Earth Science Enterprise Technology Planning Workshop

Precision Navigation

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23-24 January 2001

Earth Science Enterprise Technology Planning Workshop

Precision Navigation

Focus:

- Enabling technologies for navigation sensors and actuators for LEO and MEO orbiters and distributed spacecraft constellations
- Results of this session will flow into the Distributed Spacecraft Infrastructure session to address the hardware aspects of autonomous closed-loop control

Sensor technologies to be considered that may require flight validation:

- GPS, RF cross-links, optical, and inertial instruments for the purposes of precise orbit determination and relative navigation
- Critical actuator technology includes low impulse micro- and nano-thrusters, accelerometers, and associated closed-loop architectures
- Extended applications of these technologies to science measurements such as occultations and reflections are also included in the scope of this session

Primary science drivers for precision navigation requirements:

- Topography and Gravity field determination over land, ice and oceans
- Efficient spatial and temporal coverage of the Earth for imaging
- Real time POD and formation flying for Radar and lidar measurements
- Co-ordinated measurements from constellations of satellites

Earth Science Enterprise Technology Planning Workshop
Precision Navigation

Agenda

Tuesday, Jan 23, 2001

Topic	Presenter
Introduction and Overview	Co-Chairs
Oceanography	John Ries - UT Austin
Oceanography	Steve Nerem - U. Colorado
Reference Frames Gravity	Peter Bender - U. Colorado
Navigation for NASA Solid Earth Sci9ence Interferometer Missions	Paul Rosen - JPL
Lidar/Altimetry	Dave Harding - GSFC
GPS Reflections	Jim Garrison - Purdue
Real-time onboard position determination (navigation of satellites to the centimeter-level using new GPS tracking system)	Steve Lichten - JPL
GNC in LEO/MEO	Jesse Leitner - GSFC
POD & GNC	Larry Young - JPL
Propulsion control	Scott Benson - GRC
Highly Compact, Ultra-low Power Tightly Coupled Micro GPS/INS	Michael Watson - MSFC
GPS Modernization	Dave Turner - Aerospace Corp
Interim Summary of Issues	All participants

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Wednesday Jan 24, 2001

- Identify convergence of Science needs and candidate Technology approaches
  - new capabilities enabled
  - reductions in implementation and life-cycle costs
- Define specific capability/technology needs for each measurement class
- Describe and illustrate the current state of the art for the technology
- Itemize the major technology components and current technology readiness level
- Identify ongoing investments
- Identify technology development gaps
- Formulate draft technology development roadmaps
  - Show key development and flight validation objectives and milestones
    - Ground development and validation needed
    - include technology flight validation where necessary
- Summary Plenary Session
  - 10-minute presentations by Chairs of each Breakout Session
- Adjourn

Participants

Penina Axelrad	U of CO
John C. Ries	UT/CSR
Pepper Hartley	NASA/ESTO
Stephen Lichten	JPL
Larry Young	JPL
Tae Kim	MITRE/CAASD
Scott Luthcke	GSFC
Eric Stoneking	Orbital Sciences
Ed Moulton	Honeywell
Matt Nicholson	SPAWAR
Charles Kodak	GSFC/SLR
Tim Brand	Draper Lab
R. Joseph Cassady	Primex Aero
Steve Nerem	U of CO
Scott Benson	NASA/GRC
Chuck Minning	JPL
Dennis Duven	JHU/APL
Jim Garrison	Purdue
Roger Griffin	Boeing
Robert Henderson	JHU/APL
Kenneth Wallace	ARINC
Michael Watson	MSFC
Brian Murphy	GSFC
David Chichka	CIT
Jesse Leitner	GSFC
Peter Bender	JILA/U of CO
Don Burrowbridge	OSC
Bernard Minster	UCSD/SIO
Dave Turner	Aerospace Corp
Bill Kligstein	JPL

Precision Navigation Recommendations

Issues:

- Scientific and technological advance in some NASA Earth Science applications depends on improvements in Precision Orbit Determination (POD)
- POD is reaching a noise floor of about 1 cm

Recommendations:

