# EFFECT OF ROTATING PROPELLERS ON TELEMETRY SIGNALS

**Mark Geoghegan**
**Marwan Nusair**
**Quasonix, West Chester, OH**

## ABSTRACT

The migration of aeronautical telemetry systems to C band has prompted a fresh look at many historically uninteresting facets of telemetry links. The effects of higher cable losses and smaller antenna beamwidths, for example, have been recognized and accounted for. Recent flight tests at Edwards AFB with a propeller-driven aircraft have revealed another such effect, which we have termed "prop chop". Realtime data quality metric (DQM) values showed a periodic fluctuation in DQM, related to the aircraft engine speed. An investigation of this phenomenon using detailed electromagnetic simulation of a transmit antenna in the presence of a propeller shows a mechanism for this interference, both when the propeller is in front of the transmit antenna and when it is behind the transmit antenna. This paper compares the electromagnetic propagation simulation results to measured values from the field.

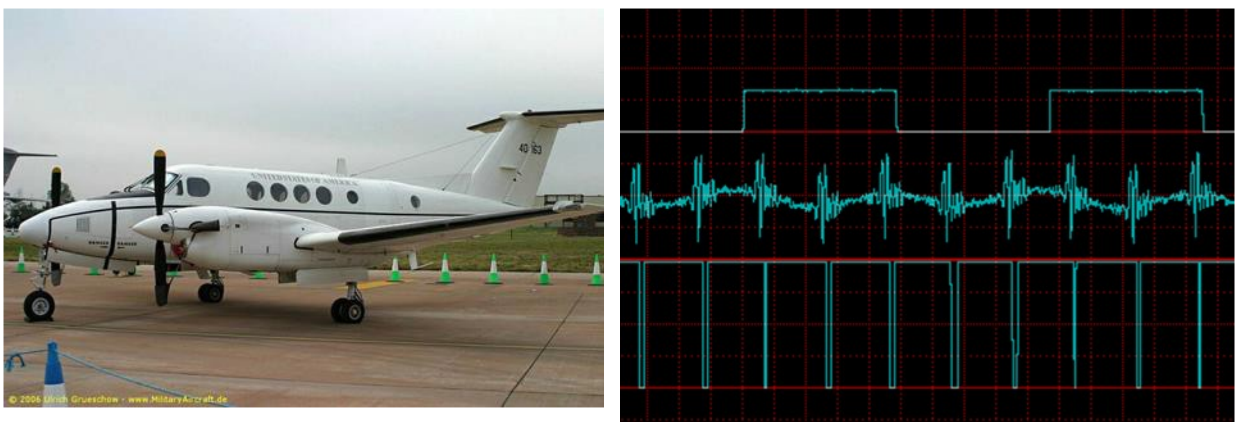
## KEY WORDS

Aeronautical Flight Testing, RF Channel, Propeller, Data Quality Metric (DQM)

## INTRODUCTION

Recent C-band aeronautical flight testing at Edwards AFB has revealed the existence of a time-varying RF channel impairment that can seriously degrade the quality of the received telemetry data. This perturbation went largely unnoticed until detailed status monitoring and high-resolution signal captures showed rapid and periodic fluctuations in the realtime data quality metric (DQM) [1]. It turned out that the average signal quality as presented to the front panel display was really a combination of rapid periods of extremely good and extremely bad data. This discovery indicated that the basic telemetry link was solid, but that it was somehow being subjected to an unknown RF condition that was responsible for all of the observed bit errors. After realizing a time-varying impairment was present, the bandwidth of the AM output was artificially increased on a test receiver to better observe the RF environment. Figure 1 shows a representative C-12 aircraft along with a high-speed capture of the following signals: 1) Top-Dead-Center (TDC) scan signal from a C-band conscan antenna, 2) AM output, and 3) real-time DQM. The scanning signal from the antenna is a square wave at approximately 30 Hz that is synchronous with the rotating feed. The AM signal shows periodic bursts of AM modulation occurring with a period of roughly 8ms (125 Hz). The DQM signal shows that the recovered data quality is normally perfect (high state) with rapid periods of complete link failure (low state) that align with the anomalies present on the AM channel.

