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Stanford Aeronautics and Astronautics
50th Anniversary Symposium
Friday 9 May 2008
Stanford, California, USA

STANFORD AERO/ASTRO:
COLLABORATIVE WORKSHOP,
COMPANY BIRTHPLACE,
AND CAREER LAUNCH PAD
This Talk

- About Stanford Aero/Astro Department with three related themes
  - Aerospace within society
  - Aircraft navigation highlights
  - Department’s contributions to one particular alum
Beginnings of Aero/Astro at Stanford

- 1914: As World War I begins, US lags Europe in aviation accomplishments, organized research, and funding for military aviation

- 1915: US establishes National Advisory Committee on Aeronautics

- 1915: William Durand establishes first aeronautics course at Stanford

Source: Stanford News Archive
WWI and After

- 1910s: Navigation by bonfires and beacons
- 1920s: Radio Range A-N navigation
- 1929: Lt. James Doolittle demonstrates first successful “blind landing”
- 1930s/1940s: Direction Finding RDF/ADF

- FAA predecessors formed (DoC AB, BAC, CAA, CAB)
WW2 and After

- 1940s: Instrument Landing System refined
- 1940s and 1950s: Radar developed
- 1950s: VOR and DME gain widespread use
- 1953: Using inertial navigation, C. S. Draper’s team flies B-29 from New York to Los Angeles (missiles, rockets, subs)

- AA departments (including Stanford) experience postwar slump
Sputnik and After

- 1957: USSR launches Sputnik on 4 October
- 1958: Independent Stanford AA Department founded
- 1958: National Aeronautics and Space Administration (NASA) formed in July
- 1962: “We choose to go to the moon in this decade…” – John F. Kennedy
- 1958: Federal Aviation Agency/Administration (FAA) formed in August in wake of 1956 crash over Grand Canyon
- 1950s and 1960s: Modern jet age ATC
- 1960s and 1970s: Radar surveillance widespread
Apollo 17

- 1972: December 7-19

Source: NASA
Global Positioning System

- 1972: Air Force Program 621B gets a new Program Manager
- Satellite-based navigation
- 3D position and altitude \textit{globally}
- 10-15 m position accuracy (SA off)
- 1995: GPS Full Operational Capability
- Category now called GNSS: GPS (US), Galileo (Europe), and GLONASS (Russia)
1970s and 1980s: Automated Cockpits

- Area navigation
  - Inertial Navigation
  - RNAV
  - LORAN
- Autoland
- Flight Management Systems
- Glass Cockpits

Source: Boeing

1982: Boeing 767
West to Stanford

- Internet weather on a recent weekday…

- Seriously…
  - Collaborative Workshop
  - Company Birthplace
  - Career Launch Pad
Stanford AA as a Collaborative Workshop

- Stanford generally…
  - Implementation oriented - not an ivory tower
  - Strong interdisciplinary bent
  - e.g. GP-B (Physics) led to GPS at Stanford

- Stanford Aero/Astro specifically…
  - Mission (as opposed to discipline) department
  - Breeds good systems-oriented and thinkers (otherwise, nothing gets off the ground…)
  - Within Stanford AA, you’ll find robots, boats, submarines, skiing, tractors, cars
  - Flight testing
Wide Area Differential GPS

- Network of fixed ground reference stations measures GPS errors
- Send corrections to users via satellite
- 2-3 m 95% position accuracy

- 1990s: Pioneering development and flight testing at Stanford
- 2000s: FAA’s Wide Area Augmentation System allows near-ILS capability at all airports in CONUS (almost continuously)
Local Area Differential GPS

- Single fixed ground reference station measures GPS errors
- Send corrections to users via datalink
- Position accuracy from meters to sub-centimeter using GPS carrier phase
- Can be used among a set of GPS antennas on a vehicle to determine attitude (roll, pitch, heading)

- 1970s: Differential GPS conceived
- 1990s: Pioneering development, flight testing, and dirt testing at Stanford

Source: Stanford
Other Enabling Technologies

- Dramatic increase in CPU capability
  - Driven by PC revolution
- Embedded 3D graphics chipsets
  - Driven by gaming community
- Flat panel displays
  - Driven by laptop market
- Low-cost inertial sensors integrated with short-baseline GPS attitude array
  - Complimentary sensor characteristics
  - 1990s: Pioneering work at Stanford
Stanford AA as a Company

