



free THE UNITED STATES AIR FORCE TEST PILOT

SCHOOL VIRTUS

"SCIENTIA EST VIRTUS"

"KNOWLEDGE IS POWER"

# *PNT Flight Test at the USAF TPS*



**Wei "FUG" Lee**  
**Instructor, USAF Test Pilot School**  
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# TPS Overview: Why Our Mission



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## Need:

**Test Professionals** to support U.S. (and Allied)  
Developmental and Operational Flight Test

## USAF TPS Mission:

Produce highly-adaptive, critical-thinking  
flight test professionals to lead and conduct  
full-spectrum test and evaluation  
of aerospace weapon systems

## USAF TPS Vision:




A “world-class” institution for  
flight test education, training, and research

# USAF TPS Overview



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- 48-week Program, MS Degree in Flight Test Engineering
- 2 classes per year (24 students per class)
  - A Class (Jan – Dec)
  - B Class (Jul – Jun)
- 4 integrated courses
  - Manned Aircraft Pilot
  - Remotely Piloted Aircraft Pilot
  - Combat System Officer
  - Flight Test Engineer

Course	Time in Service	Education	Experience
<b>PILOT</b> 	< 9yr, 6 Mo	BS in Engr, Math or Physics (≥3.0 GPA)	IP or ≥750 / 1000 hours total time*  ≥12 months AC
<b>RPA/CSO</b> 	< 9yr, 6 Mo	BS in Engr, Math or Physics (≥3.0 GPA)	RPA: IP or ≥750 hours total time*  CSO: IN or ≥500 hours total time
<b>ENGINEER</b> 	< 8yr	BS in Engr, Math or Physics (≥3.0 GPA)  Technical MS highly desired	≥ 2yr experience in:  13XX, 14NX, 21AX, 21CX, 21LX, 21MX, 33SX, 61SX, 62EX 63AX  (civ: ≥ 2yr in T&E)

# TPS Graduate/Class Statistics



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- **3,086 Total Graduates**
  - 112 General Officers
  - 65 NASA Astronauts
  - 85 Civilian Graduates



# What Makes USAF TPS Unique?



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- **Flying Course + Graduate Engineering Course**
- **Rigorous Student Selection Process**
  - *Comprehensive Candidate Evaluation Program*
  - *Application -> Central Selection Board -> Week-Long Interview*
- **Master of Science in Flight Test Engineering**
  - *World-Class Instructor Cadre*
  - *9 PhDs on staff*
  - *7 PhD students in the pipeline*
- **Airborne Laboratories**
  - *Curriculum Aircraft*
  - *Qualitative Evaluation (Qual/Eval) Aircraft*
- **Test Management Projects (TMPs)**
  - *Cradle-to-Grave (Test Planning-to-Reporting) Test Project*
  - *Unique “Laboratory” Aircraft + Sims + Virtual*

# Avenues to Flight Test: Test Management Projects



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- **What are TMPs?**
  - End-to-End Student/Staff Real-World Flight Test Opportunities
    - Flight test project of limited scope and duration that senior students plan, execute, and report on
  - Conduct ~ 8 Projects/Year
    - Two week execution window (approx 6-12 flights)
    - 4 projects in Sep; 4 projects in Mar
- **Customer Provides:**
  - Hardware/software flight ready with proper documentation
    - Flight clearance, airworthiness
    - Government Sponsorship

# Avenues to Flight Test: Test Management Projects



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- **What TPS Provides**

- Test Aircraft at **No or Minimal Cost** to the customer
- Risk reduction
- Dedicated Test Team of pilots/engineers at **No Cost**
  - (4-6 students + staff)
- Test Ranges, mission support, project and budget overview
- Results: Test data, Data reduction, Analysis & Formal report
- Plans & Programs Division (TPS/XP) assists in planning 12-18 months prior to execution
  - Ensures customer and student learning objectives are aligned
  - Provides oversight - ensure milestones are met & project is executable
  - Communicates with customer throughout planning and execution

# Avenues to Flight Test: Test Management Projects: Advantages



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- **Affordable:**

- TPS is budgeted to execute TMPs as part of the curriculum
- Student/staff time, aircraft flight hours/fuel, etc. provided at low/no cost
- Cost of simple aircraft/instrumentation mods typically covered by TPS

- **High Quality:**

- Instructors average ~15+ yrs flt test experience (mix of M.S. & Ph.D.)
- Students competitively selected/highly motivated; most have M.S.
- Dedicated staff for PM, finance, instrumentation, scheduling, etc.
- Modern control rooms, customizable ground sim, VSS aircraft, etc.

