The Great Sand Dunes National Park and Preserve

Unmanned Aircraft System Aerial Survey

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Figure 1: Final data product combining three dimensional data products with orthophoto collected by the Black Swift Technologies SwiftTrainer™ UAS

Introduction

A landmark set of Unmanned Aircraft System (UAS) operations were conducted in the Great Sand Dunes National Park and Preserve as part of a collaborative project to produce accurate, three-dimensional maps of the area. This required the combined efforts and expertise of Wohnrade Civil Engineers (WCE), Black Swift Technologies (BST), UAS Colorado, and the National Park Service (NPS). Two flights were successfully completed on October 19th 2016, making Wohnrade Civil Engineers of Broomfield, Colorado the first FAA licensed operator to use an UAS to conduct a sanctioned mission over the Great Sand Dunes. Additionally, the photos collected during the flights allowed the team to generate first-of-its-kind data products over a 1-square-mile area of the park.

The Great Sand Dunes National Park is a very unique environment, resulting in many technical challenges for aerial data collection. Specifically these include:

- The placement and surveying of ground control points using GPS in an area inaccessible to vehicles.
- Conducting a mission over an Area of Interest (AOI) several miles from the launch site while maintaining safe operations through constant voice communications between visual observers and the Pilot in Command (PIC).
- Variable environmental factors, most notably gusting wind and contrasting shadows.
- The use of photogrammetry to process a relatively homogeneous scene where feature detection and correlation across photos was difficult.

The focus of this white paper is to provide details about the encountered issues as well as the solutions the team employed to overcome them. It will demonstrate how the team's experience and calculated approach ensured the

Figure 2: Photo of the visual observer stationed on top of the Star Dune.

work culminated in a successful and safe flight-deployment as well as a valuable data product for the NPS.

1 Purpose of the Study

The primary purpose of this work was to provide meaningful data to the National Parks Service. "The Great Sand Dunes contain the tallest dunes (maximum height about 750 feet, or 230 m) in North America. These dunes cover an area of 72 square kilometers (28 square miles) and contain an estimated 10-13 billion cubic meters (2.4 to 3.1 cubic miles) of sand. The dunes accumulated in an embayment that formed where the trend of the Sangre de Cristo Range changes from southeasterly to southwesterly. They owe their exceptional height to a combination of factors including range-front geometry, topography, an abundant sand supply from the nearby basin, a complex wind regime, and the Sangre de Cristo Range, which prevents continued eastward migration of dune sand deposited by the prevailing southwesterly and westerly winds. Although the sand on the surface of the Great Sand Dunes is of late Holocene age, most of this massive sand body is a complex of deposits that accumulated episodically for more than 130,000 years."[1]

Although the dunes system as a whole is fairly stable, changes still occur within the field. According to the NPS, "Currently, there is enough vegetation on the valley floor that there is little sand blowing into the main dunefield from the valley. However, even today there are still some small parabolic dunes that originate in the sand sheet and migrate across grasslands, joining the main dunefield. At other times, some of these migrating dunes become covered by grasses and shrubs and stop migrating."[2] Additionally, although the larger formations, such as the Star Dune and the High Dune, have maintained their shape for hundreds of years, they will commonly change locations based on shifts in weather patterns.

One of the fundamental tenets of the National Park Service is the study and understand-

