GPS for Humanity

(1962 – 2012)

Many Applications for Worldwide Benefit –
some Anticipated and Others Surprising

A Tribute to the many Aerospace Engineers and supporters who labored and sacrificed to make it happen!

Bradford Parkinson
Stanford University

GPtS –

the ***Stealth*** Utility

- Foundation: **Initial Studies**
- The **GPS Design Meeting**
- Key **Innovations** and Engineering **Challenges**
- **Applications for Humanity**
  - **Surprises and Innovations**
- **Future** and **Threats**

Global ***P***ositioning and ***t***iming ***Service***

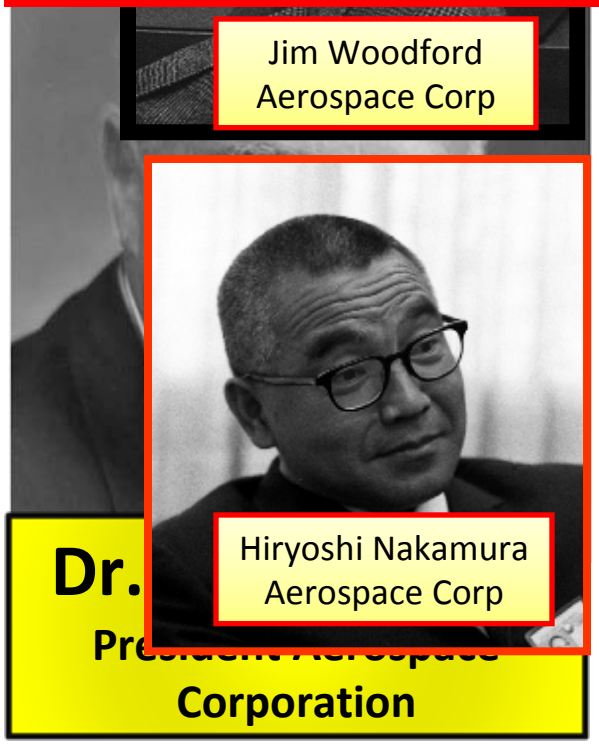
"Success has a thousand Fathers, failure is an orphan." -- *Unknown Author*

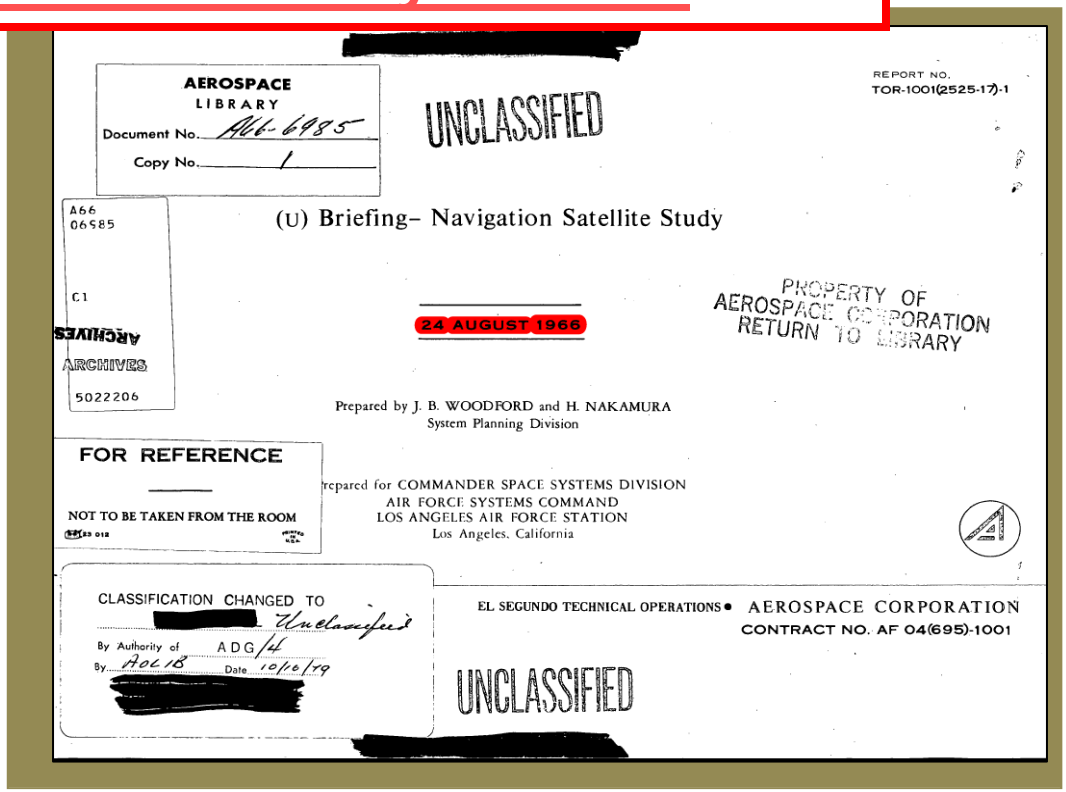
Dr. Ivan Getting

Originally Classified ***Secret*** and could not be discussed in Public

– ***Not declassified until 1979***

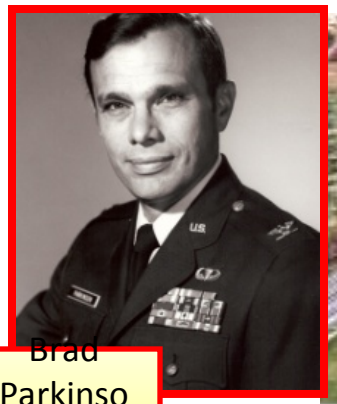
6 years after GPS Definition





Defining GPS -The Lonely Halls Meeting – GPS "Architected" - "Labor Day" Weekend

(Saturday, 1 Sept. 1973 – Monday, 3 Sept. 1973)



Brad Parkinson USAF

Frank Butterfield Aerospace Corp.