- **Predictable:**

- TMPs conducted according to set schedule
- Data products and final reports delivered on time, every time

# Avenues to Flight Test: Test Management Projects: Limitations



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- **Sponsorship:**
  - Non-gov't customers must have a US Gov't sponsor (DoD preferred)
  - In some cases, TPS can act as sponsor; other options include AFRL, AFIT, NASA, DHS, System Program Offices, DARPA, FAA etc.
- **Fixed Schedule:**
  - Allowable schedule slip VERY limited
- **Limited Scope:**
  - Must be executable in ~2 weeks using ~10 sorties (5-20 flight hours)
  - Larger projects can be split and conducted over 2-3 TMP cycles
  - Project must meet TPS instructional objectives (students can't just collect data—must also be able to reduce/analyze and report)
- **Affordable, Not Free:**
  - Extensive aircraft hardware/software mods outside the TPS budget can be funded by the customer
- **Flight Worthiness:**
  - SUT must be shown to be safe/airworthy

# Recent PNT Flight Tests



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- **Class 16B: Project GRIFFIN (Customer: UIUC)**
- **DT Navfest 2017 (University Participants: Stanford and UIUC)**
- **Class 18A: Have UPDAWG (Customer: 746<sup>th</sup> Test Squadron)**
- **Class 18B: Have Double Vision (Customer AFRL/AFIT)**
- **Class 18B: Have FLEX (Customer: Test Pilot School)**
- **JAGER 2019 (University Participants: Stanford)**
- **Class 19A: Have Lightsaber (Customer: AFIT/Draper)**
- **Class 19A: Have DRAGON (Customer: Stanford)**
- **DT Navfest 2019 (University Participants: CU Boulder, Auburn University, and UC Irvine)**



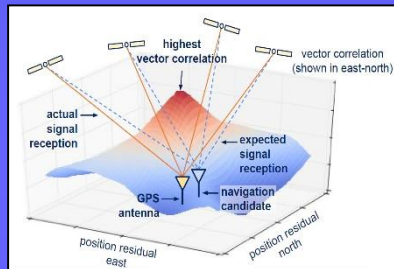
# Class 16B – Project GRIFFIN

## GPS Receiver Integration for Facilitating Improved Navigation



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**OBJECTIVE:** Demonstrate the capability of the multi-antenna, multi-receiver system and advanced navigation algorithms for navigation in the flight environment

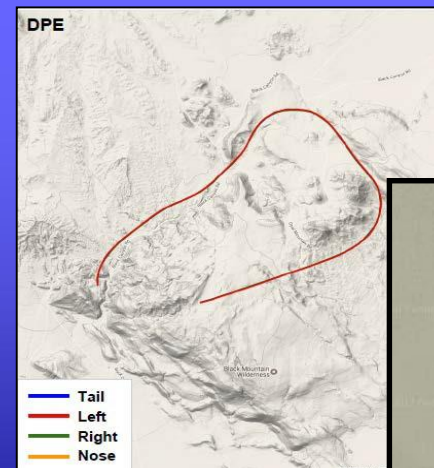


### BACKGROUND/TEST APPROACH:

- Four antennas and receivers mounted to the nose, tail, left wingtip, and right wingtip of a C-12C
- Variety of flight test maneuvers including ground static, taxi, stable maneuvering, dynamic maneuvering, low level, tower flyby, and over water

### SIGNIFICANT FINDINGS:

- First trial of multi-antenna, multi-receiver DPE in a full-scale airborne environment
- Limited demonstration of DPE in the ground and air environments
- Position, velocity, and attitude errors characterized via recognized truth source (TSPI)