It was realized that this might be attributable to the propeller since 125 Hz with 4 blades gives 1875 RPM which is a realistic engine speed for this aircraft. In order to rule out other potential sources, the engine speed was varied and the anomalies followed the change in engine speed. Given that this effect was shown to impact the telemetry performance, it was decided to look at the data in more detail. This paper investigates the RF effects due to rotating propellers and their potential impact on telemetry systems.



**C-12 Propeller-Driven Aircraft**

**Observed Telemetry Signals (Antenna TDC, AM, Instantaneous DQM)**

**Figure 1: C-Band flight testing revealed segments of a high-speed time varying channel**

## PROPELLER MODEL

In order to understand the potential RF effects of a propeller, a simulation of a simplified model was performed. Figure 2 shows the model propeller which consists of 4 blades with the approximate dimensions of the Beech C-12 aircraft used in the data collection. The propeller blades were pitched at 15° and the transmit antenna was positioned slightly offset and behind the propeller. Calculations of the three-dimensional farfield pattern were performed for several frequencies ranging from L-band at 1485 MHz up to C-band at 5000 MHz.

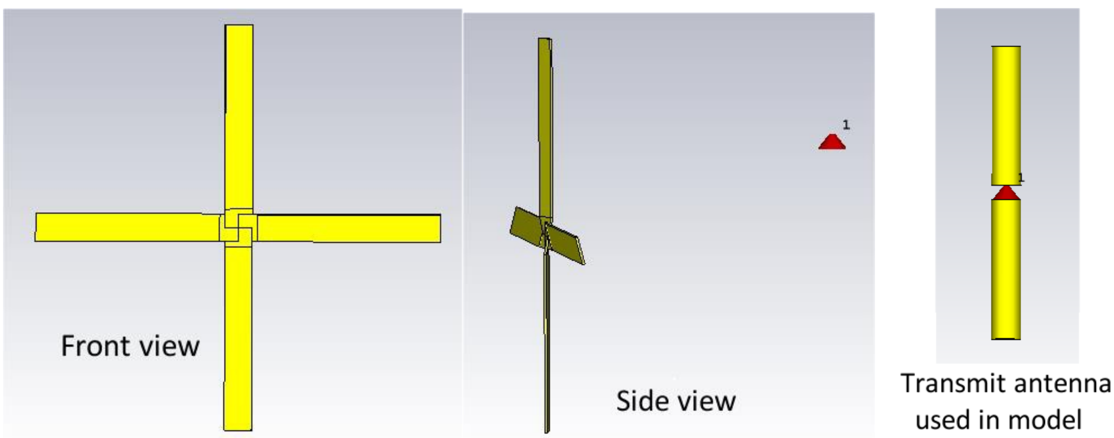



**Figure 2: Propeller Simulation Model**

Figure 3 shows the results consisting of the "donut" shape for the antenna by itself and the patterns from the front and back of the aircraft at a propeller angle of 20°. The first observation is that front and back views look very different. A possible explanation is the fact that the front view behaves somewhat like a simple shutter that is either blocking the source or not, while the back view has a direct view of the source along with reflections from the propeller. This may explain the more complex pattern shapes seen from the back. Another observation is that as the frequency gets higher, the details of the propeller blade become much more pronounced. It seems reasonable that the RF interactions will become more active at higher frequencies.

