New Folder Name Dent Calculation

LIGO-T940054-00-B

FACSIMILE MESSAGE

CBI
1501 North Division Street
Plainfield, Illinois 60544-8929

Fax No. is: 815 439 6010
Verify No. is: 815 439 6000

Page 1 of 9

August 26, 1994

To: Larry Jones
LIGO Project Caltech Pasadena, California

Fax No. (818)304-9834

From: M. L. Tellalian Phone (815)439-6517

Plainfield Engineering - PAE

RE: Dent Calculation Example & GPS Convention
LIGO Design & Qualification Test - Caltech Contract C146

Larry,

Attached is the letter regarding dents in a sugar silo center column that I talked about on Wednesday. The center column is a stiffener cylindrical shell subjected to external pressure and column load. In this case I believe that the reduction in allowable column load was governed by the axial load. Due to the relatively small axial load, the beam tubes may be governed by the external pressure. I've asked Mark Such to look into this problem and have asked for a response by September 12.

Also attached are a couple of pages out of a brochure for a GPS convention which will be held in Salt Lake City from September 20 - 23. The convention is sponsored by the Satellite Division of the Institute of Navigation and is entitled "ION GPS-94, GPS Goes Operational: Applications and Technology". Steve Hand and possibly Steve Peters will attend tutorials 501A, B, C, & D which deal with High Accuracy GPS Positioning Techniques & Survey Applications. It may be beneficial for someone from Caltech to attend as well. You can receive additional information from the Institute of Navigation, 1800 Diagonal Road, Suite 480, Alexandria, VA 22314. Their phone number and fax number are (703) 683-7101 and (703) 683-7177, respectively.

Regards,

Marty Tellalian

M. L. Tellalian - Plainfield Engineering cc: CDM/Chron

June 18, 1993

[redacted]

Ref: Center Column for Weibull Sugar Silo
Bay City, Michigan
Contract #933441

Five dents were accidentally made in ring number 14 of the center column near the lower edge as shown on Sheets 1 and 2. An angle stiffener 6x4x5/8 was installed 6 in. above the seam with the 4 in. leg horizontal. An analysis has been made to determine the effects of the dents on the axial compression buckling load based upon two papers (1,2) of mine and using the ECCS rules (3).

Miller Method

The local elastic buckling stress, F_{xe}, of an axially compressed cylinder is given by the following equation.

$$F_{xe} = \alpha 0.605 Et/r \qquad (1)$$

The inelastic buckling stress, F_{xc}, is given by the smaller of Eq. 1 and Eq. 2.

$$F_{xc} = \frac{233F_y}{166 + R/t} \qquad (2)$$

The following equation is given in Ref. 1 for 0.605α=C.

$$C = 0.605\alpha = -0.025 - 0.286 \log(UR/t) \qquad (3)$$

The following equation is given in Ref. 2 for the relationship between the amplitude of imperfection, w_o, and the unevenness factor U.

$$UR/t = \frac{w_o}{4t} \qquad (4)$$

For the center column, R=71 in., t=0.3125, w_o=0.4375, and UR/t=0.35. From Eq. 2, C=0.1054 and from Eqs. 1 and 2, F_{xc}=13.46 ksi.

The following equation has been derived in a recent research contract for column buckling.

$$F_{ca} = [1-0.74(\lambda-0.15)]^{0.3} F_{xc} \qquad 0.15 < \lambda < 1.41 \qquad (5)$$

where $\lambda = \frac{KL}{\pi r}\sqrt{\frac{F_{xc}}{E}}$.

For the center column, λ=0.233 and F_{ca}=13.21 ksi. With FS=1.67 the allowable load is 920 kips.

<u>ECCS Method</u>

$$F_{xe} = \alpha\ 0.605\ Et/R \qquad (1)$$

$$F_{xc} = \frac{F_{xe}}{\gamma} \qquad \gamma = 4/3 \qquad F_{xe} \le 0.5F_y \qquad (6)$$

$$F_{xc} = \left[1-0.4123\left(\frac{F_y}{F_{xe}}\right)^{0.6}\right]F_y \qquad F_{xe} > 0.5F_y \qquad (7)$$

$$\alpha_o = \frac{0.70}{(0.1+0.01R/t)^{0.5}} \qquad \text{For } w_o = 0.4\sqrt{Rt} \qquad (8)$$

$$\alpha = 0.5\alpha_o \qquad \text{For } w_o = 0.08\sqrt{Rt}$$

$$\alpha = 0.338\alpha_o \qquad \text{For } w_o = 0.4375 = 0.093\sqrt{Rt} \qquad \text{(By extrapolation).}$$

For center column F_{xc}=8.91 ksi. From Eq. 5, λ=0.190 and F_{ca}=8.83. With FS=1.5 the allowable load is 820 kips.