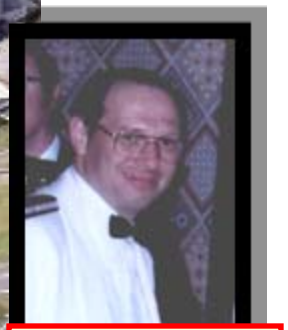
MS Aero/Astro Stanford

Gaylord Green USAF

Bi

USN

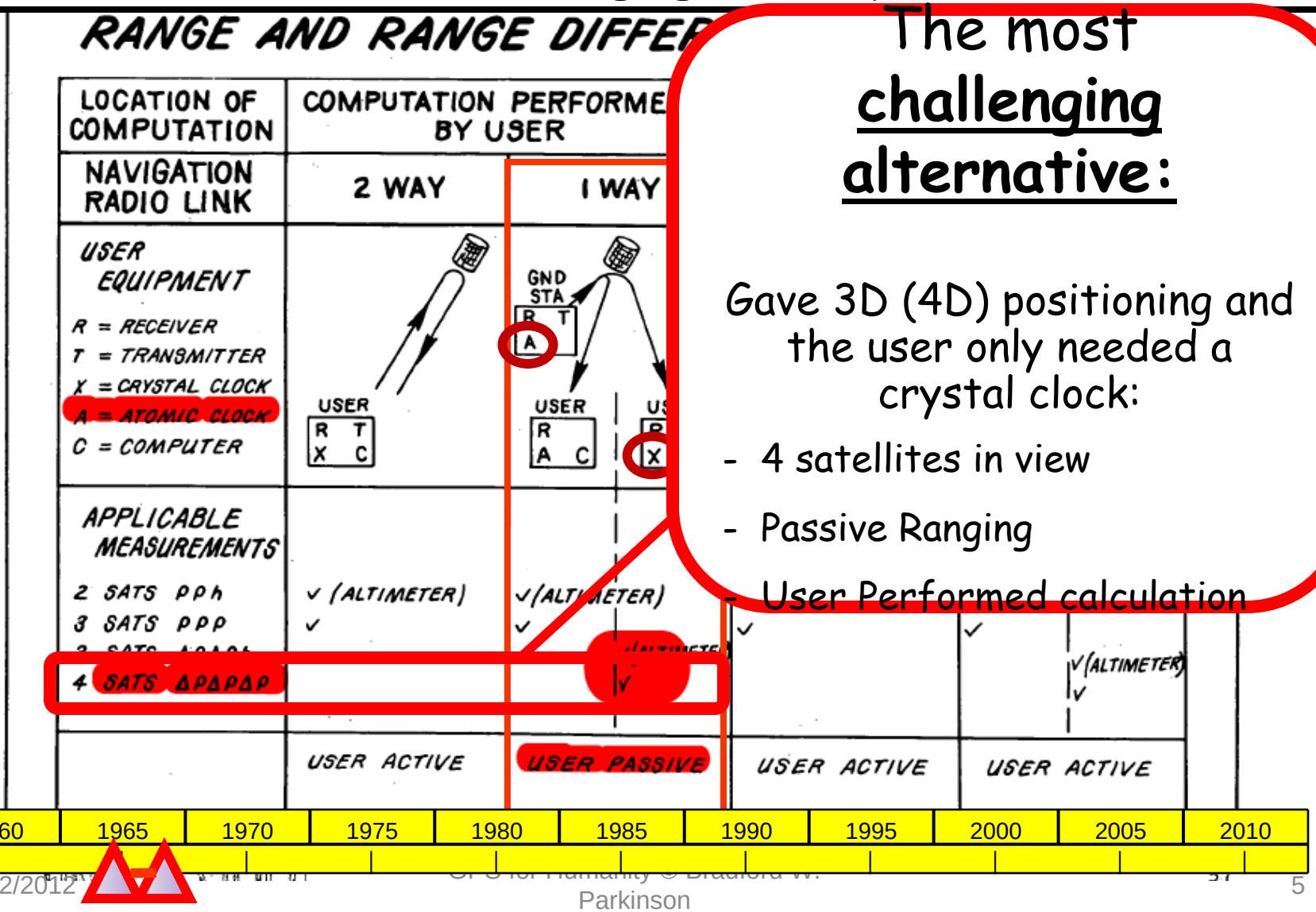
Steve Gilbert USAF



Mel Birnbaum USAF

USAF/621B Woodford Study –

14 Alternative Passive Ranging Techniques (1964-1966)

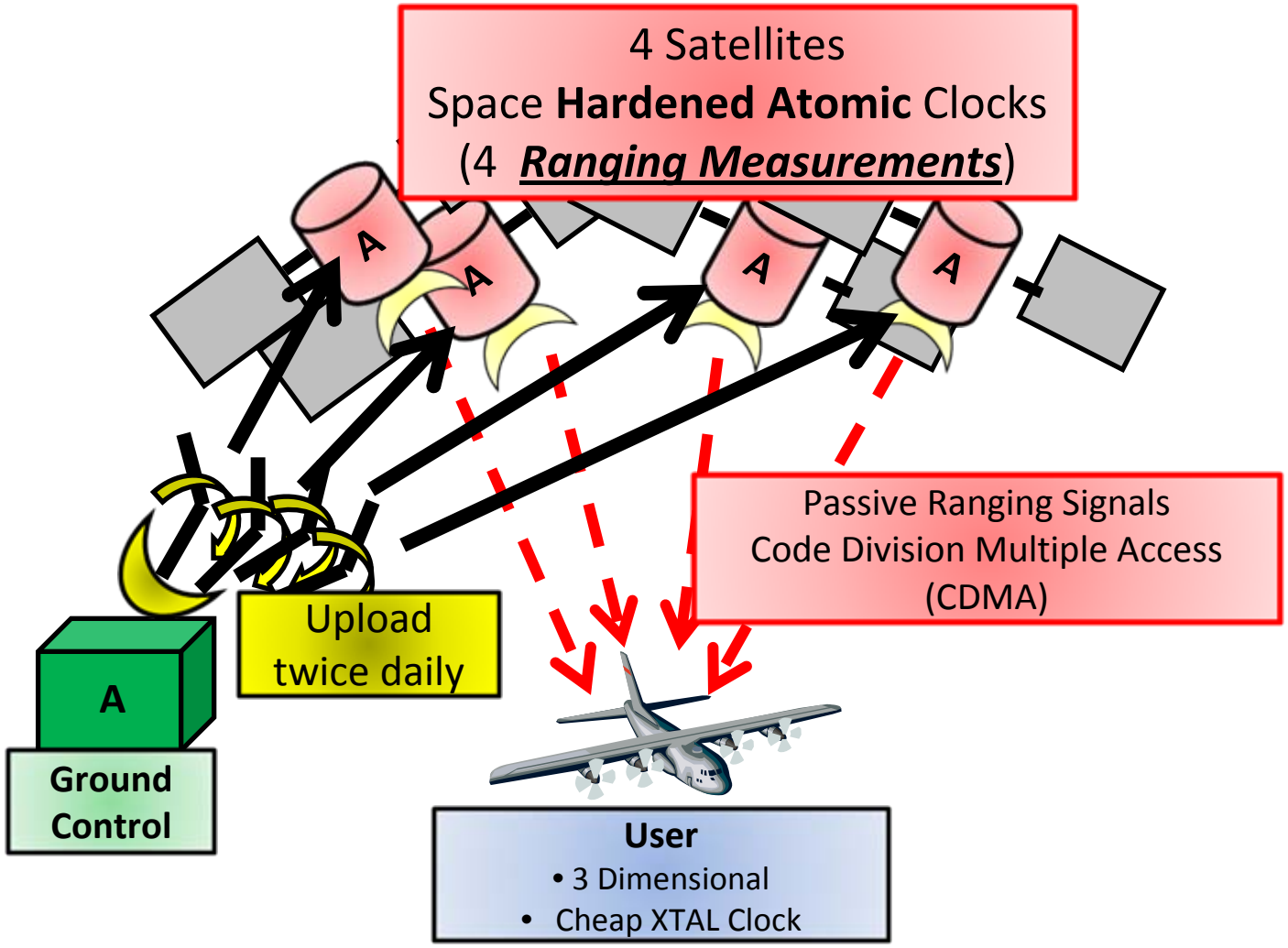


The most **challenging alternative:**

Gave 3D (4D) positioning and the user only needed a crystal clock:

- 4 satellites in view
- Passive Ranging
- User Performed calculation

System Approved in Dec. '73



Key New Technology - The Unique GPS Signal (CDMA) – now the Worldwide Standard

Jim Spilker
Stanford
Telecom

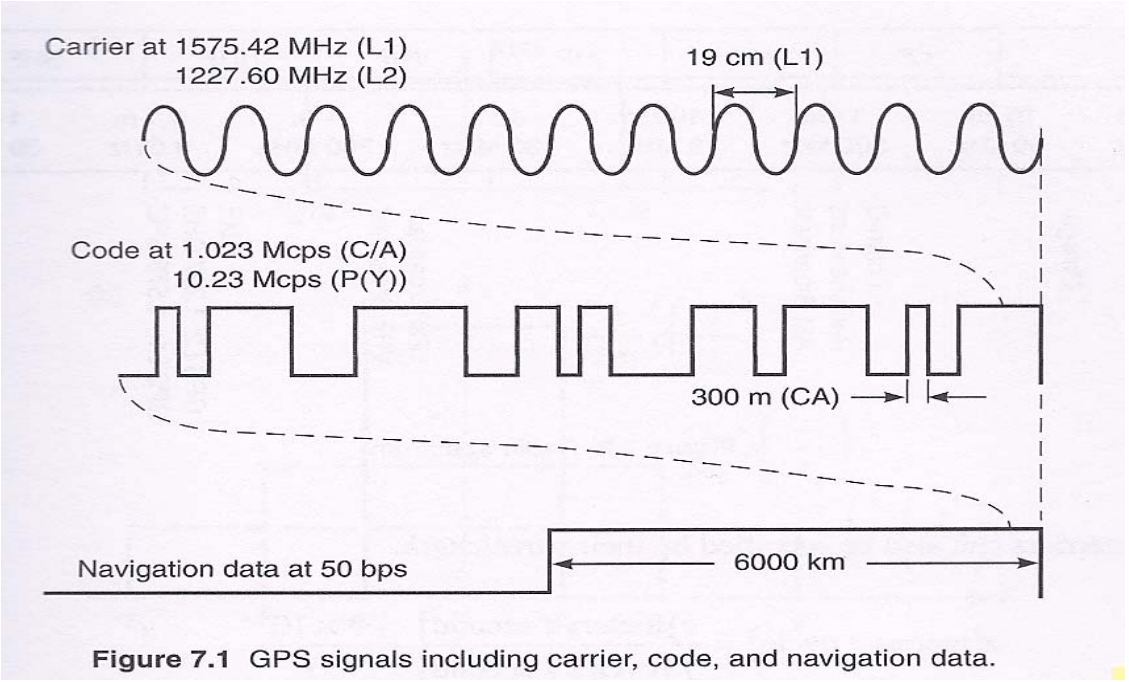


Figure 7.1 GPS signals including carrier, code, and navigation data.

The "new"
GPS signal (1972)

Selecting the Signal ***Type*** was not enough…

The Additional Frontiers:

Five Major Engineering Challenges (For GPS Success)

1. Details of GPS **CDMA signal structure**
   (coherence, acquisition, spreading, com. structure, error correction, message structure, etc.)
2. **Space-hardened** (upper Van-Allen belt qualified) **atomic clocks**
3. **Orbit prediction** - a few meters (URE) in ***90,000 miles of travel***
4. **Spacecraft lifetimes** approaching ten years (GPS affordability)
5. **User equipment** that could eventually be miniaturized and produced at low cost.