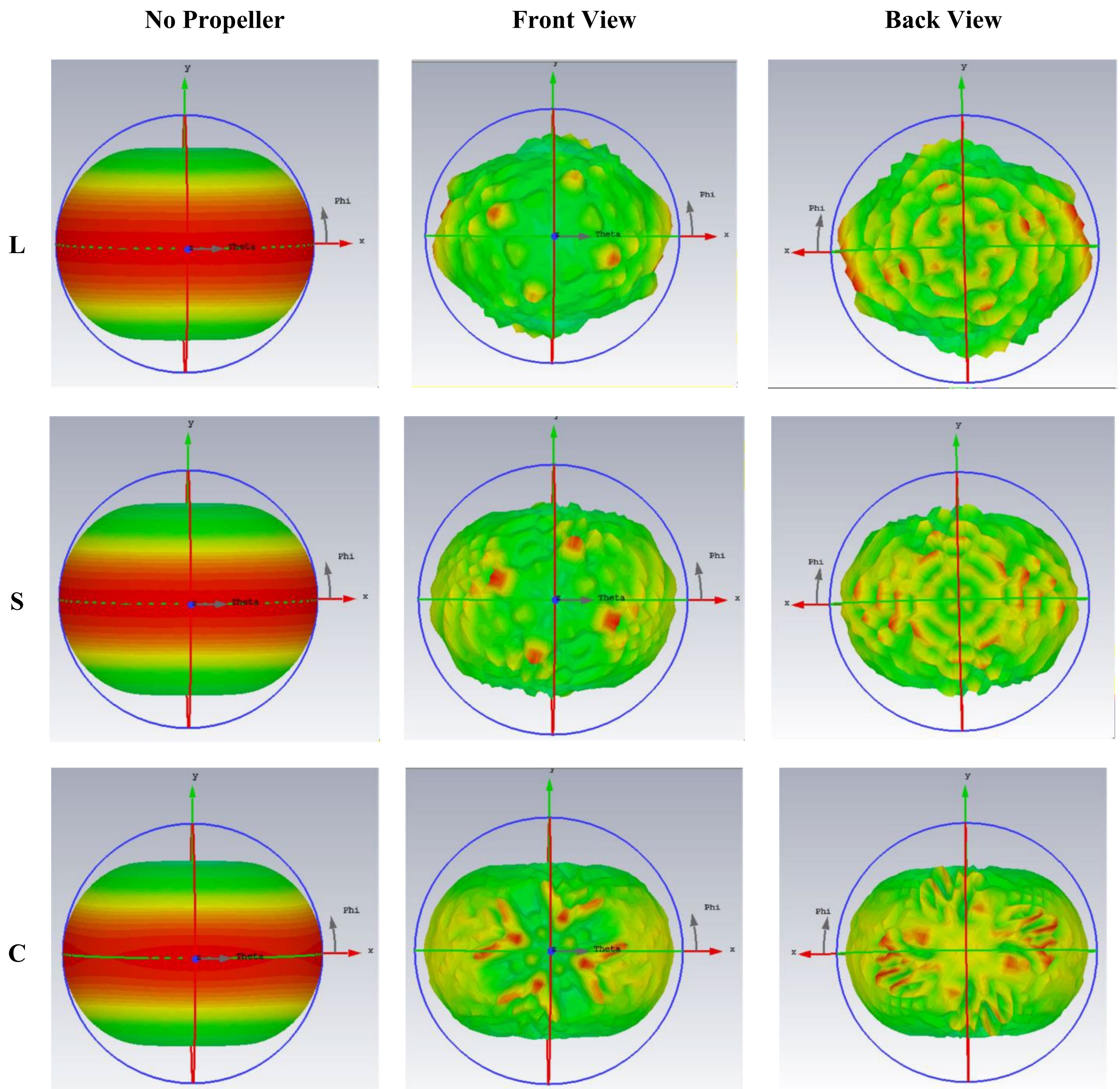
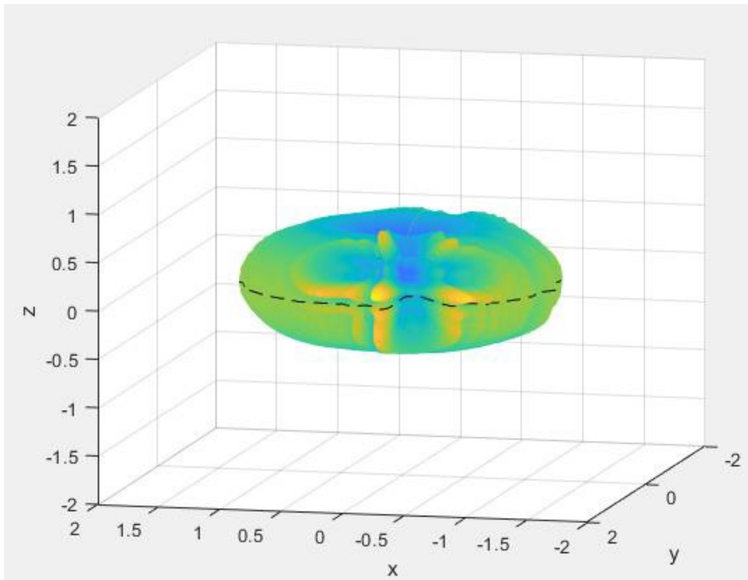
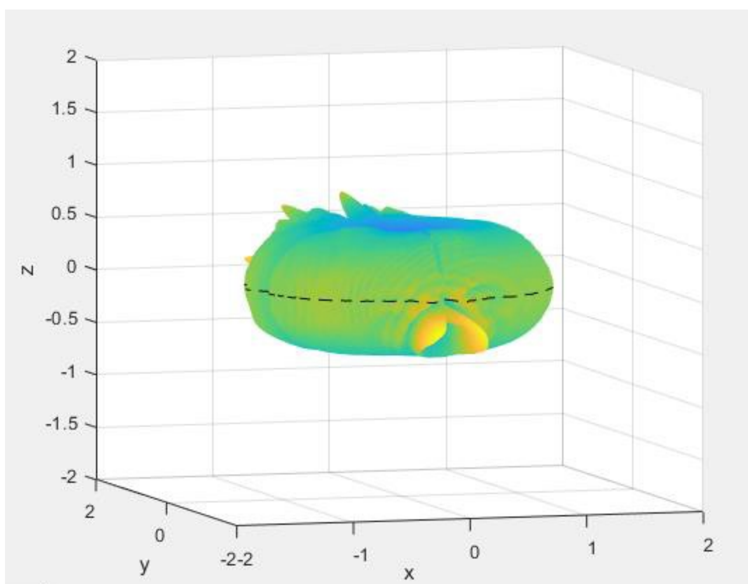



