



## PSIONIC DEFENSE

# Sensor-fused Doppler Lidar/IMU for Terrestrial Navigation

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## Overview

Alternative methods to GPS

Grades of inertial measurement units

Navigation Doppler Lidar development (NASA/Psionic)

Navigation Doppler Lidar/IMU architecture

Sensor fusion optimization

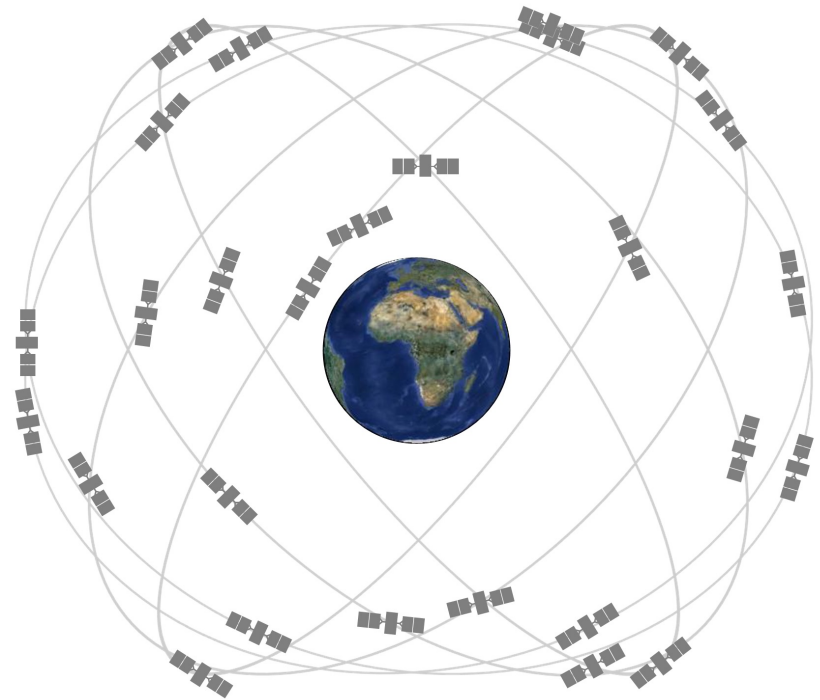
Test run protocols and results

Next steps and conclusions

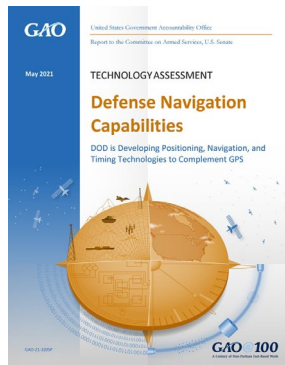
## Need for alternatives to GPS

### Causes of uncertainties in GPS




- **Satellite integrity**—Instabilities, clock bias, failures
- **Orbital mechanics**—Orbit eccentricity, trajectory deviation, relativistic effects
- **Signal propagation**—Ionospheric or tropospheric effects, multipath errors, dilution of precision, loss due to terrain features or urban construction
- **Receiver errors**—Accuracy differences between receiver and GPS clocks, noise
- **Natural causes**—Space weather, spectrum interference
- **Human causes**—Selective availability, scheduled maintenance, jamming, spoofing



“PNT information is essential in many facets of DOD operations. Given the ubiquity of GPS, the failure, malfunction, or jamming of its signals or equipment could disrupt military activities involving aircraft, ships, munitions, land vehicles, and ground troops. This possibility has led DOD to explore alternatives to GPS.”



- **Relative PNT**—Use of onboard sensors to track the position of a platform and keep time without the use of an external signal.
- **Absolute PNT**—Use of external sources of information, other than GPS, to determine the position of a platform, geo-referenced to Earth

	Approach	Potential technologies	Capabilities	Limitations
Relative PNT	Inertial sensors 	Mechanical: e.g., microelectromechanical systems	New materials could improve performance and lower cost	Mechanical noise limits performance
		Non-mechanical: e.g., thermal beam atomic	Could exceed performance of fiber optic gyros	High precision sensor alignment makes production challenging; environmental sensitivity
	Clocks 	Chip-scale atomic clocks	Compact and low power	Expensive and limited precision - efforts underway to improve with algorithms and manufacturing
		High precision atomic and optical clocks	Potential GPS-level timing	Manufacturing challenges; larger size and power requirements
Absolute PNT	Environmental maps 	Celestial navigation (stars and satellites)	Day/night coverage 50 meter accuracy	Limited access to stars and satellite (e.g., clouds)
		Magnetic	100 meter	Need for magnetometer

## A compendium of navigation methods and *limitations*

- **Piloting**

Use of known fixes and landmarks.

*Limited to visible or sensed references.*

- **Feature matching**

Correlating observed features against reference map.

*Requires high degree of processing.*

- **Celestial navigation**

Determining a fix using positions of celestial bodies.