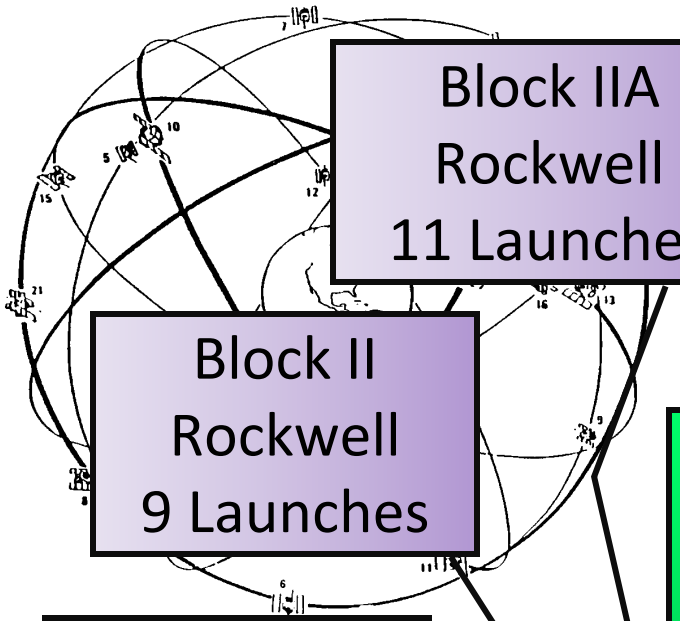
Essential Political and Mentoring Support

The GPS "Godfather"

Mal Currie

Undersecretary of Research and Engineering for the Office of Defense

Sequel: GPS Launch History – 53 Successes



Block IIA
Rockwell
11 Launches

Block IIRM
Lockheed
Martin
(9 Launches)

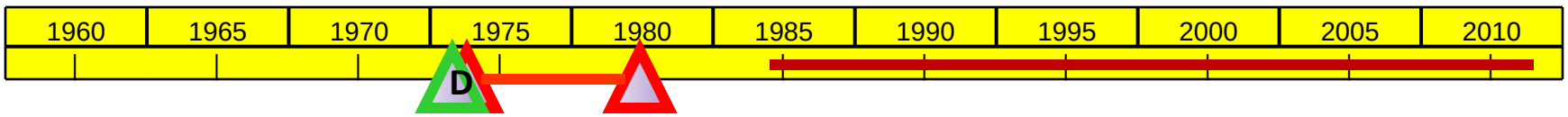
Block IIIA
Lockheed
Martin
(1ST Launch
2014)

Block II
Rockwell
9 Launches

Block IIR
Lockheed
Martin
(12 Launches)

Block IIF
Boeing/Rockwell
(2 Launches +
10 Planned)

Block I
Rockwell
10 Launches

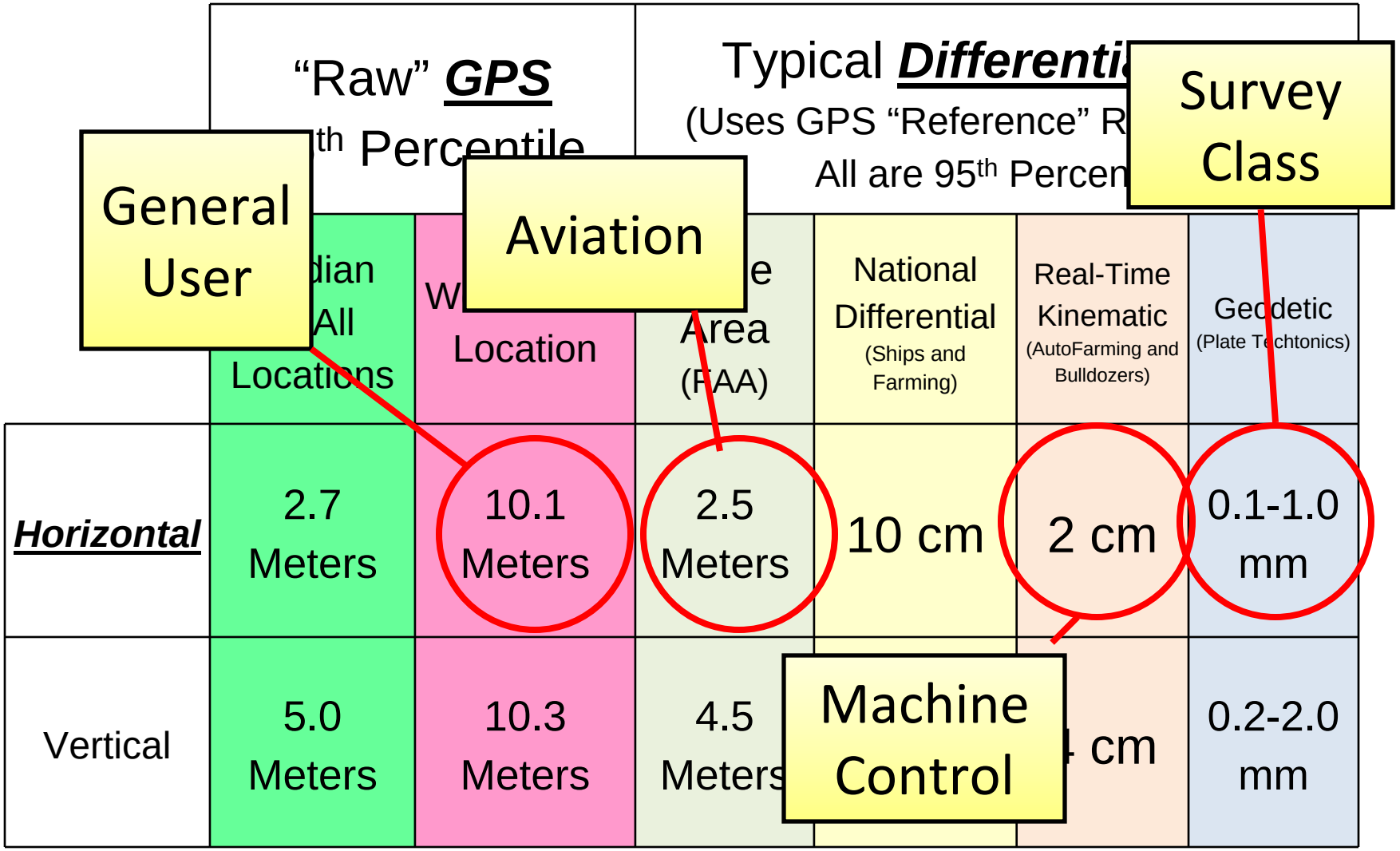


Two Defining Events

(insured Availability of an accurate, worldwide system)

- **President Reagan Commits GPS to the World**
  - A KAL 007 civilian airliner shot down by Soviet Interceptors on 1 September 1 983, over the Sea of Japan (Navigation Error?)
  - US President Ronald Reagan announced on 16 September 1983 that GPS would be freely available for civilian use to avert such a future incedent
  - While the civil signal had been known and available since 1978, this was the first guarantee of world wide availability
- **President Bill Clinton ordered Deliberate Errors (SA) turned off at midnight May 1, 2000 (UTC).**
  - Civilian GPS users around the world would no longer experience the up to 100 meter random errors that SA added