**Figure 3: 3D Radiation Patterns - No Propeller, Front, Back Views at L, S, and C bands**

A calculated farfield radiation pattern at 4400 MHz was imported into a generic mathematical software tool and lightly filtered to smooth the response. Three dimensional plots of the front and back view are shown in Figure 4. The transmit source is located at the origin (center of the donut) and a horizontal black-dashed reference line helps visualize its relative position. From the front, the propeller outline is visible and the surface shows areas of blade blockage. The view from the back primarily shows areas of intensity that are consistent with reflections.




**Front View**




**Back View**

**Figure 4: Front and back views of the smoothed surface at 4400 MHz**

In order to understand how a moving blade may influence RF propagation, azimuth cuts at different elevation angles were investigated. Rotating the azimuth observation angle at a fixed elevation is similar to the propeller rotating with the azimuth observation angle fixed. Moving the observer and leaving the propeller fixed reduced the electromagnetic simulation time significantly.

Two scenarios were investigated; viewing directly through the blades and viewing below the blades as shown in Figure 5. Figures 6 and 7 show the calculated directivity versus azimuth angle cuts at elevations of -28 degrees (below scenario) and -10 degrees (through scenario) respectively. In addition to the black-dashed reference line, a red line is added to show the slice location. Note that for the area within +/- 45 degrees of the propeller blade location, the response has been replicated to mimic the effect of a rotating four blade system. Comparing Figure 6 and 7, it's obvious that looking through the blades has a much larger impact on RF propagation than looking below the blades. Also, the response from back has more rapid amplitude fluctuations than the front.