- Develop and demonstrate reliable drag-free flight capability
- Recommend to DoD enhancements in GPS as part of GPS III
  - Improved satellite response to non-conservative forces
  - Improved phase center determination
  - Improved maneuver control and advisories
  - Improved signal structure, power
  - Improved navigation message for clock and ephemerides
  - Satellite Laser Ranging (SLR) tracking of GPS satellites for improved ephemerides
- Demonstrate centimeter level real time POD using GDGPS
- Demonstrate nanometer laser based inter-spacecraft ranging and formation flying for gravity measurement and optical interferometry

Drag-Free Technology: Benefits

- Science Benefits
  - Gravity missions (GRACE Follow-On)
  - Synthetic Aperture Radar (SAR) interferometry, topography
    - SAR orbits could maintain very close repeats for interferometry
  - Ocean, Ice, and land altimetry science enabled by POD
    - Only gravity errors remain, which will be minimal after GRACE

- Other Benefits
  - Much improved navigation with GPS if GPS satellites were drag-free
  - Autonomous spacecraft navigation accuracy significantly improved
  - Orbit prediction accuracy improved
  - No orbital decay due to atmospheric drag
    - Repeat orbits automatically maintained without maneuver interrupts
  - Improved formation flying (differential surface forces cancelled)

Drag-Free Component Technologies

Thrusters

- Field Effect Electric Propulsion, Ion, Colloid, Hall, Pulsed Plasma Thruster
- 1-10 micro-Newtons (μN) per thruster
- $< 0.1\ \mu N/Hz^{1/2}$ noise
- Near-continuous, clean, and adjustable thrust
- 1-200 mHz
- Long lifetime

Precision Accelerometers

- $10^{-13}\ m/s^2/\ Hz^{1/2}$
- 1-200 mHz
- No US supplier
- Flight validation required to test accelerometer

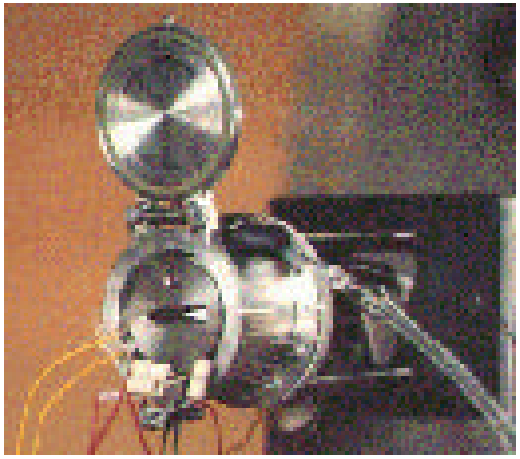
Drag-Free Control Algorithms

- $10^{-10}\ m/s^2/\ Hz^{1/2}$ or better
- 1-200 mHz

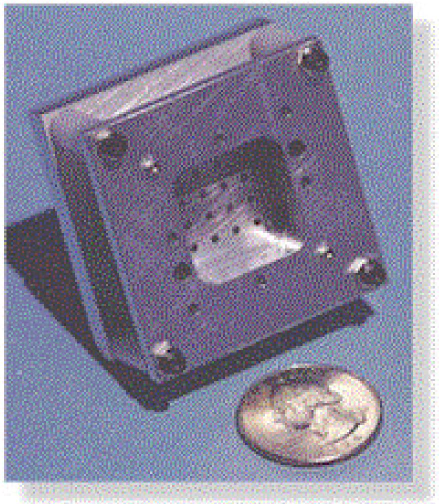
mN Thruster Technology

Pulsed Plasma Thruster (PPT)

Hall Current Thruster (HCT)

