimation filter. These proprietary algorithms make the VN-300 more robust and intelligent, enabling it to reject poor GNSS data and perform accurately in high dynamic maneuvers and challenging operating conditions. VectorNav's expertise in aerospace-grade filtering enables the VN-300 to maintain accurate pitch, roll, yaw, position and velocity estimates at rates up to 400 Hz. The VN-300 does this not only in benign and ideal conditions, but also in edge cases such as an inverted aircraft reversing course at 230 mph and pulling up to 12 g's.

As can be seen in Figure 2, when the plane inverts and starts to track the reflected signal, the VN-300 GNSS/INS (blue trace) reverts to free inertial navigation and propagates the position based on inertial data. Notice how the trace follows a smooth trajectory through the next air gate until such time that the GNSS data finally converges with the INS position. Not only were Red Bull Air Race finally able to have an accurate representation of the position and time of the aircraft, but the VN-300 also provided Red Bull Air Race with estimates of heading to within 0.3° RMS and pitch and roll to 0.1° RMS.



Results, Return on Investment and Future Plans

For the first time in the history of Red Bull Air Race, Ghost Plane imagery can be generated for the full race and multiple pilots can be compared with one another. Not ones to rest on their laurels, Red Bull Air Race and VectorNav continue to explore new ways in which VectorNav solutions can provide even more precise estimates of position and attitude. “We are just scratching the surface of what is possible using VectorNav’s products” said Navas. “Their sophisticated solutions are opening up a world of possibilities to help our fans learn and appreciate the greatness our athletes demonstrate when they compete in these races.”

KEY SPECIFICATIONS

NAVIGATION

Heading (GNSS Compass, 1 m)	0.3 ° RMS
Heading (INS)[1]	0.2°, 1σ
Pitch/Roll (INS)[1]	0.03°, 1σ
Accelerometer Range	±16 g
Gyroscope Range	±2,000 °/s
Max Output Rate (INS)	400 Hz

PHYSICAL & ELECTRICAL

Dimensions	36 x 33 x 9.5 mm
Weight (SMD)	16 g
Max Power Consumption	500 mW

1. With sufficient motion for dynamic alignment.

VN-300 Dual GNSS-Aided INS

VN-300 Rugged

10501 Markison Road, Dallas, TX 75238, USA | +1 512 772 3615 | sales@vectornav.com | www.vectornav.com

About

VectorNav Technologies is a leading developer and manufacturer of high performance inertial navigation systems using the latest inertial sensor and GPS/GNSS technology. Since its founding in 2008, VectorNav has provided systems integrators in the Military, Aerospace, Marine, and Robotics industries with inertial navigation solutions with best-in-class price to performance ratios.

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Dallas, TX 75238, USA

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