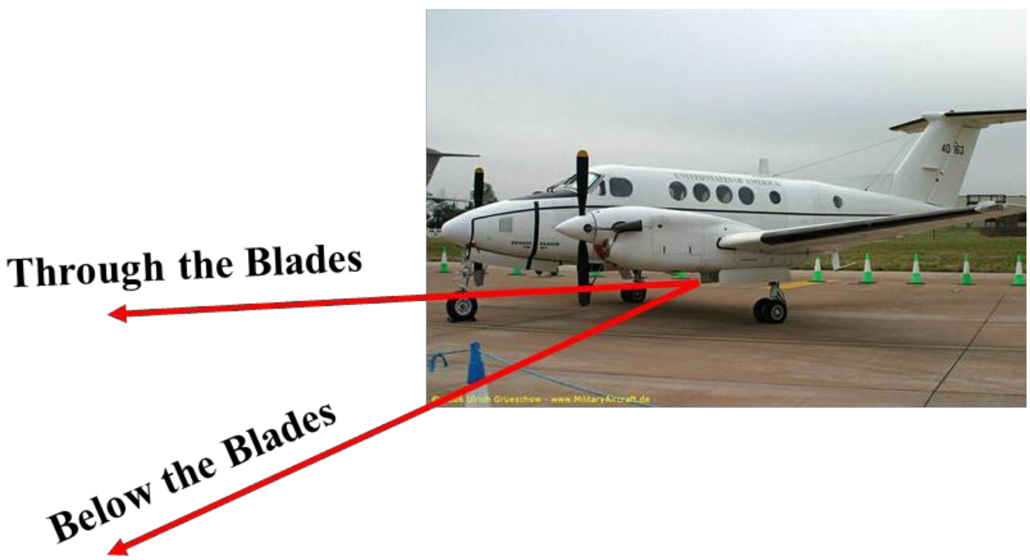



**Figure 5: Simulation scenarios (through and below the blades)**

Even with this simple model (propeller in space with no aircraft), there are a surprising variety of RF propagation profiles ranging from shallow to deep fades, slow to rapid fluctuations, and very different behavior between front and back viewing angles. The next section compares some of these simulation results to measured observations that occurred during field testing at Edwards AFB.