GPS Accuracies Today



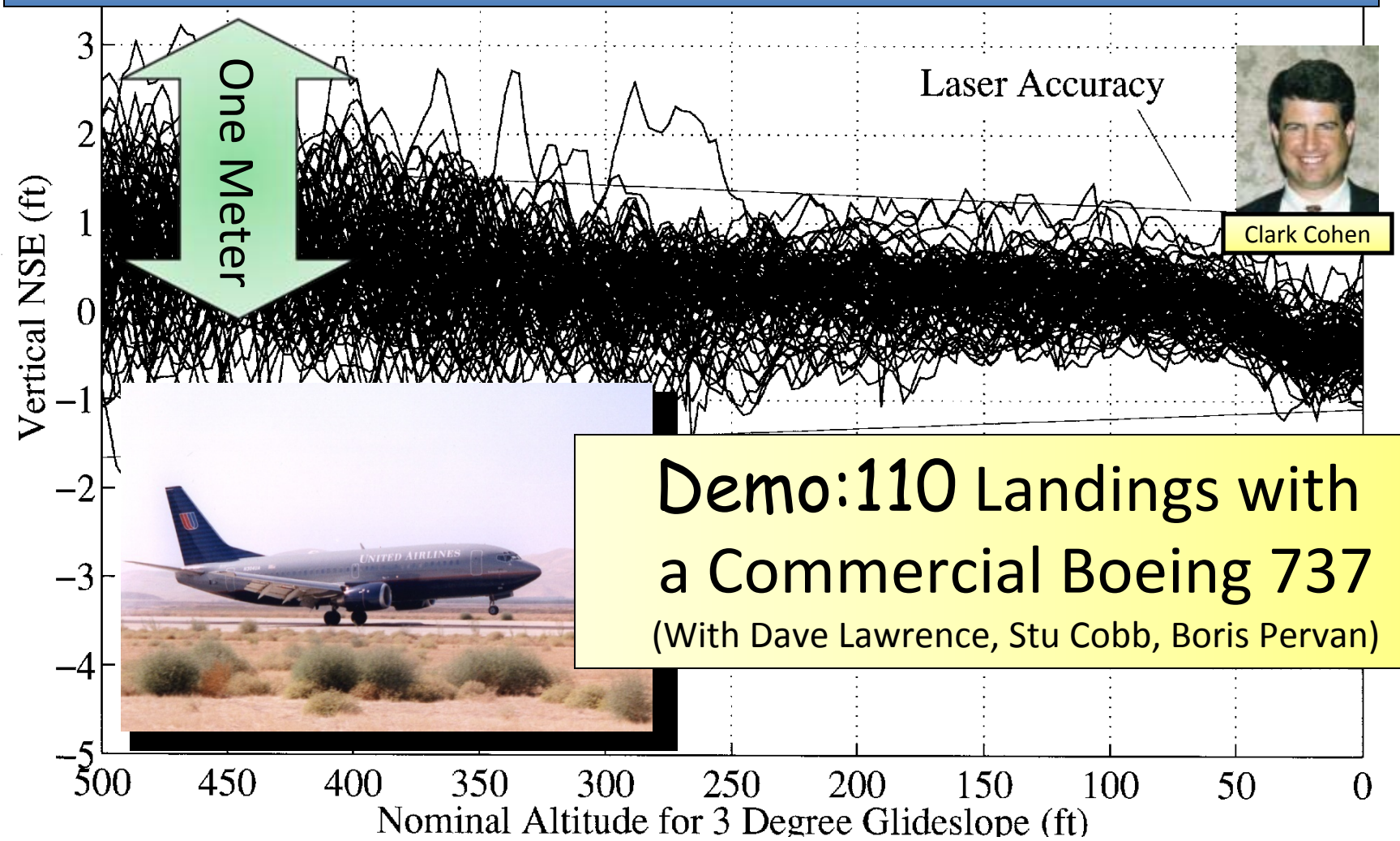

Why would anyone want to track sheep with GPS?

??????????????????????????

"GPS for Humanity" Applications
(At ***least*** 10 major application categories)

- **Aviation** (Area Navigation, Approach, Landing up to Cat III, NextGen)
- **Emergency Services** (911, Ambulance, Fire, Police, Rescue Helicopters)
- **Timing** (Cell Phone Towers, Banking, Power Grid)
- **Agriculture** (AutoFarming, Crop spraying, Precision Cultivating, Yield Assessment)
- **Rescue** (Emergency Beacons, Airplane and Ship Locaters, OnStar)
- **Recreational /Automotive** (GeoCaching, Turn by Turn Auto Guidance)
- **Tracking** (Fleets, Children, Animals, Alzheimer's victims, Cargo, Parolees, Criminals)
- **Scientific** (Earth Movement, Atmospheric, Ionospheric, Earth's shape)
- **Military** (Rescue, Precision Weapon Delivery, Unit and individual location)
- **Robotics/Machine Control** (Many)

- *The Expected in 1974*: Aircraft Navigation
- *The Surprise - 1992*: Hands –Off to Touchdown!



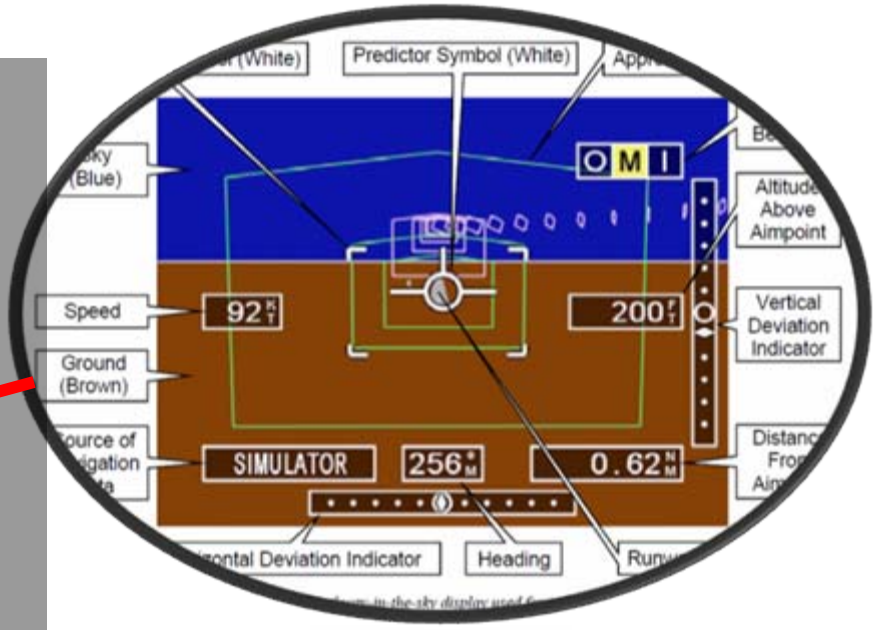
Demo:110 Landings with a Commercial Boeing 737