*Must be able to observe targets.*

- **Beaconing and radio navigation**

Obtaining relative bearing from fixed transmitters—intersection of bearings or use of distance measuring equipment can determine position.

*Transmitters must be maintained; beams can be blocked by intervening objects.*

- **Signals of opportunity**

Exploiting relative bearing from sources whose primary function is not navigation, for example radio/TV antennae, cell towers, etc.

*Signals are not designed for navigation; may require special equipment or receivers.*

- **Inertial navigation systems**

Measuring orthogonal forces with accelerometers and gyroscopes, from which velocity and position can be determined.

*Integration of measurements generates both linear (velocity) and quadratic (position) drift.*

## Grades of Inertial Measurement Units (IMUs)

### Grade, cost, and performance parameters for IMUs

	\$1,000,000	0.001°/hr		
Navigation/Strategic	\$100,000	0.01°/hr	< 0.01 mg	< 1 mm/10 km
Tactical	\$10,000	0.1°/hr	0.1 mg	1 mm/400 km
Industrial/Commercial	\$1,000	1.0°/hr	1.0 mg	6 mm/3,900 km
	< \$100s	> 100°/hr	> 10.0 mg	6 cm/39,000 km
GRADE	Cost	Gyroscope Bias Stability	Accelerator Bias Stability	Position Error @1 S/@1 Hr

Source: <https://www.vectornav.com/resources/inertial-navigation-primer>

## Technology developed by NASA for landing on planetary bodies



# Improved Performance, Reduced SWaP, and New Applications



Exclusive core technology patents to NASA NDL technology awarded to Psionic

Psionic improves performance, reduces SWaP, and develops new Space and Defense products

Psionic granted additional patents

Breadboard without real-time processing: ~200 kg



NASA Doppler Lidar Development (NDL): 10 years and \$60+ million

Psionic Doppler Lidar (PNDL) + SurePath

2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024

NASA 1st generation NDL development

NASA 2nd generation NDL development

NASA 3rd generation NDL development

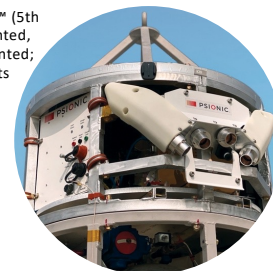
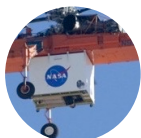
NASA 3rd generation NDL development; Xodiac flight tests

Six foundational NASA patents licensed exclusively to Psionic

Psionic 4th generation PNDL development; Masten integration

Psionic granted additional patents

Psionic SurePath™ (5th generation) invented, patents filed, granted; Masten flight tests

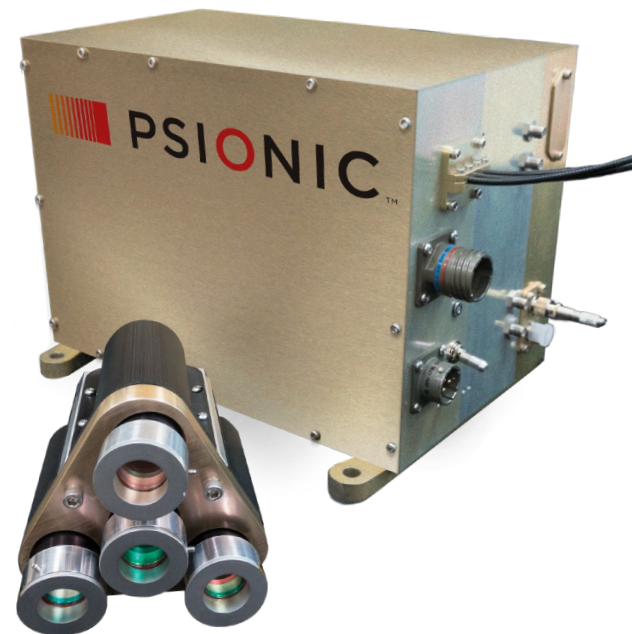


## Psionic Navigation Doppler Lidar

Doppler lidars improve upon standard time-of-flight detectors by coherent combination of return signals with reference beams resulting in highly precise measurements of both range and relative velocity