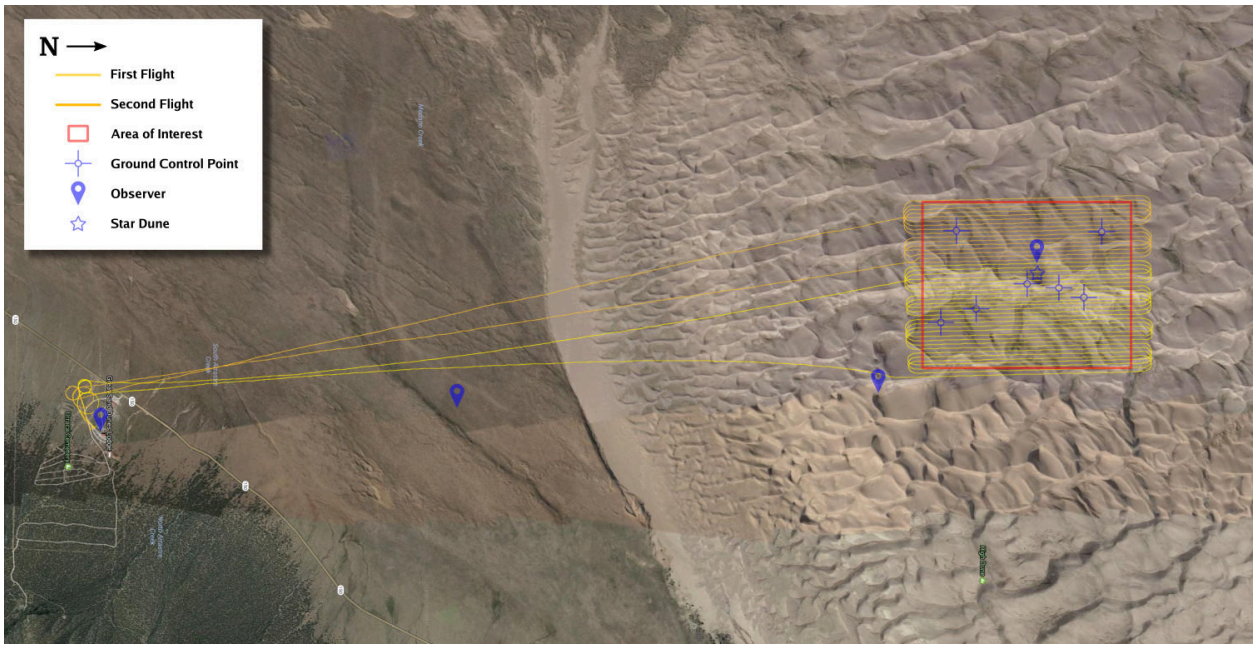

Figure 3: Flight path of the two flights conducted over the Star Dune area of interest. Note the straight flight tracks and significant distance between the AOI and takeoff and landing location.

ing of the resources they are charged with protecting. For the Great Sand Dunes system, this involves remote and in situ sensing to monitor change detection. Work to date largely involved labor intensive traditional surveying methods, consuming valuable resources from an already over-constrained workforce. In an effort to alleviate these issues, this investigation was conducted to develop precision mapping capabilities through the use of UAS. Specifically, a desire exists to measure terrain height in the vicinity of the largest park feature, the 750ft (229m) tall Star Dune, as well as provide change detection for the dune itself.

2 Mission Planning

2.1 GPS Ground Control Points

The AOI for the project consisted of an one square mile rectangle, centered on the Star Dune (Figure 3). This size and shape were chosen to balance the requirements of the NPS with the limited resources available for the collect. Specifically, this size of survey would generally require up to 24 ground control points (GCPs) to provide an absolute reference for the photo set, as well as several check points (CPs) to use in error analysis of the final data product. However, the AOI was inaccessible by vehicle and required travel by foot, which consequently meant the establishment of GCPs and collection of their individual GPS x,y and z coordinates would take significantly longer than usual.

Over a period of eight hours on October 18, 2016, a combined total of seven surveyed GCPs and check points CPs were set by a two man crew from Wohnrade Civil Engineers. Although well short of the desired 24, this was the maximum number achievable by a two man team in the period allotted for the mission. Measures were taken to ensure that the GCPs did not shift on the dune or become covered in sand before the collect could take place.

2.2 Flight Path Generation

The flight paths were generated using the SwiftTab™ user interface software from BST. This software allows for the simple creation of mapping plans based on only a few specified parameters from the operator. Specifically these include the height above ground level for the mapping mission and percent overlap of the photos. Tracks are automatically generated to achieve these parameters, and photo trigger locations are based on GPS location, eliminating incorrect spacing due to strong tail or head winds.

One of the challenges for this particular project was the collection of data over very diverse terrain, given the area of interest contained terrain variations of up to 750ft (229m). Use of the SwiftTab™ app greatly simplified the mapping plan generation process as it makes use of digital elevation maps to 1) ensure the waypoints remain within a specific height of the ground (thus maintaining a uniform ground sample distance for the photos taken throughout the flight) and 2) inform the operator if any flight paths will intersect particularly sharp terrain features.

