Unmanned Aircraft for Airborne Gravity Measurements

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I. Executive Summary

The capability for using an unmanned aircraft for airborne gravity measurements is transitioning from research to operation based on a successful Small Business Innovation Research (SBIR) Phase II field test. This capability will likely reduce costs and risks to NOAA through the National Geodetic Survey's (NGS) Gravity for the Re-definition of the American Vertical Datum project (GRAV-D) that is collecting airborne gravity data to provide more accurate heights for a variety of applications, including marine transportation and coastal resilience applications. The GRAV-D program will bring large societal and economic benefits to the United States, with an estimated $522 million in annual economic benefits and approximately $240 million saved from improved floodplain mapping alone.[1] In addition, private industry has shown interest in this capability and other NOAA operations could use the same platform for different measurements.

Developing the capability for measuring gravity from an unmanned aircraft was proposed and awarded under the NOAA Small Business Innovation Research (SBIR) program. This goal was to identify an unmanned platform and sensor (gravimeter) that would meet requirements as defined by the NOAA to reduce costs and improve efficiencies of airborne gravity operations. Aurora Flight Sciences Corp. under a Phase II SBIR, WC-133R-14-CN-0101, has successfully combined the best of manned and unmanned surveillance aircraft capabilities. They have coupled their Centaur aircraft with the Micro-g LaCoste (MGL) TAGS-7 gravimeter to provide useable and reliable data to NOAA's National Geodetic Survey (NGS).

This capability was developed in coordination between the OAR UAS Program Office, OAD Technology Partnerships Office, and NGS. With the successful completion of Phase II, this capability is transitioning to a SBIR Phase III where governmental and commercial services will be provided. NGS is planning a standard 1-2 month survey to confirm results and determine it is fully operational. Upon successful completion of this survey this capability will be used to augment standard manned flights that are conducted year round across the U.S. and territories. The exact locations and amount of surveying time will be determined annually based on priorities, budget, and weather.

Figure 1: Aurora Centaur aircraft

II. Background

NOAA GRAV-D Project

The mission of NOAA's National Geodetic Survey is to define, maintain, and provide access to the National Spatial Reference System, which includes the official U.S. datums: the North American Datum of 1983 (NAD83), and the North American Vertical Datum of 1988 (NAVD88). In 2022 NGS will be replacing the official datums to address known systematic issues. The vertical datum will use newly collected airborne gravity data obtained through the GRAV-D project.

There are two phases to the GRAV-D project: 1) a complete snapshot of the U.S. and territories with airborne gravity to support a geoid accurate to 1 centimeter where possible and 2) a long term monitoring program.[2] Airborne gravity was selected to provide medium wavelength information to complement existing gravity data sources and to easily bridge the littoral gap between marine and terrestrial gravity measurements. Data collection is over 52% complete. To support a 1 centimeter accurate geoid the GRAV-D project requires gravity data accurate to 1 mGal.

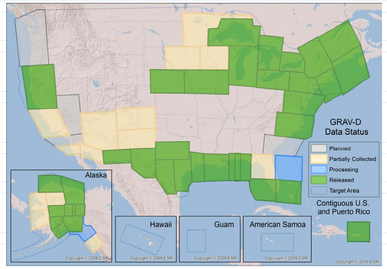


Figure 2: Data collection and release status of GRAV-D

Aurora Flight Sciences and the Centaur Aircraft

A Small Business Innovation Research (SBIR) contract was competed and awarded to Aurora Flight Sciences to develop and test the Centaur aircraft with a gravimeter to demonstrate successful gravity data collection with unmanned aircraft operations. The Centaur Optionally Piloted Aircraft (OPA) is an Aurora-modified Diamond DA-42MPP aircraft where the modification enables interchangeable flight operations in a manned and unmanned mode of flight operations. It is additionally unique in the sense there is a third mode called the "augmented" mode of operation. This mode allows a "hands-off" safety pilot to be on-board the aircraft while it is controlled remotely from a ground control station just as an unmanned aircraft is controlled. Real mission operations and test operations can be flown using this augmented mode. This allows the system to be used anywhere, anytime regardless of FAA approval to fly in the unmanned mode.