### 4th Generation Psionic Navigation Doppler Lidar (PNDL)

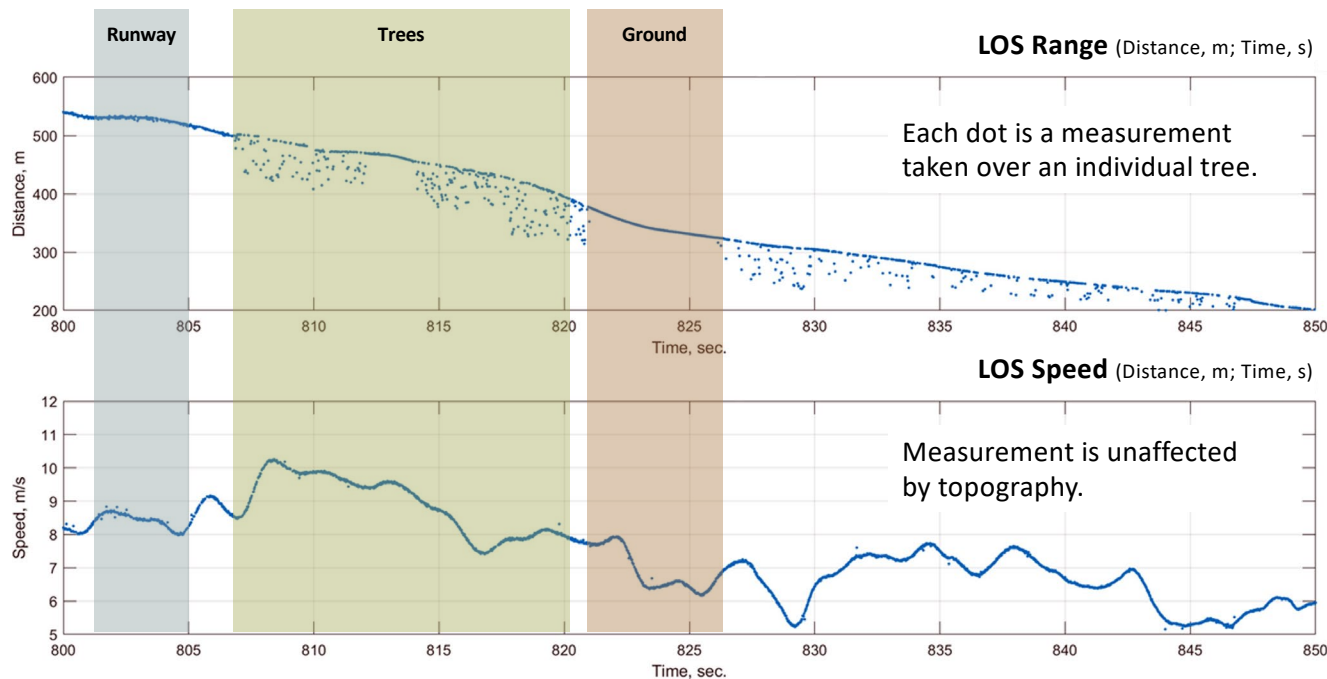
- Optical Power:
  - 1 Watt Laser: Long Range (1-10+ km) measurements
  - 30 mW Laser: < 500 m measurements
- Sensing Measurements
  - Line of sight range and velocity
- High Accuracy Measurements
  - Range Accuracy: 7.5 cm
  - Velocity Accuracy: < 1 cm/sec
- Additional attributes:
  - Measurement update rates application dependent (1 Hz–1 kHz)
  - Class 1 eyesafe (1.5 $\mu$ m)
  - All fiber-optical design (ruggedized)