3 Aerial Data Collection

3.1 The SwiftTrainer™ UAS

The UAS team of Wohnrade Civil Engineers and Black Swift Technologies chose the fixed-wing SwiftTrainer™ (Figure 4) for the Sand Dunes project for its ease of use, accurate ground tracks, accurate geotagging of images, extended range, and ability to map large areas in a single flight (up to 2.25 sq-mi). The SwiftTrainer is a small, fixed-wing UAS that is sold by BST to primarily conduct these sorts of aerial campaigns.

Figure 4: Launch of the SwiftTrainer™™ UAS from a small dirt road.

The SwiftTrainer™ provides industry-leading AOI coverage through the uniform spacing of images, tight flight tracking, and consistent overlap pattern. These factors are essential for producing an image set capable of deriving accurate geospatial data from. This was especially important for this particular data set, given the incredibly limited number of features that could be extracted from the dunes themselves.

One of the conditions of the NPS Scientific Research and Collecting Permit was to locate the launch and landing site outside of the Great Sand Dunes National Park boundary. This not only extended the collection time considerably, but also required operations from a very short dirt road. The hand launch capability and automated landing functionality of the SwiftTrainer™ proved invaluable in being able to conduct the missions given the NPS constraints.

The 1-square mile AOI was flown in 2 hours and 30 minutes over two flights, collecting 1,755 images. The automated "resume mapping" feature of the SwiftTrainer™ was used to ensure proper overlap between the data sets. A total of 1,289 images were collected during the first flight, and 466 images were collected during the second.

4 Post Processing

The geo-tagged images collected with the SwiftTrainer need to be processed after the flight to generate useful data products. The NPS desired both a detailed orthomosaic image of the entire 1 sq mile area as well as a 3D point cloud.

4.1 Computed Image/GCPs/Manual Tie Point Positions

Several different software suites were used to process the data in an attempt to determine which one would produce the most accurate and complete data products. As expected, many software packages had issues with uniform nature of the large sections of sand visible in the images. The photogrammetry process relies on the ability to distinctly identify and match overlapping features in different photos, something inherently difficult in photos of homogenous regions. Even with significant intervention this issue caused data artifacts and even complete failure in many of these software packages. Fortunately, the team was able to eventually find a set of settings and software package which produced a satisfactory data product.

Figure 5 shows the offset between initial image positions (blue dots) and computed positions (green dots) as well as the offset between the GCP initial positions (blue crosses), and computed positions (green Xs) in the x-y plane. Omitted images (red dots) are a result of both intense elevation change, as well as homogeneous ground surface textures. Both of these conditions make it difficult for photogrammetric algorithms to identify common match points between overlapping photographs. While these environmental factors commonly make processing difficult, this set proved to be particularly difficult for identifying and matching tie points. Despite these difficulties the software was still able to generate an orthomosaic image and three-dimensional point cloud.

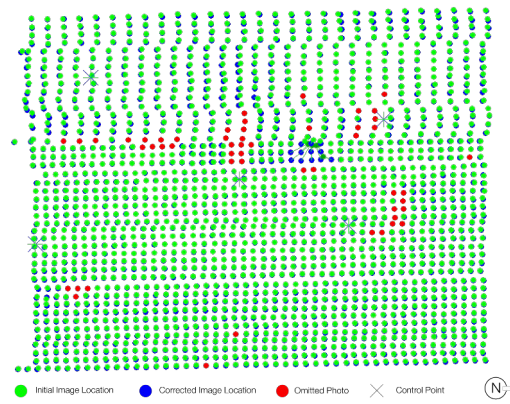

Figure 5: Original and corrected photo locations provided by the ESRI Drone2map software.

4.2 ASPRS Accuracy Calculations

Wohnrade Civil Engineers, Inc. calculates the RMSE accuracy for each project using method-