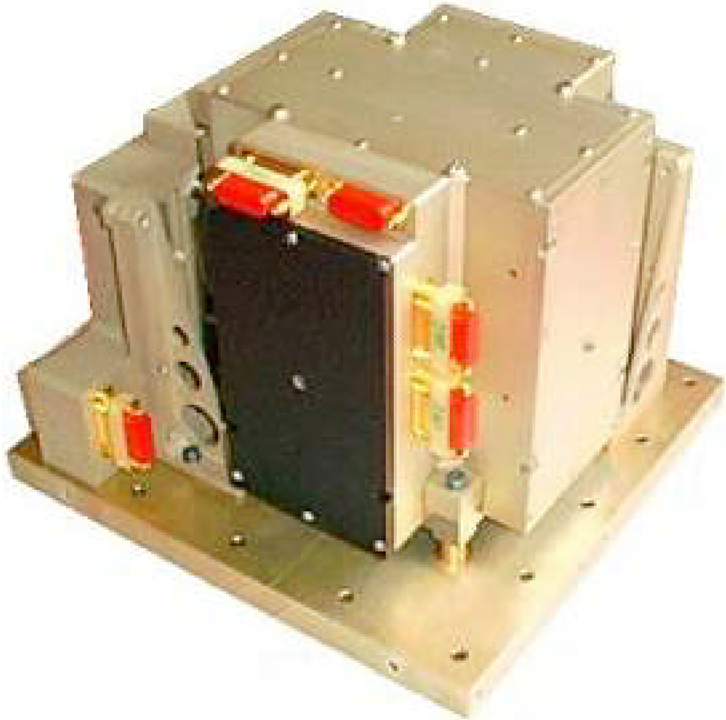


Field Emission Electric Propulsion (FEEP) Thruster



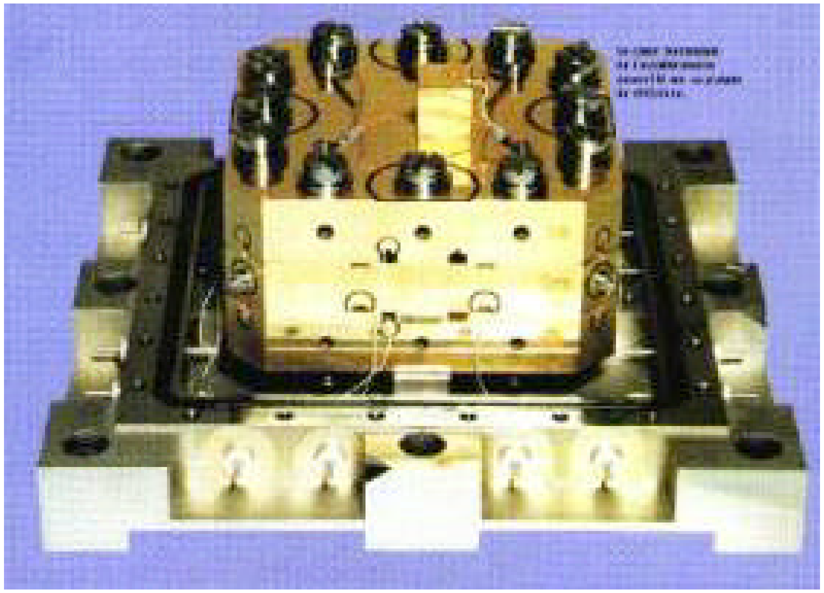
Colloid Thruster

Drag-Free: Accelerometers - ONERA

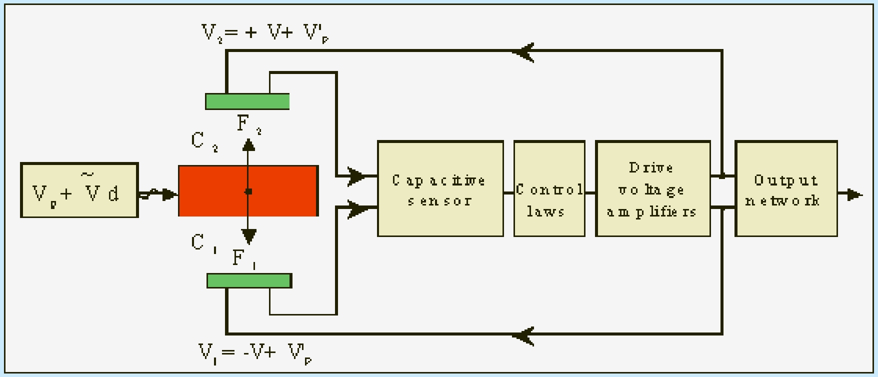


http://www.onera.fr

Drag Free: Accelerometer Principles



- Proof-Mass : motionless with respect to the cage
- Position detection : capacitive sensors with high resolution
- Actuators : Electrostatic levitation
- Measurement : from restoring voltage
  -> tri-axial acceleration of SC