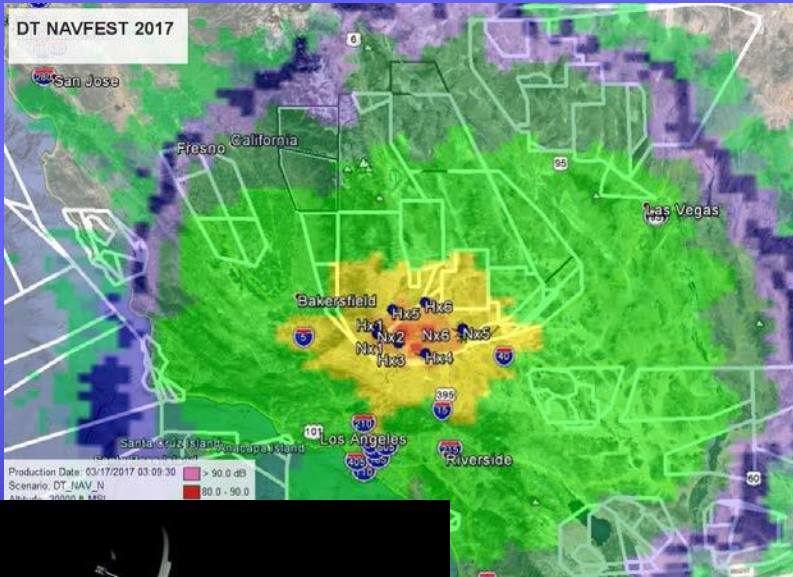


# DT Navfest 2017 & 2019



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- Large scale GPS jamming flight test including multiple Air Force customers (F-35, F-22, F-16, B-2, and B-1)
- University participants (Stanford, UIUC, CU Boulder, Auburn, UC Irvine) allowed to participate at no cost



# Class 18A – Have UPDAWG

## UHARS Position Data Acquisition without GPS



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**OBJECTIVE:** Assess the utility of the pod-mounted ultra high accuracy reference system (UHARS) for use in GPS-denied environments (combination of inertial and LocataLite ground stations).



### SIGNIFICANT FINDINGS:

- RASCAL pod mounted UHARS was able to produce position and velocity data during flight profiles.
- Locata data had errors of 2-3m on straight and level runs vs the expected 0.04m during previous testing.
- Because of high Locata errors, UHARS performance in a GPS-denied environment could not be evaluated.

### BACKGROUND/TEST APPROACH:

- Current “truth” solutions rely on GPS and are unavailable during GPS jamming flight tests
- RASCAL Pod mounted UHARS has the ability to fuse enhanced EGI, Novatel GPS, and Locata Rover to produce a single solution
- 16x LocataLite ground sites already in place on White Sands Missile Range
- T-38 profiles flown in open air and GPS jamming conditions including simulated stand off weapon profiles





# Class 18B – Have Double Vision



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**OBJECTIVE:** Assess the performance of a stereo vision relative position and attitude estimating system for automated aerial refueling and collect an inflight dataset for further research and development

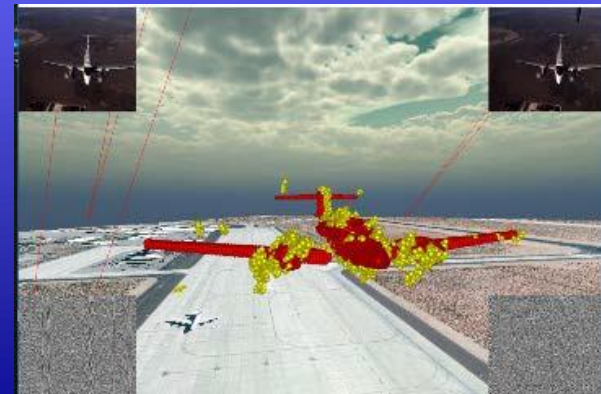


## **SIGNIFICANT FINDINGS:**

- System as tested exhibited unacceptably large translational (~4m radial) and rotational (up to 8 deg yaw) errors
- System needs improvement in military utility to reduce the sensitivity to daily calibration and increase the real-time refresh rate

## **BACKGROUND/TEST APPROACH :**

- Two EO and two IR cameras mounted under C-12 “tanker”
- C-12 (primary) and T-38 “receiver” perform maneuver block in the traditional pre-contact and contact positions
- Algorithm provided real time and post-processed estimation of receiver relative position
- Formations flown over mountain, desert, ocean, and urban





# Class 18B – Have Double Vision



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**T-38 in “aerial refueling” position behind C-12C tanker surrogate**



# Class 18B – Have FLEX



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**OBJECTIVE:** Investigate the accuracy and utility of low cost, commercial GPS navigation systems under a variety of flight conditions



## **SIGNIFICANT FINDINGS:**

- For cruise conditions devices showed position accuracy as low as 50ft and as high as 800ft
- Velocity accuracy was within 1-2 knots ground speed
- Errors not significantly different for low level flight (500ft AGL)
- Figures of merit self-reported by the devices were inaccurate and optimistic

## **BACKGROUND/TEST APPROACH :**

- Eight low-cost commercial GPS navigation systems under test (SUTs) were chosen based on those commonly used in the general aviation
- SUTs were flown on the F-16, T-38, and C-12 in variety of flight test environments/maneuvers and data were compared to certified TSPI systems (ARDS/GAINR)
- Test team evaluated utility for flight test and contingency flight operations (RTB navigation and instrument recoveries)