Table B.7 Vertical Accuracy/Quality Examples for Digital Elevation Data

Vertical Accuracy Class	Absolute Accuracy			Relative Accuracy (where applicable)		
	RMSEz Non-Vegetated (cm)	NVA at 95% Confidence Level (cm)	VVA at 95th Percentile (cm)	Within-Swatch Hard Surface Repeatability (Max Diff) (cm)	Swath-to-Swath Non-Veg Terrain (RMSDx) (cm)	Swath-to-Swath Non-Veg Terrain (Max Diff) cm
1-cm	1.0	2.0	3	0.6	0.8	1.6
2.5-cm	2.5	4.9	7.5	1.5	2	4
5-cm	5.0	9.8	15	3	4	8
10-cm	10.0	19.6	30	6	8	16
15-cm	15.0	29.4	45	9	12	24
20-cm	20.0	39.2	60	12	16	32
33.3-cm	33.3	65.3	100	20	26.7	53.3
66.7-cm	66.7	130.7	200	40	53.3	106.7
100-cm	100.0	196.0	300	60	80	160

ology and equations established by the American Society for Photogrammetry and Remote Sensing (ASPRS)[3]. The horizontal RMSE accuracy for the Sand Dunes project falls short of their usual high standards for several reasons, namely the limited number of GCPs, and the difficulty in processing images of large homogeneous regions. The horizontal accuracy of the final collect is summarized as follows.

$$RMSE_x = 0.22 \text{ ft}$$
$$RMSE_y = 0.72 \text{ ft}$$
$$RMSE_r = 0.75 \text{ ft}$$

Based on Table B.3 of the ASPRS Positional Accuracy Standards, the Horizontal Accuracy Class for the Sand Dunes collection is 17.50 cm. When an adequate number of ground control points are used, the accuracy of their final deliverables usually fall within a Horizontal Accuracy Class of 10.00 cm or less.

The vertical accuracy was computed to be:

$$RMSE_z = 1.84 \text{ ft}$$

Based on Table B.7 of the ASPRS Positional Accuracy Standards, the Vertical Accuracy Class for the Sand Dunes project is between 33.3 and 66.7 cm. Again, when an adequate number of ground control points are used, final deliverables usually fall within a Vertical Accuracy Class of between 2.5 and 10 cm.

Table B.3 Common Horizontal Accuracy Classes According to the New Standard

Horizontal Accuracy Class $RMSE_x$ and $RMSE_y$ (cm)	$RMSE_r$ (cm)	Orthoimage Mosiac Seamline Maximum Mismatch	Horizontal Accuracy at the 95% Confidence level (cm)
0.63	0.9	1.3	1.5
1.25	1.8	2.5	3.1
2.50	3.5	5.0	6.1
5.00	7.1	10.0	12.2
7.50	10.6	15.0	18.4
10.00	14.1	20.0	24.5
12.50	17.7	25.0	30.6
15.00	21.2	30.0	36.7
17.50	24.7	35.0	42.8
20.00	28.3	40.0	49.0

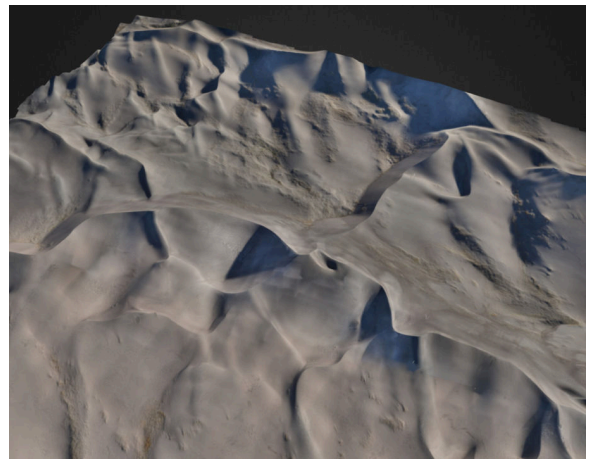

Figure 6: 3D rendering generated from UAS Data.

4.3 The Photogrammetric Process/3D Point Cloud

The photogrammetric process generates a point cloud containing millions of points, with each point representing approximately 1 to 1.5 square inches on the ground. The precision mapping products generated by WCE utilizing the SwiftTrainer are routinely supplemented with traditional ground survey from a licensed land surveyor, to create a type of hybrid topographic map with very high vertical and horizontal accuracies.

The three-dimensional image in Figure 7 below represents a point cloud that was developed using photogrammetry, and includes over 145 million points to provide a complete representation of the ground surface. Each point represents roughly 1.5 square inches on the ground.