(With Dave Lawrence, Stu Cobb, Boris Pervan)

"GPS for Humanity" Applications

Aviation

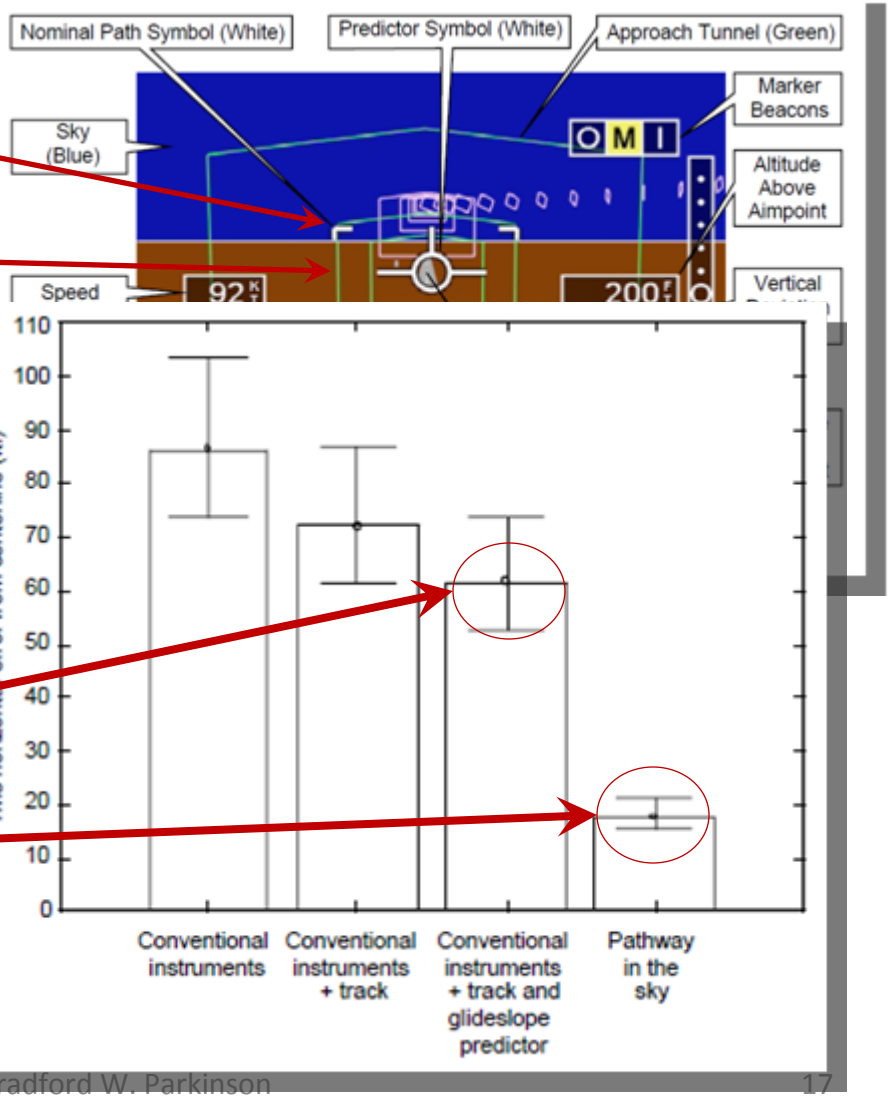
- Area Navigation
- Non-Precision & Precision Approach
- ***Pathway in the Sky***
- Automatic Dependent Surveillance (ADS-B) (tracking)
- Landing up to Cat III
- Runway Incursion Warning &Tracking
- ***NextGen***



Aviation Example: Pathway in the Sky

(Enabled by Precision 3-D GPS -Pioneered by Dr. Andy Barrows)

- Pathway calculated as series of Pentagons
- Own Plane predicted position shown in center
- Intuitive projection of 3-D
- Especially suited for curving and dog-leg approaches
- Real data show errors reduced to 1/3 of best conventional technique



GPS/FANS based Tailored Arrivals – UAL HNL-SFO

True 4-D **procedure "tailored" for flight using continuous descent**

NextGen
- FAA Air Traffic Control for the Future

Average Fuel Saved (Boeing 747) = *1600 lbs!*

(There are ~**28,500** Commercial flights in the US **per Day**!!!)

Payoffs:
- Better Safety
- Less Delays
- More Airways Capacity
- Smaller ***Fuel and Carbon Footprint***

"GPS for Humanity" Applications

Emergency Services (Land)

- 911
- Ambulance
- Fire
- Police
- Rescue Helicopters
- Response Tracking

Over 150,000 users in US –

GPS used to:

- **Pinpoint** situation location (e.g. 911)
- **Vector** police/ambulance responder
- Allow dispatcher to precisely **track progress**

Coordinated International Time (UTC)USNO Clock Vault, Washington, DC – 44 Atomic Clocks