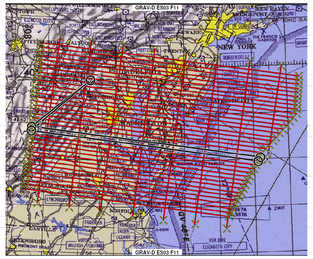
Micro-g LaCoste TAGS-7 Gravimeter

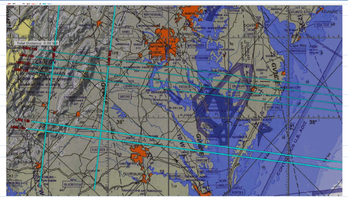
Aurora Flight Sciences partnered with Micro-g LaCoste (MGL), a U.S. manufacturer of gravimeters. In addition to the platform integration, MGL modified the sensor to work with the unmanned aircraft system. The current Turn-Key Airborne Gravity System (TAGS) 6 gravimeter was improved and modified for this work and based on the results MGL as incremented the model to signify the improvements.

III. Flight Test Design

Test flights were planned out of Aurora's facilities at the Manassas Regional Airport in Virginia over existing data that were previously collected for GRAV-D. The system was operated in its "augmented" mode of operation where a hands-off safety pilot was on-board with remote control performed at the ground station like an unmanned aircraft. This allowed testing the system over Virginia without the need to have the FAA approve unmanned operations. The test flights included the MGL TAGS7 gravimeter, GPS receivers on the aircraft and ground, and an inertial measurement unit on the aircraft to improve positioning.

Flights were planned to cover both east-west and north-south lines as well as collect data over areas with a high gravity signal. In Virginia this covered an east-west line over the coast and a north-south line that covered higher terrain. Initial flights were planned to be shorter to confirm all systems were operational with subsequent flights using the full range capability of the aircraft to simulate operational flights.





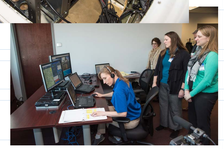


Figure 3 (left): Completed GRAV-D lines
Figure 4 (above): Lines flown in UAS test
Figure 5 (above right): Gravimeter
Figure 6 (right): Ground control operation

IV. Flight Test Results

Successful flight tests confirmed that the gravimetric data are suitable to NGS and this capability is now in the transition to operations phase. The flight tests were performed April 12-18th, 2016 with five flights conducted on five different days. As mentioned above, two of the flights were flown as multiple-repeats of existing lines of GRAV-D airborne gravity data collected with the older MGL TAGS gravimeter. At right, we compare the existing GRAV-D TAGS data with the overlapping new Aurora Centaur/TAGS-7 data.

The TAGS-7 data were processed by both by MGL and NGS, with similar results. Not only were the gravity measurements repeatable within specifications, but the aircraft performed extremely well with minimal motion during flight. The Centaur could repeat a line with high accuracy and provide real-time adjustments to airspeed to maintain a constant ground speed. The system is ready for commercial operations and can be flown manned or unmanned.

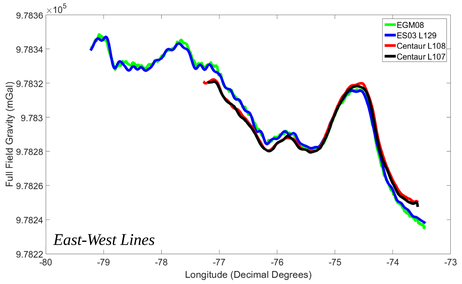


Figure 7 (above): Gravity comparison for the East-West lines. Centaur/TAGS-7 data (red and black) are plotted with the existing GRAV-D TAGS data (blue) and a global gravity model (EGM 2008, green).

Figure 9 (below, left): Difference between E-W Centaur/TAGS-7 lines.