4.4 Final Deliverables to the Great Sand Dunes National Park Research Staff

The processed data from this set of flight experiments was used to put together a set of useful deliverables for the research staff of the Great Sand Dunes NP. These include:

1. High-resolution Orthomosaic Image (3 cm/pixel) of the 1 sq mile area.

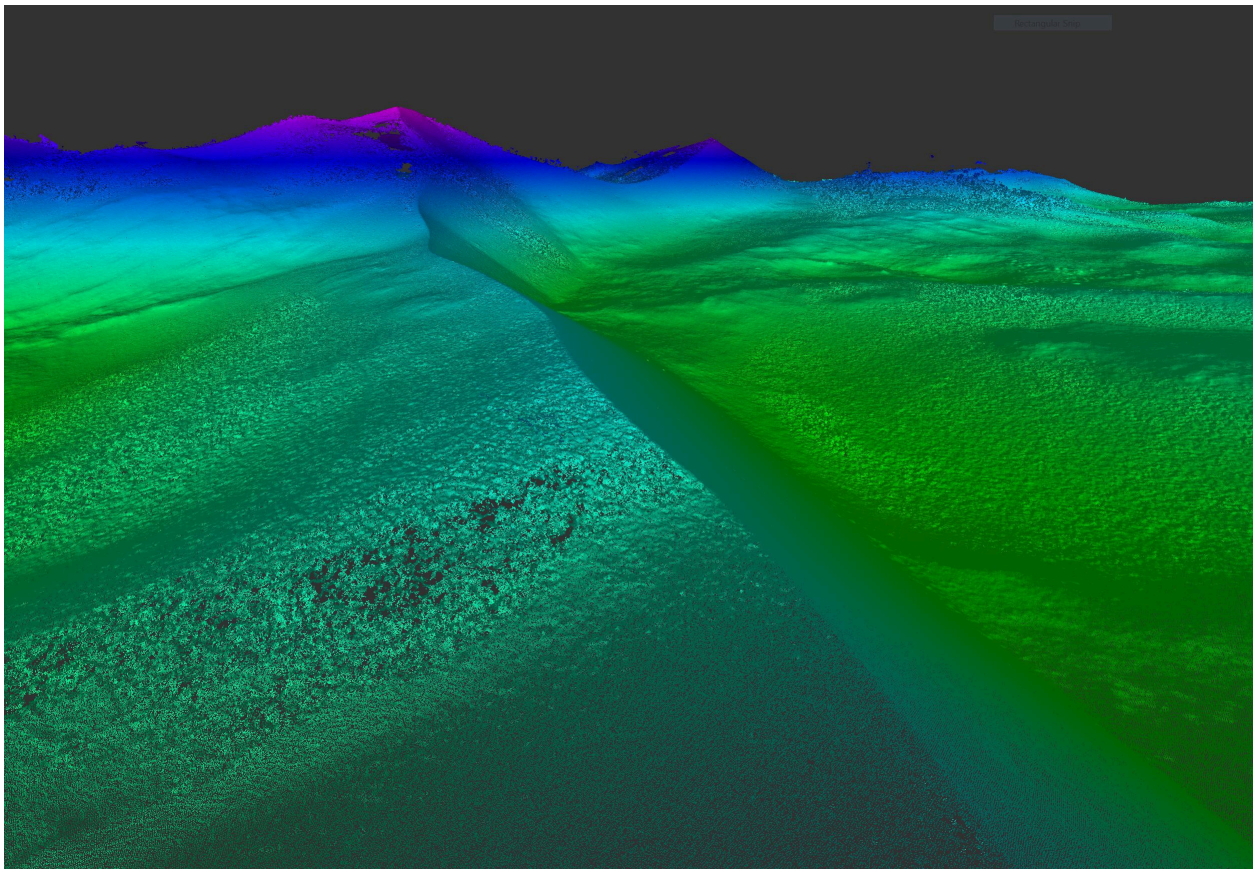

Figure 7: Three dimenstional point cloud data set visualization from the Sand Dunes project.

2. One-foot contours in a .shp file format.
3. Point cloud of the DEM in a .las file format containing over 145 million points.
4. 3D Model in a .obj file format.

5 Conclusion

The Great Sand Dunes National Park aerial data collection was performed under very challenging conditions under the purview of the National Park Service. Numerous site and environmental factors affected the final accuracy of the collection, and much has been learned about how to mitigate these factors in the future. It is the hope of the entire team that this work can help inform future projects of both the technical and regulatory challenges of (1) operating in National Parks, (2) performing photogrammetry missions in uniform areas such as deserts, and (3) operating in areas that are many miles from a possible launch and landing location.