# Class 18B – Have FLEX



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- Video shows the attitude indicator of the Sentry “tumble” and indicate +45deg/-90deg pitch deviations when the C-12 aircraft was in a level ~2g turn
- Similar phenomena observed on other devices during benign maneuvers





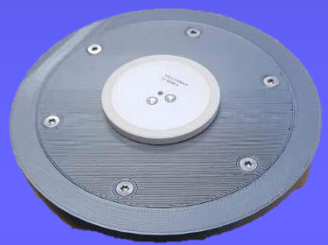
# Class 19A – Have DRAGON

## Detect, Recognize, and Adapt to GPS Overt Noise



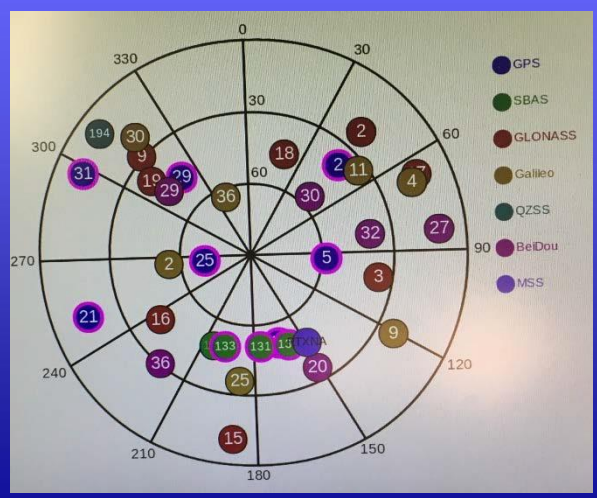
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**OBJECTIVE:** Investigate ARAIM and DPA's capability for improving airborne GNSS system robustness.



### BACKGROUND/TEST APPROACH :

- Load two DPA and a Multi-frequency GNSS receiver on a 586th FLTS C-12J, Callsign "Mable."
- Expose both antenna to a variety of test conditions, including maneuvering flight, multipath effects from oceans and mountains, and GPS jamming.





# Class 19A – Have DRAGON

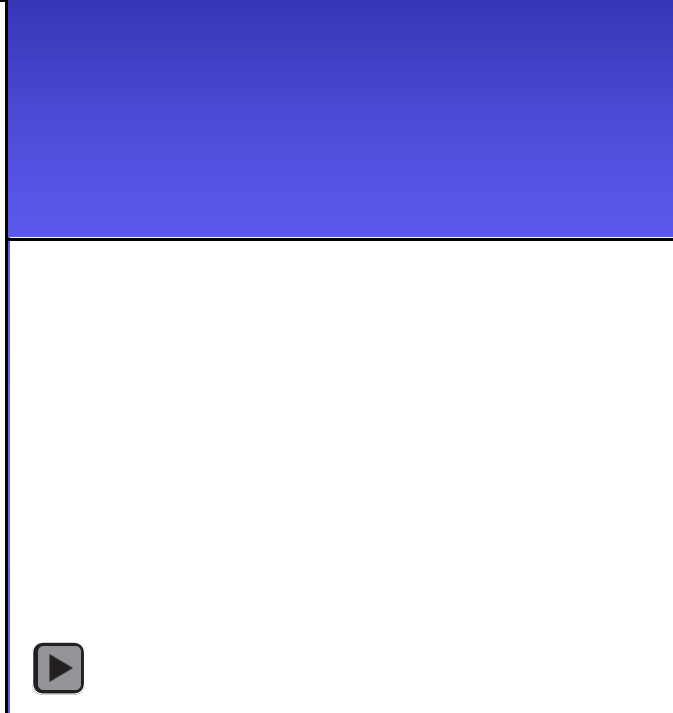
Detect, Recognize, and Adapt to GPS Overt Noise