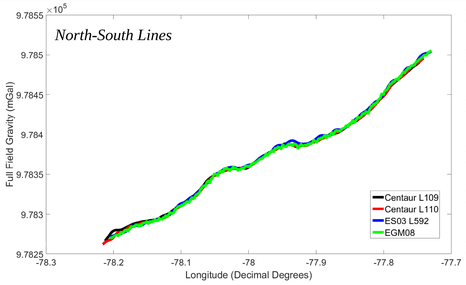
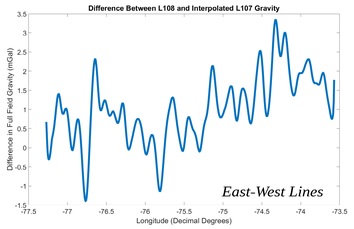


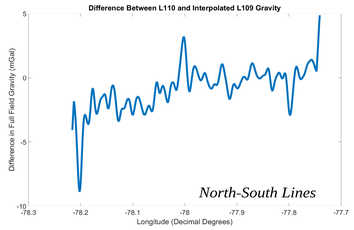
Figure 8 (left): Gravity data comparison for the North/South lines. Centaur/TAGS-7 data (red and black) are plotted with the existing GRAV-D TAGS data (blue) and the best global gravity model for the area (EGM 2008, green)

Figure 10 (below, right): Difference between two N-S Centaur/TAGS-7 lines.

Table 1: Statistics Showing Repeatability within Spec. for Centaur/TAGS-7 Lines

Lines	Mean (mGal)	Standard Deviation (mGal)	RMS (mGal)
L108-L107	1.0233	0.8783	1.3529
L110-L109	-0.9075	1.7450	1.9669





V. Benefits/Other Uses

NOAA GRAV-D Project

This capability will impact the GRAV-D project by likely reducing cost of operations, reducing human risk in operations, and improving environmental impacts. The GRAV-D program will bring large societal and economic benefits to the United States, with an estimated $522 million in annual economic benefits and approximately $240 million saved from improved floodplain mapping alone.[1] Two aspects will likely reduce the costs of this project: decreased fuel consumption and increased survey efficiency.

Figure 11: NOAA, Aurora Flight Sciences, and Micro-g LaCoste team at Virginia test flights (April 2016).

In terms of fuel efficiency, the current systems used by NOAA consume between 70-750 gallons of jet fuel per hour of flight operation. The Centaur-based system uses approximately 8 gallons of jet fuel per hour of flight operation, and will have reduced transit times due to longer endurance and on-station times. This will greatly reduce fuel cost and carbon emissions. The increase survey efficiency will come from reducing the number of days required to survey an area. Because the aircraft motion is minimal it will increase the number of days data can be collected based on weather while reducing the number of lines that need to be re-flown.

Other NOAA Applications

There could be other NOAA applications that could benefit from this work. The Aurora Centaur has the capability to integrate a wide variety of payloads and easily obtain FAA clearance. This project demonstrated that the Centaur has very good stability and repeatability of flights that may be important for other applications.

Private Industry

In addition, this capability has already generated interest in the private sector. Areas such as oil, gas & mineral exploration as well as transportation sectors will benefit from high accuracy gravity data collection with the capability for unmanned operations. Specifically, a California High Speed Rail project is likely to use this capability for accurate and efficient design of a rail system.

VI. References

[1]Leveson, Irving. *Socio-Economic Benefits Study: Scoping the Value of CORS and GRAV-D.* Report for the National Geodetic Survey. January 2009. Available 6 June 2016. http://www.ngs.noaa.gov/PUBS_LIB/Socio-EconomicBenefitsofCORSandGRAV-D.pdf

[2]Smith, Dru. *The GRAV-D Project: Gravity for the Redefinition of the American Vertical Datum.* National Geodetic Survey, 2007. Available 4 May 2015. http://www.ngs.noaa.gov/GRAV-D/pubs/GRAV-D_v2007_12_19.pdf

VII. Acknowledgements

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Photos by Derek Parks