**1 Watt System**  
17.8 cm x 17.8 cm x 22.9 cm; 5.9 kg  
Class 1 eyesafe

## Psionic Doppler Lidar Flight Test (2018)

Excellent speed and height measurements across diverse surfaces and topography

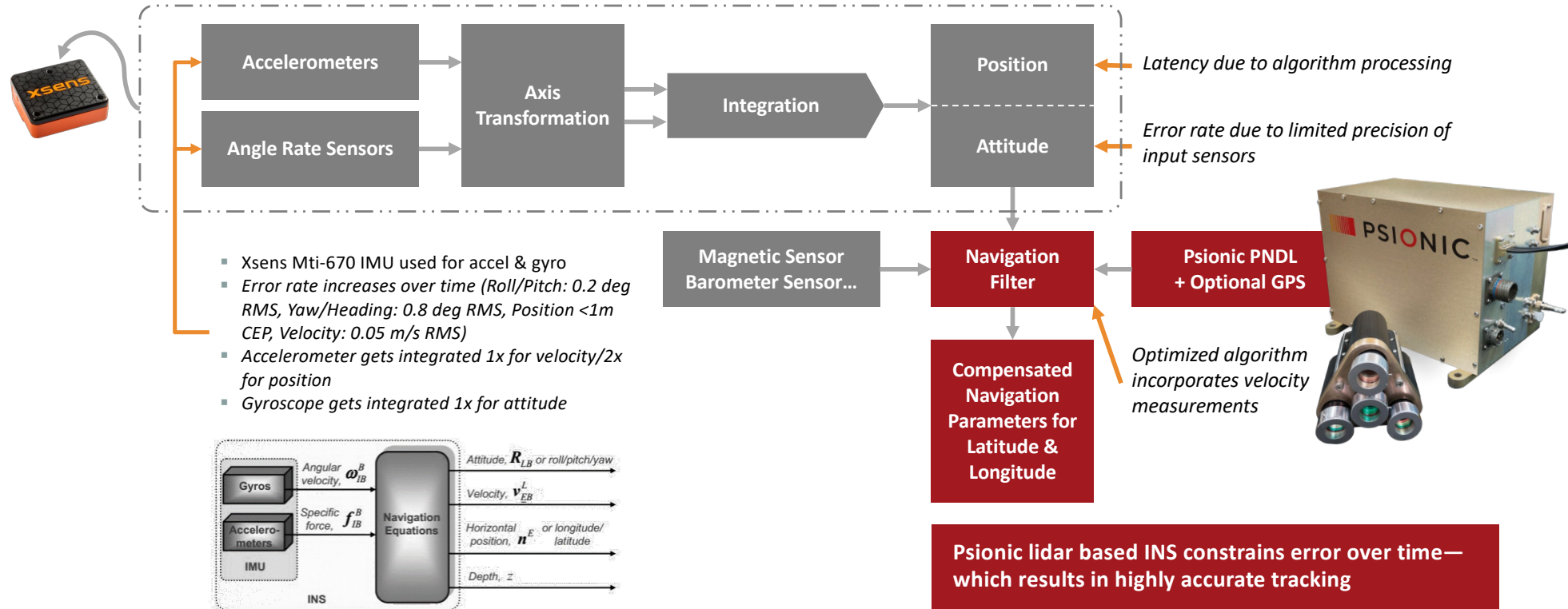


Psionic test data, 2018



PDL on Robinson R44 helicopter

# Psionic Lidar Based Inertial Navigation System

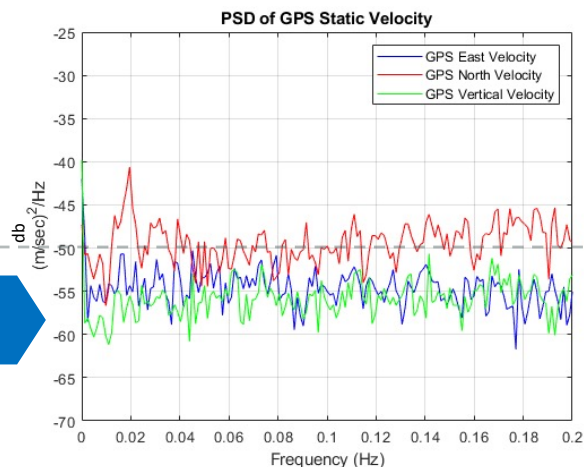


## Higher Input Precision = Higher Output Precision for INS Systems

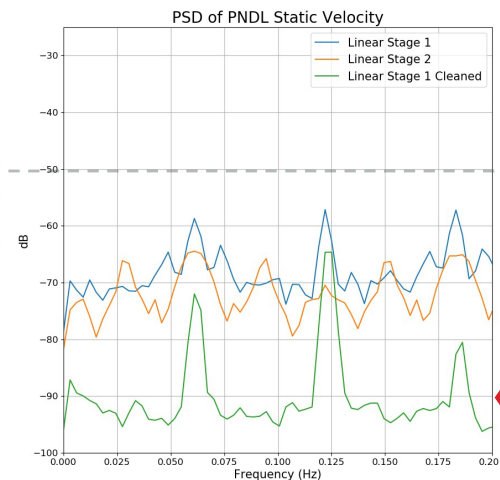
- INS output (e.g., longitude and latitude) is limited by the accuracy and nature of its input
- Psionic lidar is capable of ~1,000X lower velocity noise measurements versus GPS (90dB versus -60dB) **providing performance advantages and headroom for customization for lower cost**
- Combined with Psionic's proprietary Navigation Filter, this leads to high end INS performance

### GPS (-57 db) vs Psionic NDL (-90 db) Velocity Power Spectral Density:

GPS static velocity  
noise floor (-57 db)