ONERA

Drag Free: Technology Demonstration

- The components of a drag-free system are in a relatively advanced stage of development.
- A flight demonstration of a drag-free system is needed before science missions can begin implementing such a system off-the-shelf with a high Technology Readiness Level (TRL).
- Low cost/ high reliability implementation should be objective of development program

Real Time Centimeter Level Precision Orbit Determination (POD)

- NASA Software of the Year (2000) can provide centimeter level POD in real time.
- Space based correction broadcast being implemented
- Receiver hardware implementation being supported by ESTO/ATIP
- Flight demonstration is recommended within the near term
- Utility to OES science and applications include:

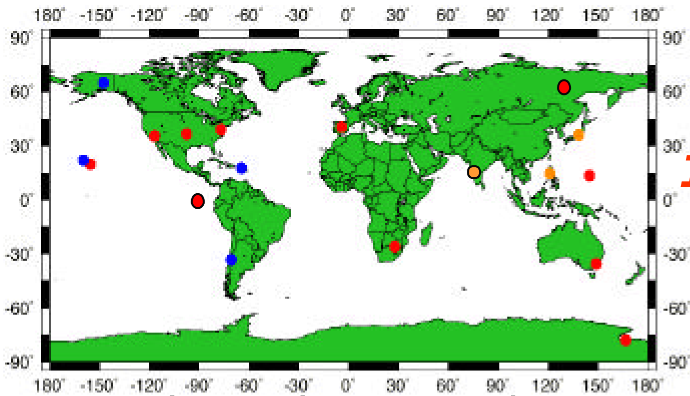
  -Reduced operations costs

  -Onboard formation flying capability

  -Onboard data processing

  -Real time precision altimetry
- Autopilot control would enable airborne repeat pass interferometry- important to natural hazards and applications programs

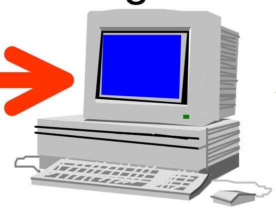
IGDG, NASA Software of the Year 2000, is applied to State-Space GDGPS System



Network receivers running IGDG

Internet

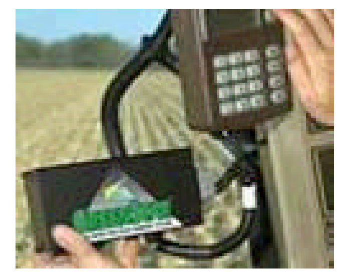
Processing center running IGDG



Broadcast

Internet

Broadcast



Remote user running IGDG

Revolutionary new capability:

decimeter real time positioning, anywhere, anytime

Capability		JPL's IGDG	Un-augmented GPS	Others (WADGPS services)
Coverage:	Global	Yes	Yes	No
	Seamless	Yes	Yes	No
	Usable in space	Yes	Yes	No
Accuracy:	Kinematic applications	0.1 m horizontal 0.2 m vertical	5 m	> 1 m
	Orbit determination	0.01 – 0.05 m (goal)	1 m	N/A
Dissemination method		Internet/broadcast	Broadcast	Broadcast
Targeted users		Dual-frequency	Dual-frequency	Single-freq.

See also: Muellerschoen et al., GPSWorld, January, 2001

For more info look up
http://gipsy.jpl.nasa.gov/igdg

Navigation System Enhancement

- Provide for Satellite Laser Ranging (SLR) tracking of GPS satellites for better orbit determination and tie between systems (GPS III and earlier)
- Improved determination of GPS antenna phase center (GPS III)
- Improved signal structure for higher SNR (GPSIII)
- Better GPS satellite design to reduce drag, solar pressure and other poorly modeled non-conservative forces (GPS III)
- Improve long term stability of Terrestrial Reference Frame to

  100 µm/yr. (IERS, IGS,ILRS,IVS)
- Provide polar orbiting geodetic GPS satellites to improve GPS constellation ephemeris (NMP).

Nanometer Inter-spacecraft Ranging

Science Requirement: Nanometer interspacecraft laser ranging will enable gravity measurement for planetary mass flux, optical interferometer telescopes, gravity wave detection.

Requires: Ultrastable laser sources and interferometers.

Flight Demonstration: Demonstrate formation flying with nanometer metrology in LEO/MEO orbit.