The Great Sand Dunes National Park Research Team is pleased with the results, and believes, "It is definitely the best imagery of the dunes to date!" The high-resolution imagery has also led to the recognition of new features on the Dunes, and possibly new discoveries. The high-resolution orthomosaic image (3 cm/pixel) proved to be a valuable source of information. This imagery revealed new information about the Great Sand Dunes, which was previously unknown to Research Staff at the Great Sand Dunes National Park.

We anticipate future data collections at the

Great Sand Dunes National Park on an annual basis in the same AOI. WCE has already begun developing new methods to increase vertical and horizontal accuracies in this very challenging and unique environment. To this end, WCE has teamed with BST to develop a custom UAS platform that includes a LiDAR scanner, and 42 megapixel camera. WCE expects to use this UAS in 2017 to map a portion of the 2016 AOI. The results from the two collections will then be compared, and evaluated for accuracy.

5.1 Acknowledgments

This milestone project was made possible through the effort of a diverse team of professionals including: Project Coordination by **Constantin Diehl** of UAS Colorado[1], and the Research Staff at Great Sand Dunes National Park, Engineering and Surveying expertise by **Mary Wohnrade**, P.E. of WCE, UAS Mission Planning by **Brendan Thompson** of WCE, and SwiftTrainer™ UAS operations by Pilot-in-Command **Jack Elston**, Ph.D., CEO of BST.

References

[1] R. F. Madole, D. P. VanSistine, and J. H. Romig, "Geologic map of great sand dunes national park, colorado," tech. rep., US Geological Survey, 2016.

[2] N. P. Service, "Great sand dunes national park & preserve colorado, geology," 2011.

[3] "ASPRS Positional Accuracy Standards for Digital Geospatial Data," *Photogrammetric Engineering & Remote Sensing*, vol. 81, pp. A1–A26, March 2015.

[1] http://uascolorado.com/

About Wohnrade Civil Engineers

Wohnrade Civil Engineers, Inc. (WCE) is an FAA Section 333 Exemption Holder, as well as an FAA Part 107 Certified Operator. WCE has been performing aerial data collections for the past eighteen months, using the SwiftTrainer™ UAS platform (developed by Black Swift Technologies). WCE makes use of the SwiftTrainer™, as well as our DJI Inspire 1, to perform data collections, which are then processed using photogrammetry. WCE is at the forefront of delivering precision UAS mapping products in a variety of digital formats, which are then used for civil engineering design.

WCE has developed a unique in-house workflow that includes: UAS mission planning; UAS field data collection; Data processing using photogrammetry; Preparation of precision mapping products. All products are generated using surveyed ground control points (GCPs), and are georeferenced in a real world coordinate system. Our deliverables generally include: High-resolution orthomosaic image (2.5 to 3 cm/pixel GSD); Digital elevation model (DEM); Digital point cloud; 3D model; Digital terrain model (DTM) with 1-foot contours. All of these products are accurate enough to be used for civil engineering design.

WCE has demonstrated that the use of UAS to generate reliable and precise ground surface models is very cost effective when compared to traditional ground and aerial surveys. WCE has accumulated a database for all of our projects, which includes actual costs for UAS aerial mapping versus traditional ground surveying. WCE is able to save our clients roughly 40% on average. The cost savings that can be achieved varies widely, depending on the size of the project and type of terrain, and relates directly to the field collection time. In most cases, a UAS platform is able to collect data in less than an hour, as compared to traditional ground survey methods, which take days.

About Black Swift Technologies

Black Swift Technologies (BST) is based in Boulder, CO and has been in operation since 2011. All UAS sold by BST are built upon the SwiftCore™ FMS that includes the autopilot, ground station, user interface, and support electronics. Unlike many competing systems that rely on open-source and low-quality avionics, BST is able to guarantee quality, robustness, and supply of the most critical components of our systems. The SwiftCore FMS was designed by BST from the ground up. This affords control of the critical parts of our products, including the design of all electronics for both the avionics and ground systems, software, mechanical assembly, and the detailed QC process for all outgoing systems. Furthermore, BST uniquely couples avionics expertise with consulting services, and has delivered products and engineering services to many government entities including NASA, NOAA, various universities along with commercial sales to end-users and aircraft integrators.