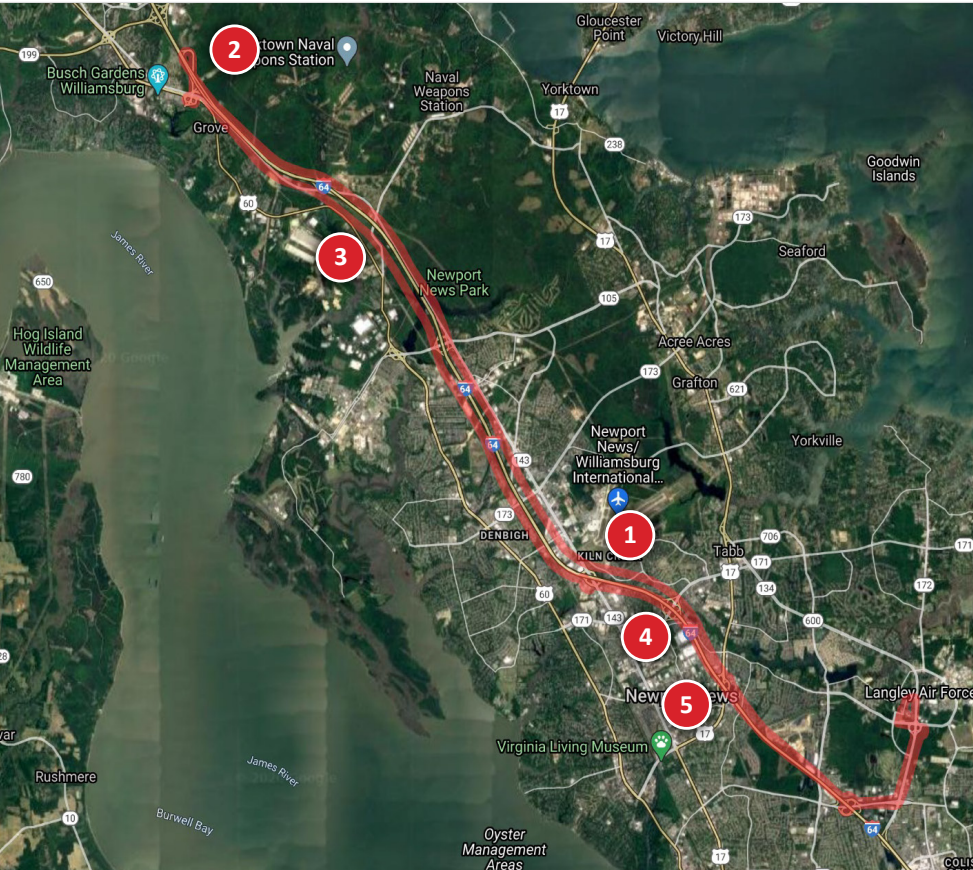


Note: db relative to 1 (m/sec)<sup>2</sup>/Hz



PNDL velocity noise  
floor (-90 db)

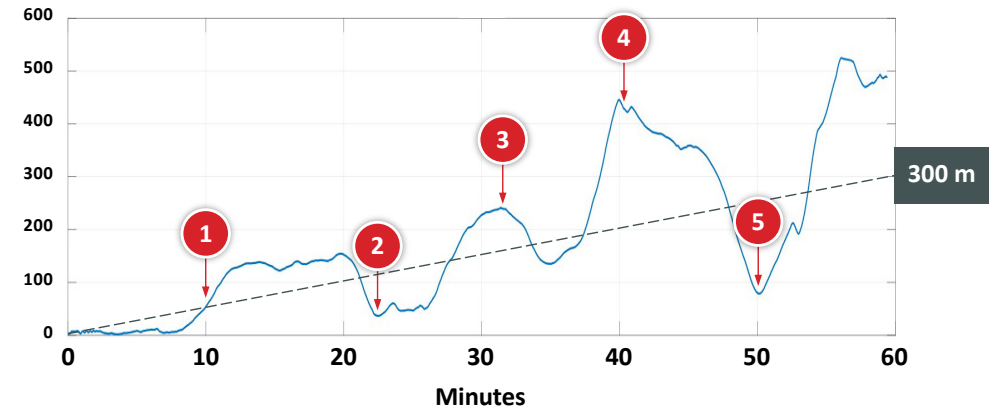
## Psionic Test: Highway route (60 minutes, 85 km)



## Demonstrated Velocity-Aided INS Performance

### Position Error Measurements vs. Time

Meters



Psionic data, March 2021

## Psionic Test: Open Innovation Lab (July 2021)



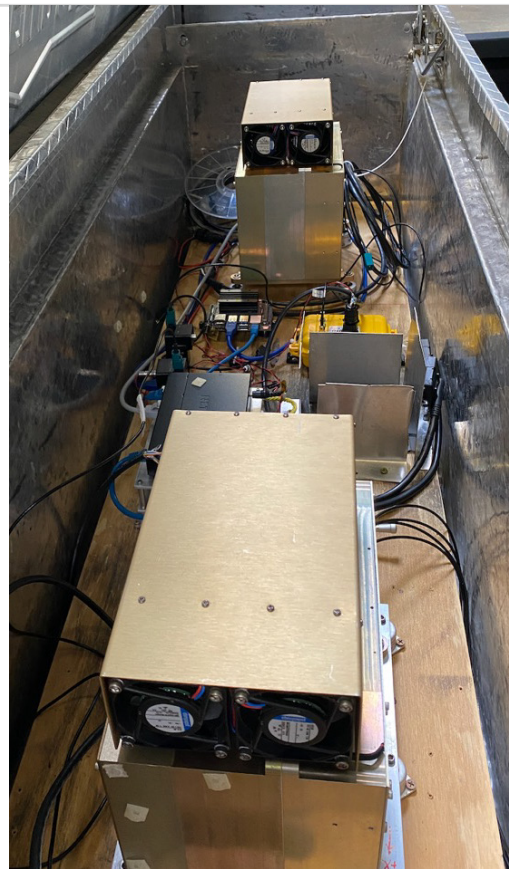
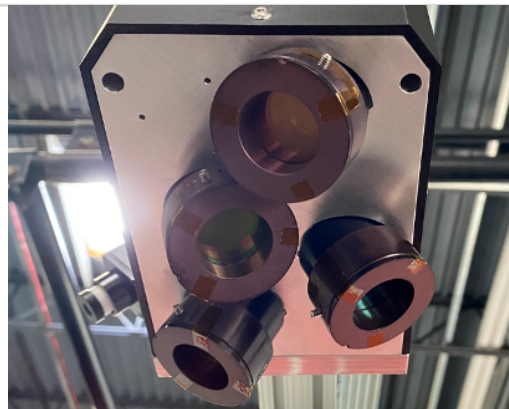
### US Army—Open Innovation Lab