Birthplace

- Aerion Corporation
- Desktop Aeronautics
- Failure Analysis Associates / Exponent
- GyroSat (→ Sequoia Instruments → Garmin)
- Integrinautics / Novariant
- Nav3D Corporation (→ Mercury Computer Systems → Honeywell)
- NetworkFab Corp. (→ Agilent)
- Real-Time Innovations
- Rosum
- Seagull Technology (→ Sensis)
- Sensing Systems LLC
- Space Propulsion Group
- SportBug / Traxsis / GeoTrax (→ 3SI Security Systems)
- Systems Control Technology, Inc.
- Televigation

- PLUS… some I’ve missed and more on the way…
GyroSat Corporation

- Developed low-cost attitude system with GPS capabilities
- 1999: Sold to Sequoia Instruments
- 2001: Sequoia Instruments sold to Garmin (NASDAQ: GRMN)
- Each Garmin G1000 avionics suite contains an ADAHRS/GPS

Source: Garmin
Highway in the Sky Displays at Stanford

- Perspective display of flightpath
- Reduced workload for greater situational awareness
- Highly accurate flight path following
- 1940s: Origins of concept
- 1980s: First flights on large aircraft
- 1995: Stanford begins HITS flights on Piper Dakota – first low-cost practical system for light aircraft
Synthetic Vision Terrain Display

- Safer operations at terrain constrained airports
- 1998: Stanford Alaska flights at Juneau, Petersburg, and Sitka on Beech Queen Air

Source: Keith Alter and Prof. David Powell
3D Traffic Displays

- Prevent midair and runway incursion collisions
- Enabled by aircraft-to-aircraft datalink of information (ADS-B)
- 1999: Stanford begins dual-aircraft flight tests of 3D displays with traffic

Source: Chad Jennings and Prof. David Powell
3D Wake Vortex Display

- Modeling of wake vortices generated by other aircraft allows display and avoidance
- 2001: Stanford flight demonstrations at Moffett Field, CA

- Advanced displays could increase bad-weather capacity at San Francisco International Airport

Source: Wendy Holforty and Prof. David Powell
Stanford AA as a Career Launch Pad

- Collaborative research environment
- Teaching experience
- Consulting opportunities
- Visibility (conferences, affiliates)

- Entrepreneurial atmosphere – especially if you want to start another business…
Nav3D Corporation

- 1999-2000: Added fellow AA alums who wanted to see this technology develop
- Customer list grew to include government, large aerospace companies, and small companies
Also worked on unmanned boats, hazmat mapping, and helping delivery people find the right door
Nav3D Boeing 757 Flight Tests

- FORESITE program with NASA and BAE Systems
- Hand flown curved approaches demonstrating SVS and EVS
- 2005: Flight tests at Wallops Island, VA
Results of 757 Flight Tests

Precision Navigation with Highway-in-the-Sky at Wallops Island, VA

Shaded portions were flown with Nav3D’s Highway-in-the-Sky display. The Boeing 757’s 49 approaches collapse down to just two tracks.

2006 Aviation Week Laureate Award
Nav3D Sale

- Partners decided it was time to switch gears
- 2006: Nav3D acquired by Mercury Computer Systems (NASDAQ: MRCY)
- 2008: Mercury avionics group acquired by Honeywell
- Impossible to imagine this story without Stanford experiences, people, environment
Taking a Break!
Synthetic Vision and HITS Mainstream

- Previously there were products by small OEMs (e.g. Universal, Chelton)
- Two leading avionics manufacturers recently announced certification
  - Honeywell (announced 28 January 2008)
  - Garmin (announced 7 April 2008)
Required Navigation Performance (RNP) Approach

- Certified curved-path instrument approaches
- Access terrain-constrained airports
- Save fuel in some cases
- 1996: RNP Approach developed by Alaska Airlines
  - First developed for Juneau, Alaska
  - Worked with FAA to develop certification criteria
- 2000s: Being developed worldwide
Continuous Descent Approach

- Optimal vertical profile from cruise to runway
- Save fuel
- Reduce noise footprint
- Developed in US and Europe
- Airlines (e.g. UPS cargo), academia, and industry leading the way
- 2000s: Being implemented worldwide (e.g. Heathrow, Los Angeles, Louisville…)