Timing and Frequency

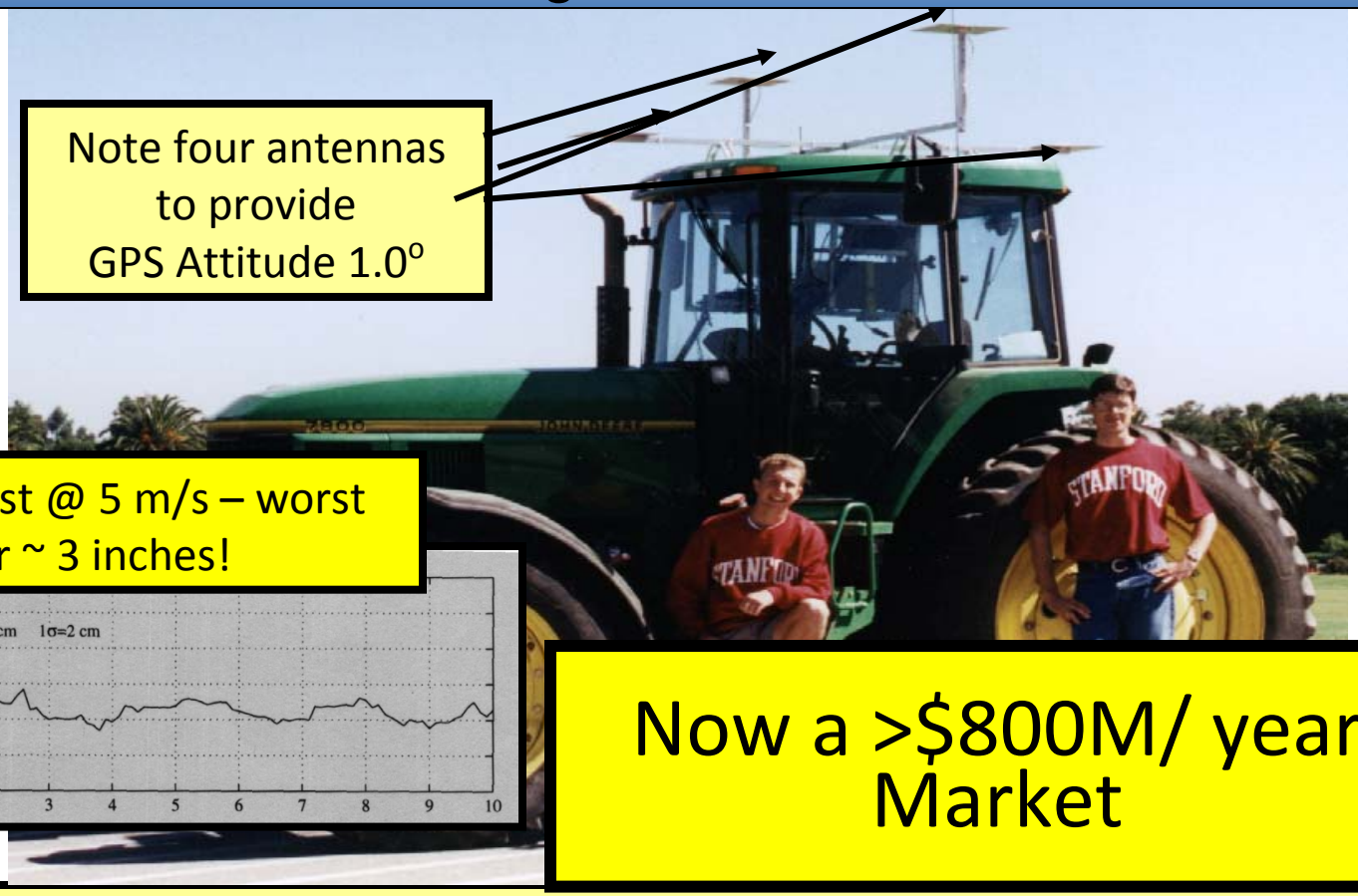
- Cell Phone Towers
- Banking
- Power Grid
- Coordinated International Time

- "A man with a watch knows w
watches is never sure."
-- Segal's Law

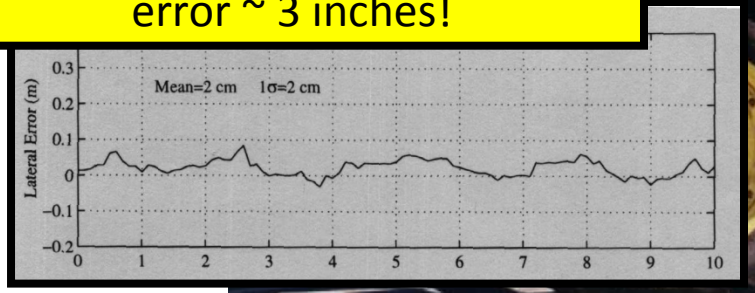
GPS Time Transfer Capability far better than Spec–

- Specified **Time transfer Capability** – ***100 Nanoseconds***
- Current capability **10 Nanoseconds**

The Expected in 1974: Land Navigation
The Surprise 1996: Automatic Steering to an inch
3 Axis attitude to 1.0 degrees



Tracking Test @ 5 m/s – worst error ~ 3 inches!