A collaborative space where industry, academia, and government can join forces to create the cutting edge of PNT technology

Course offers range of surfaces: pavement, packed dirt, foliage, and mud

## Optical head mount and hardware placement

- Proof of concept hardware in test vehicle bed
- Optical heads extend over the side
- Data processed using Psionic SurePath Navigation Filter



## Test run: High vegetation



## Route with GPS plot and Psionic Navigation Filter position estimate

**Closed Track** (July 2021; US Army Open Innovation Lab)

**Distance / Time** **1.6 miles / ~12 minutes**

**GPS Unit Error**

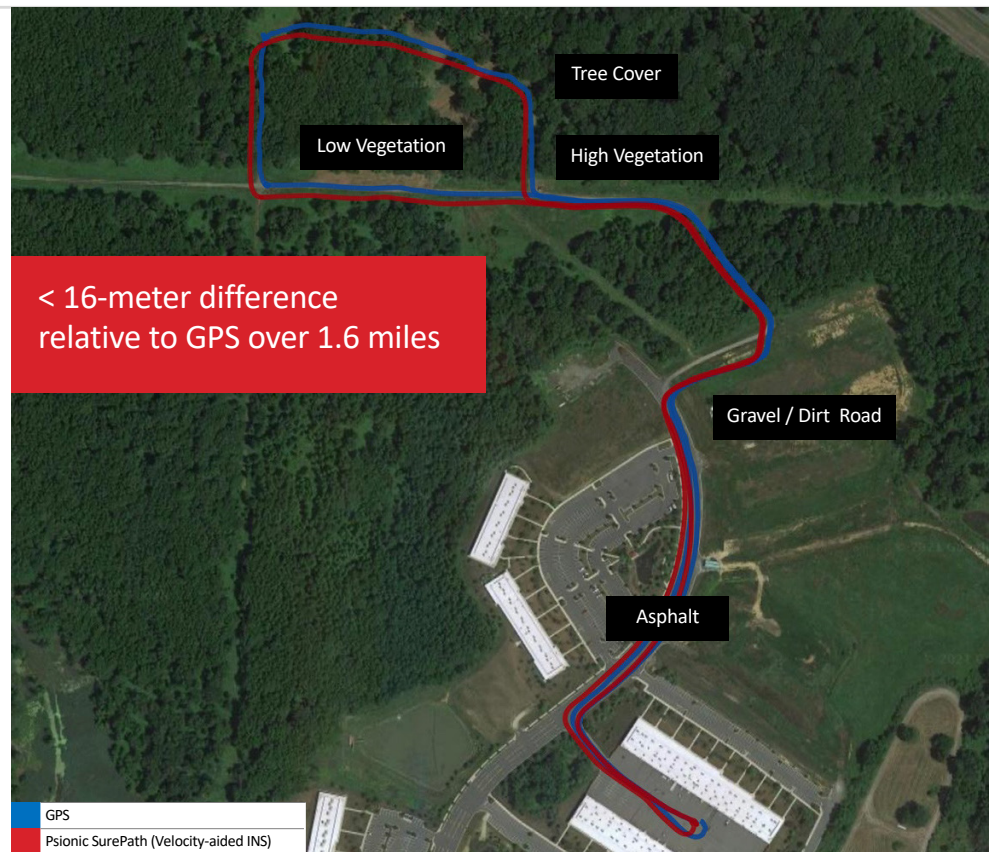
(Consumer grade GPS)

~12 meters

**Velocity-Aided INS Max Error**

(Relative to GPS position)

