PNT Flight Test at the USAF TPS

Wei “FUG” Lee
Instructor, USAF Test Pilot School
Agenda

- About Me
- About USAF Test Pilot School
- About Test Management Projects/ Educational Partnership Agreements
- Cool F-16 Videos...just because
- Invitation to Partner with TPS
About Me

- Grew up in Southern California attending air shows at Edwards AFB, Miramar MCAS, and El Toro
- Married, one son (6yo), one daughter (1.5yo)
- BS Aerospace Engineering, UCLA 2007
- MS Aero/Astro Engineering, Stanford 2012
  - DOD SMART Scholarship
  - Research in GPS/GNSS Lab
About Me

- Jobs I’ve held at Edwards AFB (home of the Air Force Test Center)
  - F-16 Weapons Test (A/G Smart Bombs, A/A Missiles, SEAD)
  - F-22 Weapons Test (A/A Missiles)
  - B-1/B-2 Electronic Warfare (RWR and RCS Reduction)
  - F-35 Simulator Instructor (PVI and Weapons)
  - Test Safety Engineer (Safety Review/Policy)
  - TPS Test Foundations Instructor (Test Management Projects, Classroom/Control Room/Airborne Instruction)
**Aircraft Flown at TPS (<2yrs)**

<table>
<thead>
<tr>
<th>List of Aircraft I Have Flown:</th>
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<tbody>
<tr>
<td>1. C-172**</td>
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<tr>
<td>2. S-2-33</td>
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<tr>
<td>3. DC-3/C-47</td>
</tr>
<tr>
<td>4. HU-16</td>
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<tr>
<td>5. C-12C</td>
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<tr>
<td>6. <em>F-16D</em>*</td>
</tr>
<tr>
<td>7. *T-38C</td>
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<tr>
<td>8. C-12J</td>
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<tr>
<td>9. C-17</td>
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<tr>
<td>10. LJ-35 VSS**</td>
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<tr>
<td>11. ASK-21</td>
</tr>
<tr>
<td>12. P-51</td>
</tr>
<tr>
<td>13. MC-130J</td>
</tr>
<tr>
<td>14. *F-15E</td>
</tr>
<tr>
<td>15. UH-1</td>
</tr>
<tr>
<td>16. U-6</td>
</tr>
<tr>
<td>17. T-6</td>
</tr>
<tr>
<td>18. Extra 300**</td>
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</tbody>
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*Aircraft I have flown supersonic

**Aircraft I have thrown up in
TPS Overview: Why Our Mission

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
Scientia est Virtus

USAF TPS Overview

• 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

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

- 3,086 Total Graduates
  - 112 General Officers
  - 65 NASA Astronauts
  - 85 Civilian Graduates
What Makes USAF TPS Unique?

• 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

• **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 6-20 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

- **What TPS Provides**
  - Test Aircraft at **No or Minimal Cost** to the customer
  - Risk reduction
  - Dedicated Test Team of pilots/engineers at **No Cost**
    - (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

- **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

• **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

- Class 16B: Project GRIFFIN (Customer: UIUC)
- DT Navfest 2017 (University Participants: Stanford and UIUC)
- Class 18A: Have UPDAWG (Customer: 746th 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: Stanford, CU Boulder, Auburn University, and UC Irvine)
DT Navfest 2017 & 2019

- 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 via EPA
Educational Partnership Agreements

- Allows participation in test events at Edwards AFB without cost to a qualified educational institution
- Participation by invitation by AF EPA manager (i.e. me)
- Ground static, vehicle, sUAS, and flight test (everything inbetween)
OBJECTIVE: Demonstrate the capability of the multi-antenna, multi-receiver system and advanced navigation algorithms for navigation in the flight environment

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)

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
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
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

T-38 in “aerial refueling” position behind C-12C tanker surrogate
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/maneuvres 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)
• 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
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

550ft over water
(marine layer at 500ft)

200ft over flat lakebed surface

Just a cool video
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
Class 19A – Have Lightsaber

Cool F-16 videos…just because…
Upcoming Projects:

- **Class 19A:** ADS-B Integrity/Spoofing (Customer: AFRL)
- **Class 19B:** Cellphone Network PNT (Customer: UC Irvine)
- **Class 19B:** Airborne Head/Eye Tracking (Customer: 711HPW)
- **Class 20A:** Magnetic Navigation (Customer: AFIT)
- **Class 20A:** Autonomous ISR (Customer: AFIT)
- **Class 20B:** Satellite C2 Surrogate (Customer: Aerospace/AFSCN)
- Your test project???