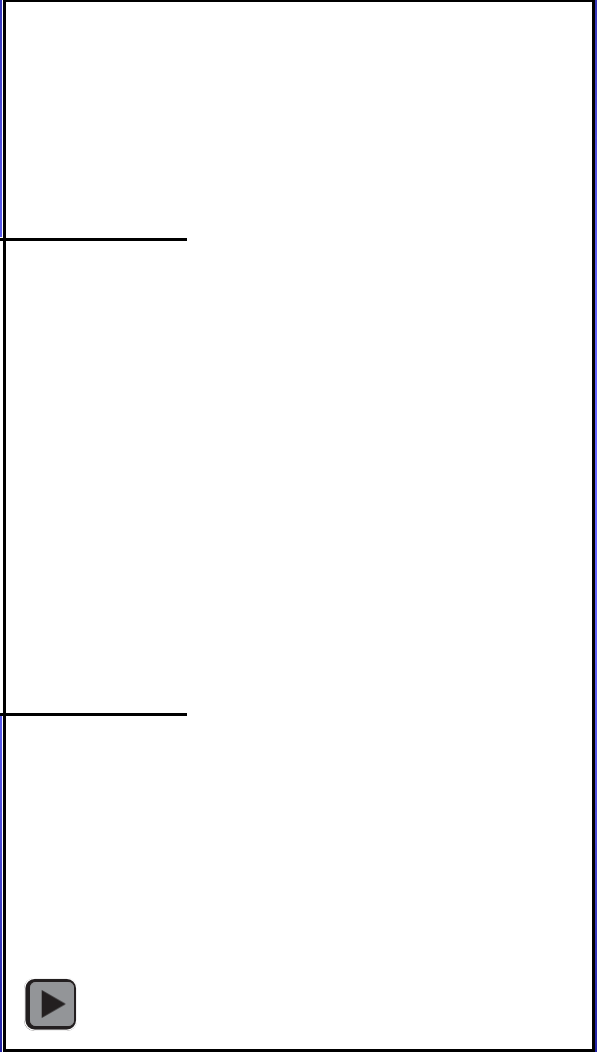
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**200ft over flat lakebed surface**



**550ft over water  
(marine layer at 500ft)**



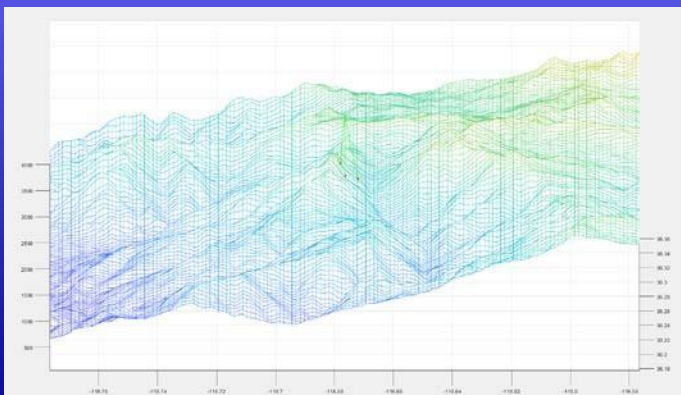
**Just a cool video**

# Class 19A – Have Lightsaber



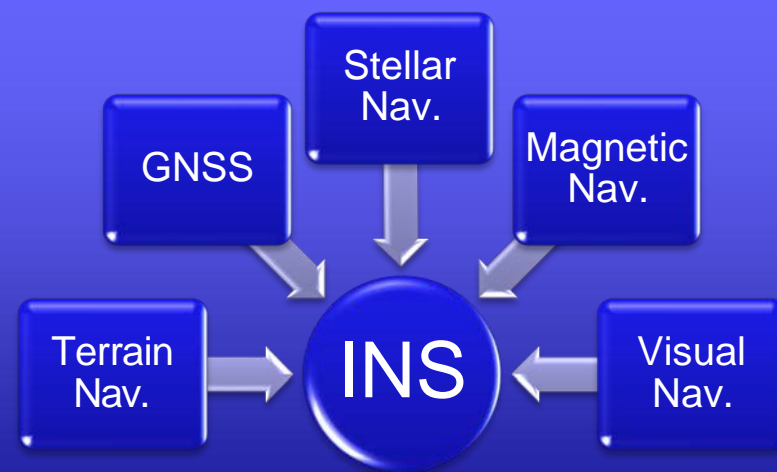
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**OBJECTIVE:** Demonstrate the navigation potential of using laser measurements of terrain to correct drift errors in an INS



**BACKGROUND/TEST APPROACH :**

- Incorporate three LIDARs and a tactical grade INS into a TPS RASCAL pod
- RASCAL pod was flown on an F-16
- Goal is precision navigation in a GPS denied environment
- Part of AFIT's multi-prong approach to robust PNT



# Upcoming PNT Flight Tests



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## Upcoming Projects:

- **Class 19B: Cellphone Network PNT (Customer: UC Irvine)**
- **Class 20A: Magnetic Navigation (Customer: AFIT)**
- **Your test project???**



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**Questions?**

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