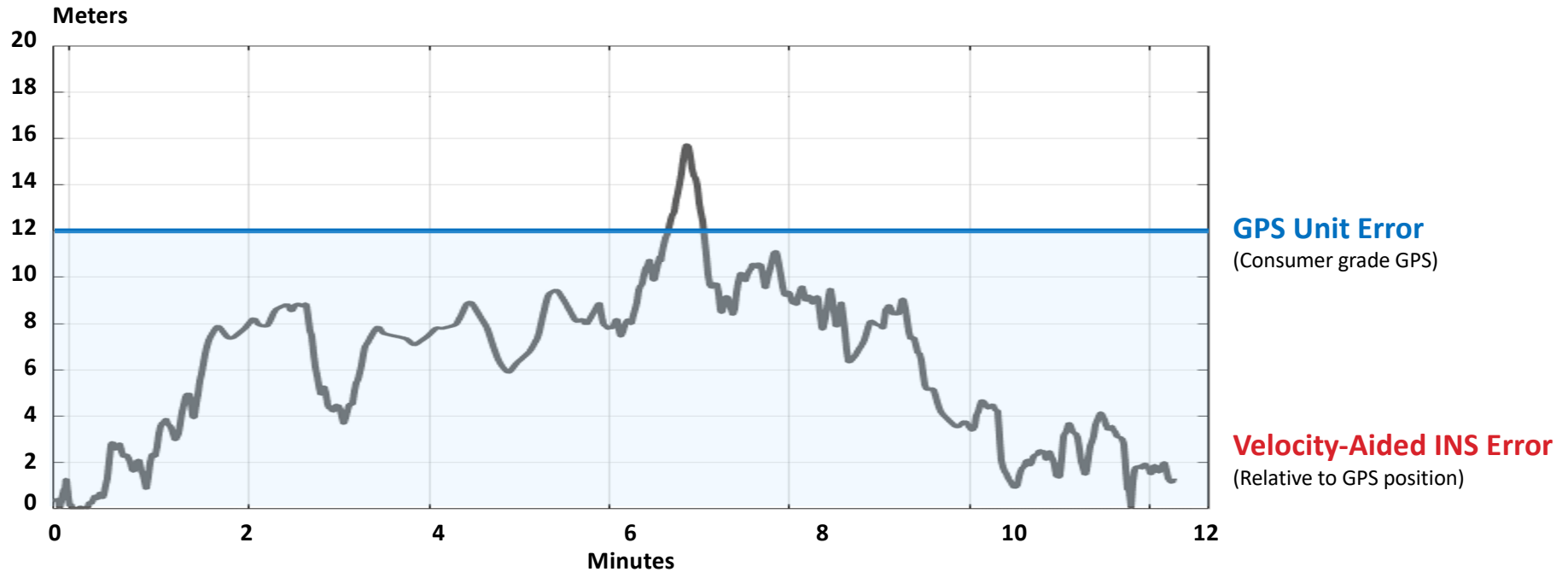
< 16 meters



Source: Psionic test data, July 2021

## Psionic Navigation Filter errors relative to GPS unit

**Off-Road Test** (12-minute test; July 2021; US Army Open Innovation Lab Test Site)



Source: Psionic test data, July 2021

## Route with GPS plot and Psionic Navigation Filter position estimate

**Surface Roads** (July 2021; Hampton, VA)

**Distance / Time** **3.75 miles / ~16 minutes**

**GPS Unit Error**

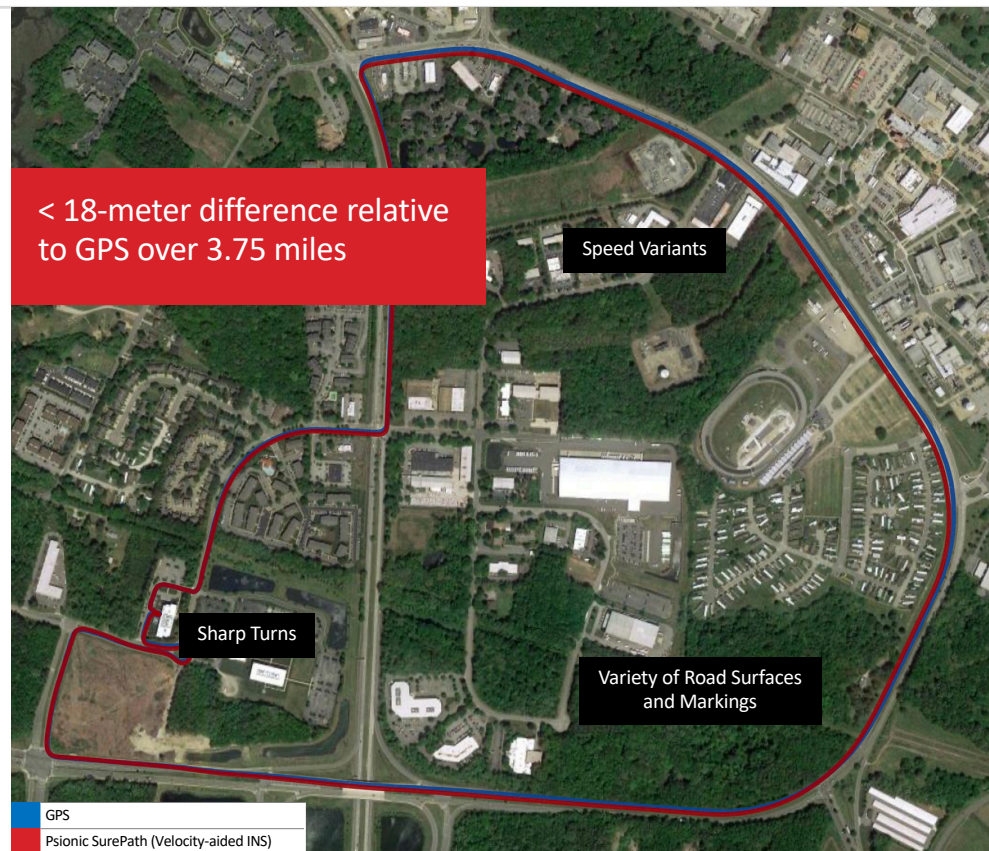
(Consumer grade GPS)