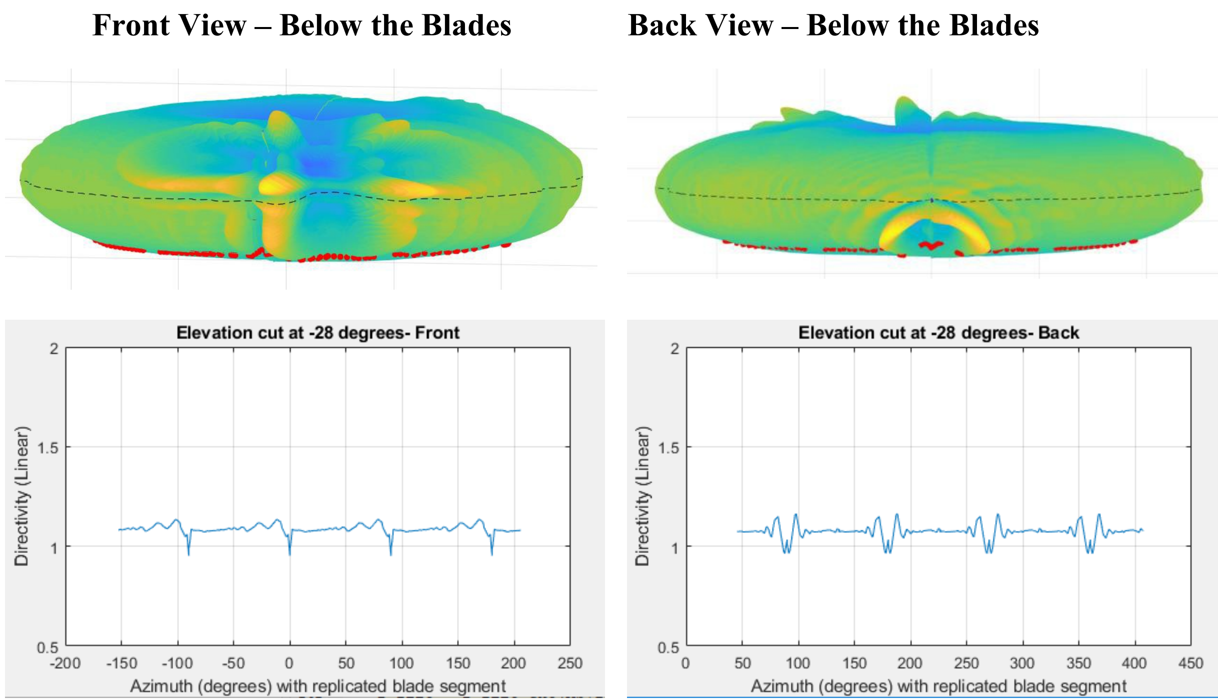



**Figure 6: Front and back views below the blades**

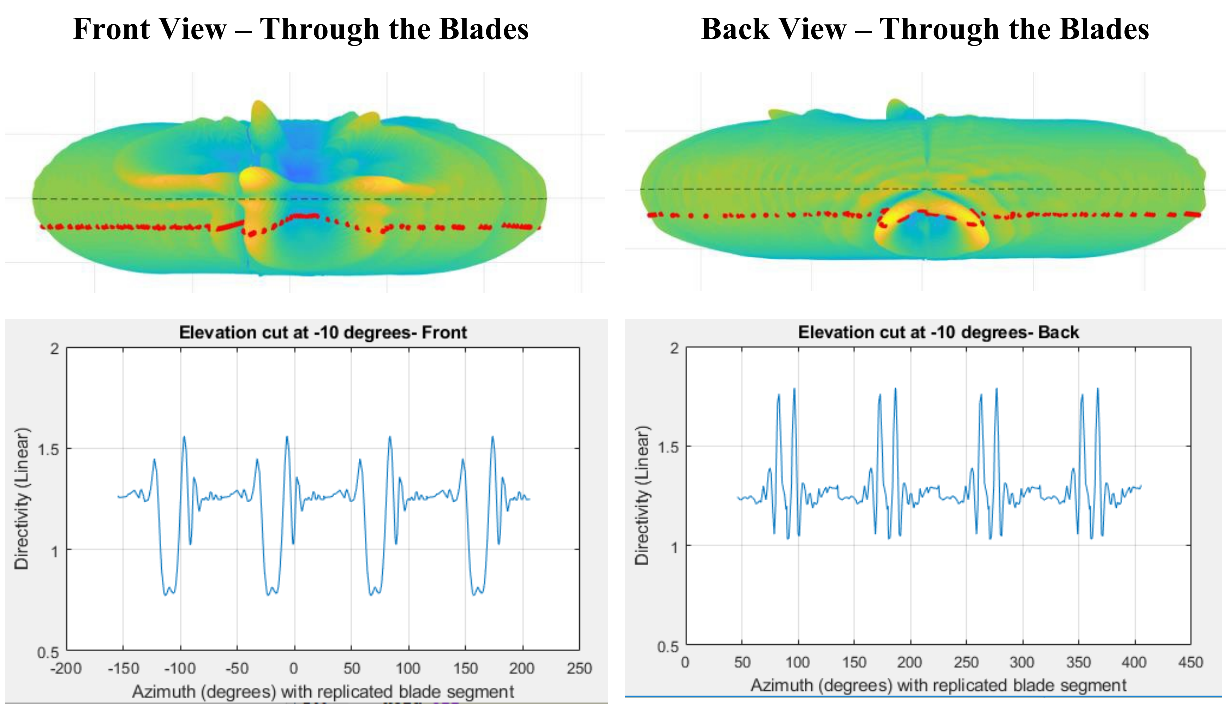
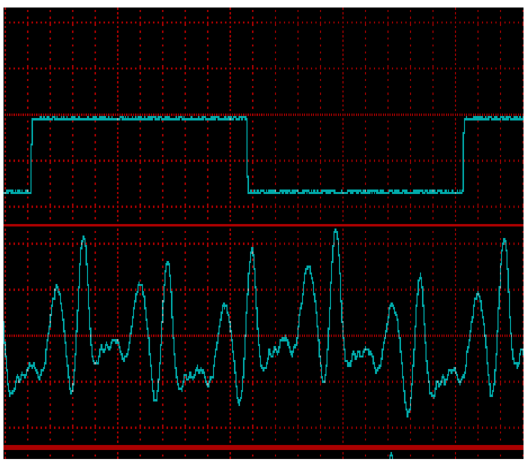