Source: Boeing
Automatic Dependent Surveillance-Broadcast (ADS-B)

- Air-to-Air and Air-to-Ground Datalink
- Broadcasts aircraft position, velocity, etc
- FAA will install ADS-B ground stations throughout lower 48 states

### ADS-B vs. Long Range Radar

<table>
<thead>
<tr>
<th></th>
<th>ADS-B</th>
<th>ARSR-4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Update Rate</strong></td>
<td>1.0 seconds</td>
<td>14.0 seconds</td>
</tr>
<tr>
<td><strong>Azimuth Accuracy (@ 100 Nm)</strong></td>
<td>6 meters</td>
<td>561.9 meters</td>
</tr>
<tr>
<td><strong>Range Accuracy</strong></td>
<td>6 meters</td>
<td>57.2 meters</td>
</tr>
<tr>
<td><strong>Altitude Accuracy (Mode C)</strong></td>
<td>7.6 meters</td>
<td>30.5 meters</td>
</tr>
<tr>
<td><strong>Quantize Level (@ 60 Nm)</strong></td>
<td>3 meters &amp; 6 meters</td>
<td>28.6 meters &amp; 281.0 meters</td>
</tr>
<tr>
<td><strong>Cost (one ground station)</strong></td>
<td>$250K</td>
<td>$25M</td>
</tr>
</tbody>
</table>

Source: Prof. David Powell and FAA ATO
FAA NextGen Vision

- Complete overhaul of the US National Airspace System
- Increase capacity, efficiency, and safety
- 2004: Plan delivered to Congress
- $15B-$22B projected spending through 2025
- Many stakeholders
  - FAA, airlines, unions, general aviation, military, industry, flying public, taxpayers, international partners
- More involved than just technology – also politics
  - Motivated by big issues
Big Issues

- **Capacity**
  - Air traffic congestion in US and Europe (increased demand for air travel)

- **Efficiency**
  - Rising oil prices (increased demand and scarcity)
  - The push for green – not just operating existing system more efficiently, but creating new propulsion, operations, manufacturing concepts

- **Safety**
  - Ever-decreasing tolerance for risk

Aerospace is as important and relevant as ever
Even Bigger Issues

- FAA funding, user fees, bureaucracy, privatization
- Shrinking NASA Aeronautics budget
- US aerospace leadership no longer a sure thing
- US higher education not guaranteed to be the best in the world
- “Silent Sputnik” – US losing its Innovation Edge?
- Global security situation changing
Relevance to Aero/Astro Education

- Technology challenges have gone from subsystem level to system level
- Issues are multidisciplinary, and go far beyond just technology to law, policy, environment, land use, diplomacy
- What’s it going to take for the next sea change in aerospace?
  - A devastating accident?
  - An environmental catastrophe?
  - A national security issue or war?
- What’s Aerospace’s next Grand Challenge? Moonshot?
- What will be Stanford’s role in this next challenge?
Stanford’s Multidisciplinary Initiatives

- Seeking solutions for society’s most formidable problems
  - Initiative on Human Health
  - Initiative on the Environment and Sustainability
  - International Initiative
  - Arts Initiative: Engaging the Arts and Creativity
  - Initiative on Improving K-12 Education

- Stanford attracts faculty and students who are inspired by this

Source: http://multi.stanford.edu/initiatives/
Example: Stanford Bio-X Program

- Supports, organizes, and facilitates interdisciplinary research connected to biology and medicine
- Operates across multiple schools at Stanford
  - Humanities and Sciences
  - Engineering
  - Medicine
  - Earth Sciences
  - Law
- “We aim to make Stanford the most exciting place in the world for combining a broad range of scientific and engineering disciplines in biosciences research and for training the next generation of leaders.”
- Why not Aero-X? Or Transportation-X?

Source: http://biox.stanford.edu/about/
The Next Fifty Years…

- Attract faculty who live to tackle impossible interdisciplinary problems (e.g. Sustainable Aviation)
- Draw students to the Collaborative Workshop, Company Birthplace, and Career Launch Pad
- Strengthen ties to other departments, including the “fuzzy” stuff
- Engage government
- Leverage alumni
- Involve industry (Affiliates Program is a great start)
- Danger in aiming too low

“What you can do or dream you can do, begin it; boldness has genius, power, and magic in it.” — Johann Goethe