~12 meters

**Velocity-Aided INS Max Error**

(Relative to GPS position)

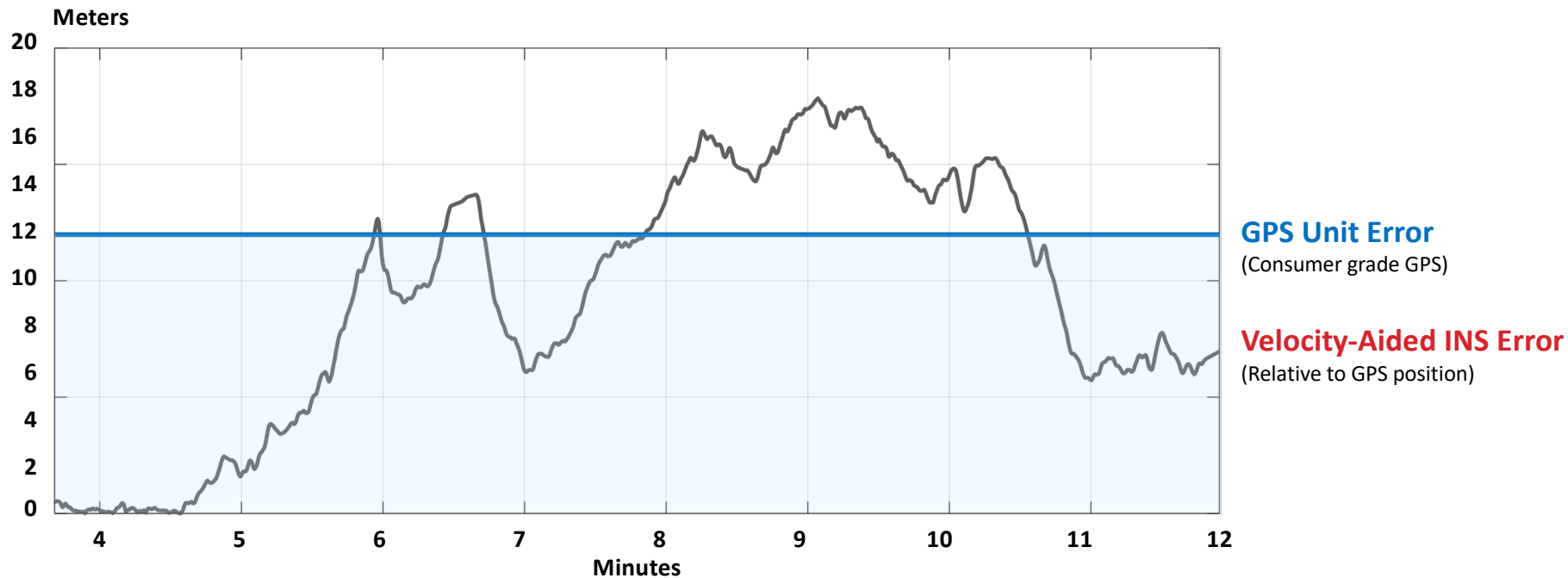
< 18 meters



Source: Psionic test data, July 2021

## Psionic Navigation Filter errors relative to GPS unit

**Surface Road Test** (12 minutes of 16-minute test; July 2021; Hampton, VA)



Source: Psionic test data, July 2021

Conclusion

Velocity-aided navigation provides “grade-jumping” INS performance

INS Errors over Time by Sensor Grade		
Grade / Time	10 minutes	1 hour
Consumer	200 km (200,000 m)	39,000 km (39,000,000 m)
Industrial	20 km (20,000 m)	3,900 km (3,900,000 m)
Tactical	2 km (2,000 m)	400 km (400,000 m)
Navigation	100 m	10 km (10,000 m)
Velocity-Aided Navigation / Psionic SurePath	15 m	400 m

Industry data: VectorNav (2021); Psionic data: Preliminary test data (2021)

## PSIONIC DEFENSE



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