**Figure 7: Front and back views through the blades**

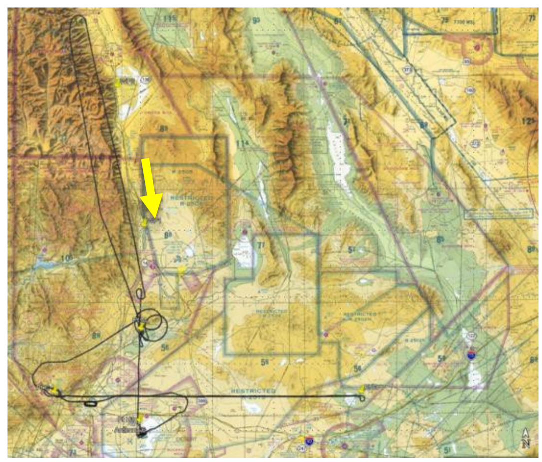
## FLIGHT TEST DATA

Obviously, the simulation model discussed above is very simplistic compared to a real aircraft with rotating propellers. However, some general comparisons between simulation and field measurements are presented below. A good place to investigate is a portion of the flight path that was heading directly away from the receive site and directly towards it on the return path. This provides a clean comparison with known aircraft orientation and high signal levels. Figure 8 shows measured signals along with the flight plan from recent C-band testing at Edwards AFB. Portions of the flight path provided extended looks from both the front and the back.

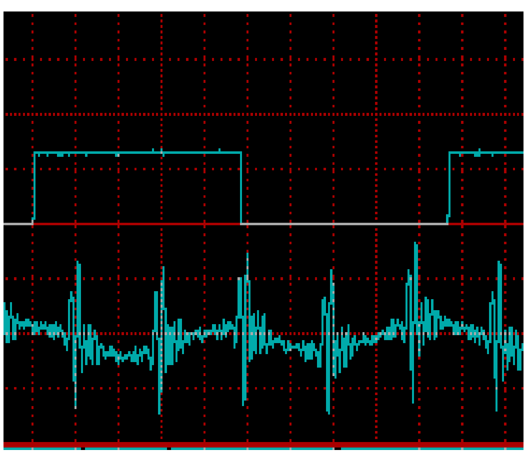
Note the rapid fluctuations in amplitude level relative to the antenna scan signal (square wave at roughly 30 Hz) and their distinctly different characteristics between the front and the back. These variations were directly tied to the propeller rate as mentioned previously. Although these levels varied by roughly 6 dB, larger amounts up to 10 dB or more were encountered at various points.



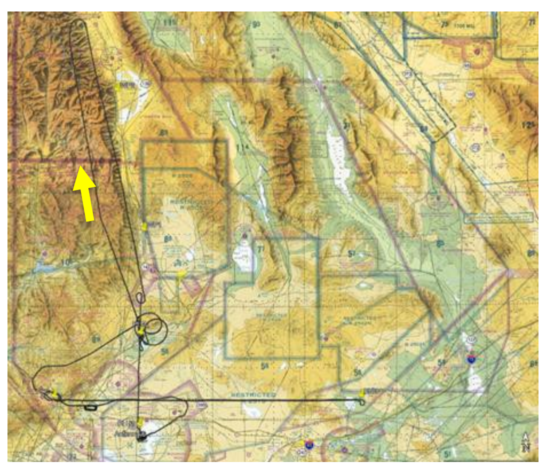
Measured antenna and AM signal (Front View)



Flight path (Front view)



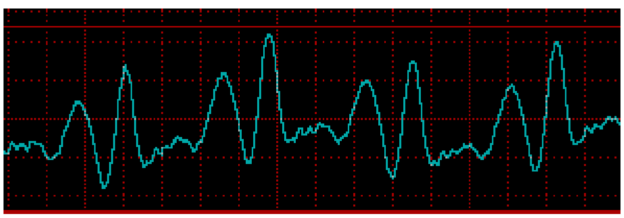
Measured antenna and AM signal (Back View)