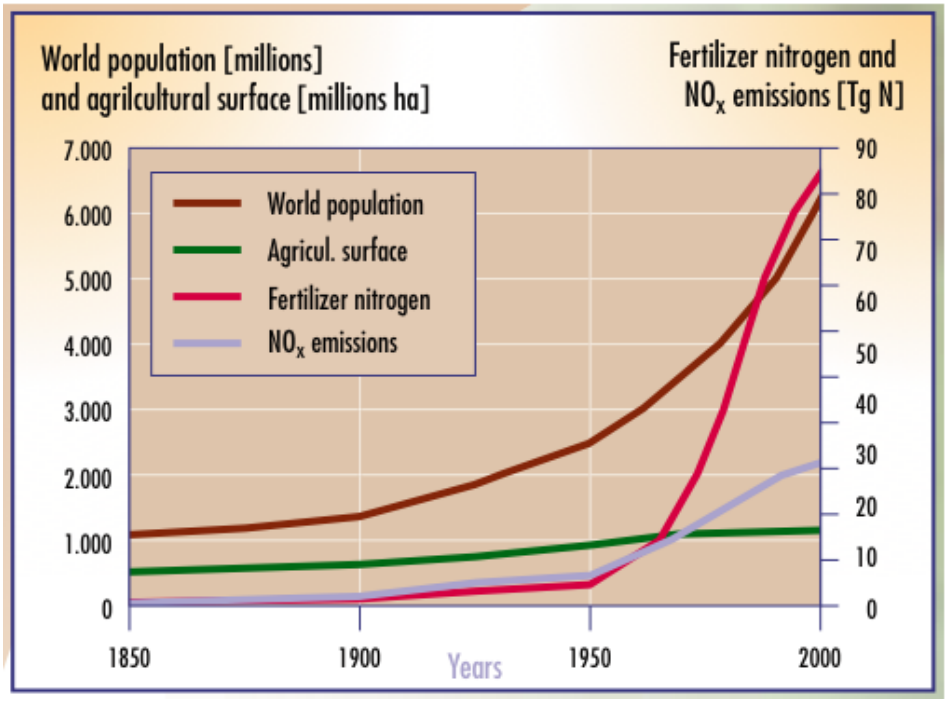
Now a >$800M/ year Market

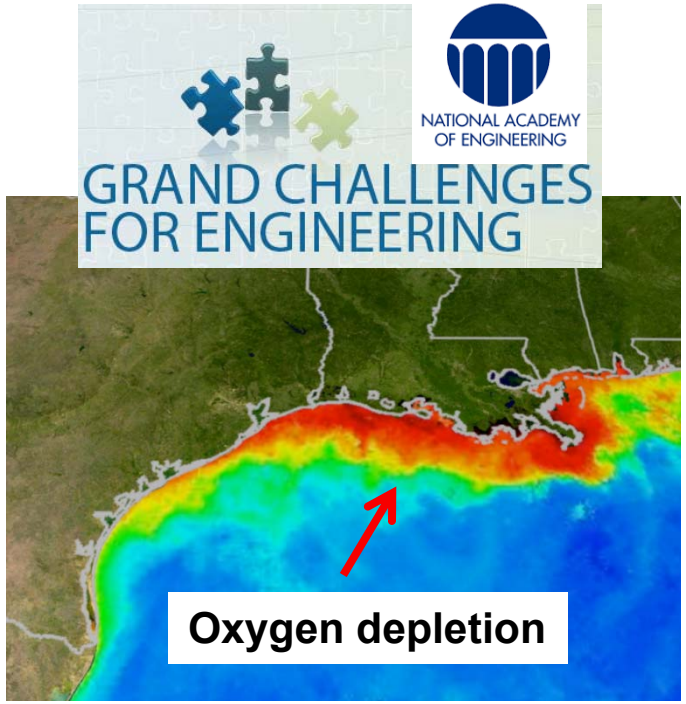
Stanford Robot Tractor –Mike O'Connor, Tom Bell, Andy Rekow

"GPS for Humanity" Applications

- **Agriculture and *Auto-Farming***
  - Precision Cultivating
  - Precision Planting
  - **Crop Spraying (Herbicide, Fertilizer, Pesticide)**
    - Aircraft/Helicopter
    - Tractor
  - Yield Assessment
  -

Compelling Need to Reduce Fertilizer Use





Fertilizer is expensive

- >$18B/year U.S.
- 30-50% of operating costs for corn & wheat
- Nitrogen use is outpacing increases in population / land

Fertilizer runoff is damaging the environment

- Oxygen depletion triggered by excessive N/P levels

Hands-free Steering = 8-10% Reduction

Potential ***savings per year:***

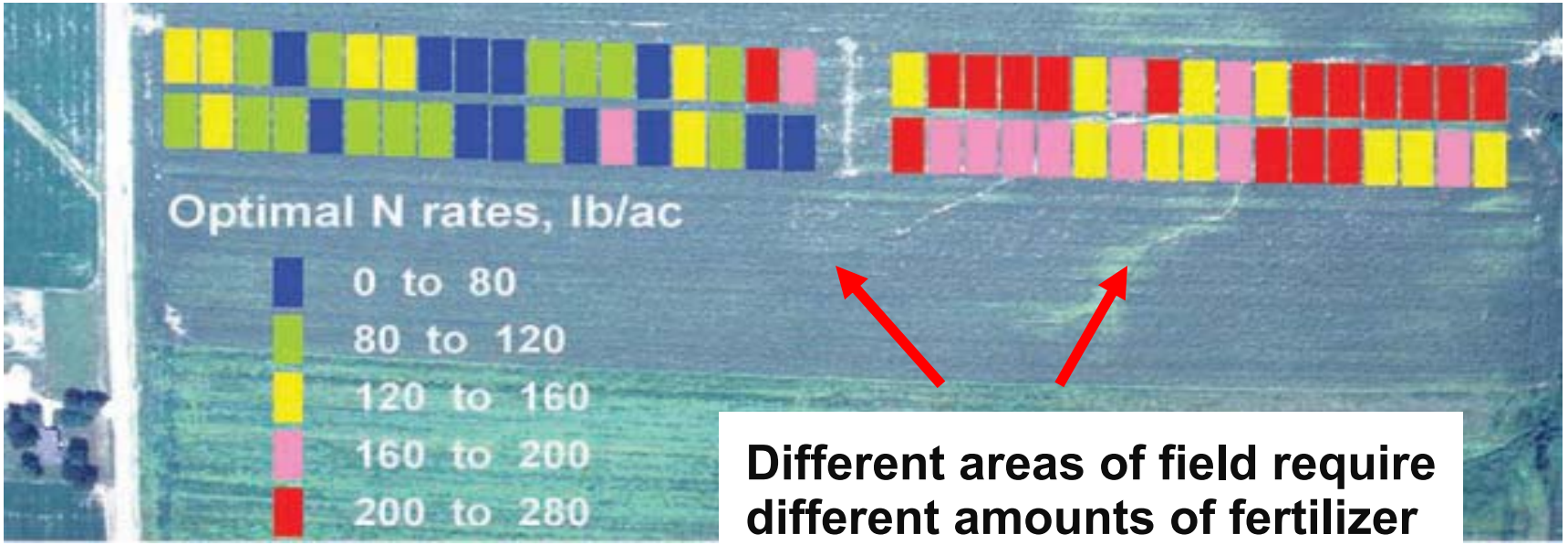
$18B x (8% to 10%) =

$1.4B to $1.8B

(US only)

- Automated steering provides clear benefits to growers
  - Runs day, night or in fog
  - Less overlap = lower fuel/labor costs
  - More rows = greater yields
- Results are visible, and economic value is compelling

Further Improvements are Possible



- Currently Growers over-apply fertilizers to ensure high yields (Driven by worst-case need!)
- Industry developing ***GPS-tagged soil nutrient measurement*** techniques.
- Will lead to more substantial savings