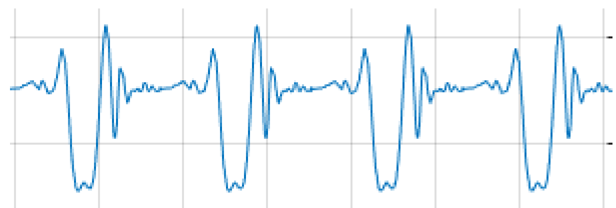
Flight path (Back view)

**Figure 8: Through the blades (front and back views)**

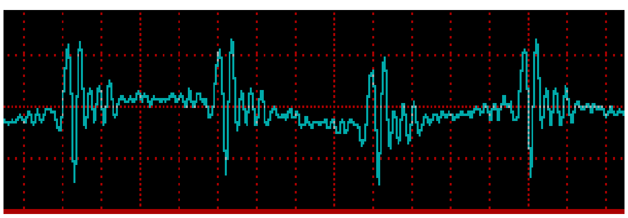
Figure 9 shows a comparison of the measured and simulated propeller induced amplitude fluctuations. It is not reasonable to expect that the simplistic 'floating' propeller model will match the real-world observations from an actual aircraft. However, the simulations do predict that the front view experiences a coarse shutter effect at the propeller rate while the back view sees much more rapid amplitude fluctuations due to the more complex reflection interaction. This general behavior is also clearly seen in the measured flight data which follows the basic pattern of slow variation from the front with much more rapid variations from the back. Although the scale is not shown in this plot, rapid signal level variations over the range of 4 to 10 dB were typical with rates of over 1 KHz on the back side. Also note that any tracking error in the conscan antenna system shows up as a slow-moving sinusoidal baseline in the measured data.



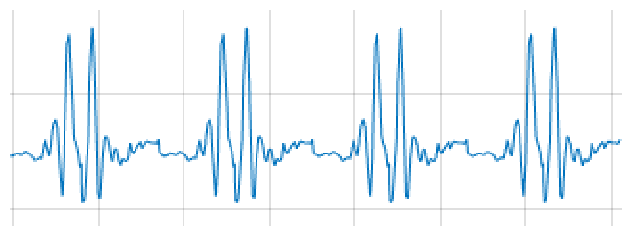
**Measured Peak-to-Peak fluctuation = 4.19 dB**



**Simulated Peak-to-Peak fluctuation = 6.02 dB**



**Measured Peak-to-Peak fluctuation = 6.35 dB**



**Simulated Peak-to-Peak fluctuation = 4.75 dB**

**Figure 9: Through the Blades (Measured – Left, Simulated - Right)**

## CONCLUSION

This paper has investigated the effect of rotating propellers on telemetry signals. It was first noticed during field testing and tied to periodic data outages. RF simulation and experiemental observations of "prop chop" both showed rapid and high-level AM modulation produced by the propellers. The model and the measurements also agreed on the different character between the front and back views. Received signal level variations over the range of 4 to 10 dB were typical with rates of over 1 KHz occurring on the back side. The simulation model also predicted that the angular fluctuations become more rapid as the carrier frequency increases. The only flight data used in this paper was performed at C-band.

General lessons learned from this investigation include to always instrument the telemetry with as much monitoring capability as possible. This is a substantial help with diagnosing subtle issues that are causing data dropouts or low-quality telemetry links. If possible, monitoring the system with a real-time version of the data quality metric (DQM) generated from a receiver can provide invaluable information in identifying and quantifying a wide range of telemetry impairments.

## ACKNOWLEDGEMENTS

The authors would like to thank their teammates at Quasonix who assisted in the data analysis and collection of field results, namely Bob Schumacher, Jim McCurdy, and Jim Uetrecht. More importantly, thanks to all the ranges and companies who have welcomed Quasonix to their facilities and graciously shared their time, equipment, and expertise.

## REFERENCES

[1] T. Hill, "Metrics and Test Procedures for Data Quality Estimation in the Aeronautical Telemetry Channel," in *Proc. Int. Telemetering Conf.*, Vol. 51, Oct. 2015.