From the above analysis the allowable load on the center column is 920 kips by the Miller method and 820 kips by the ECCS method. The difference is the two loads is due to an additional partial safety factor of λ=4/3 in Eq. 6.

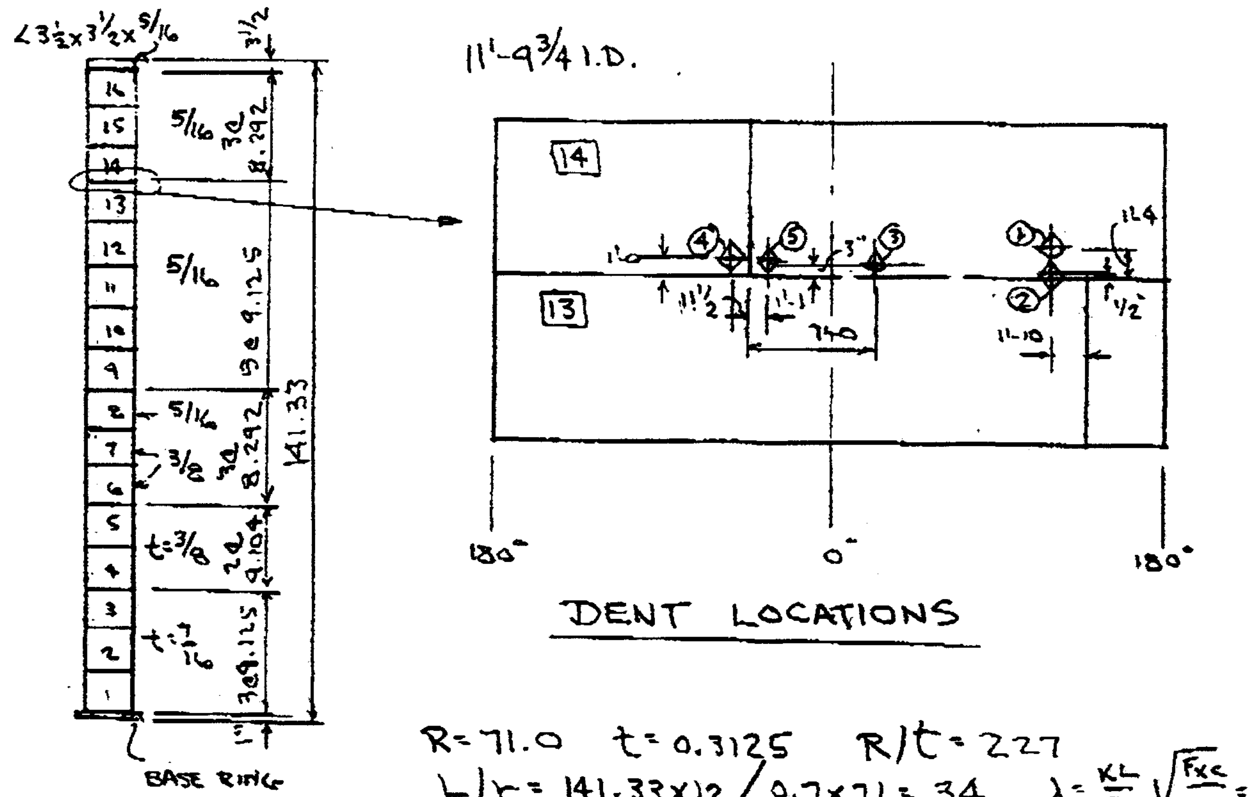
References

1. Miller, "Buckling Stresses for Axially Compressed Cylinders", CBT-5349, 1976.
2. Miller, "Effect of Imperfections on Buckling of Axially Compressed Cylindrical Shells", Research paper, September 28, 1989.
3. ECCS, "Buckling of Steel Shells", 4th Edition, 1988.

C.D. Miller
Plainfield Development, RDE

krl

WEIBOLL SUGAR SILO
BAY CITY, MICH.
CONT. 933441



DENT LOCATIONS

$R = 71.0 \quad t = 0.3125 \quad R/t = 227$

$L/r = 141.33 \times 12 / 0.7 \times 71 = 34 \quad \lambda = \frac{KL}{\pi r}\sqrt{\frac{F_{xc}}{E}} =$

ECCS RULES

$\bar{w} = .4375 \quad l_r = 4\sqrt{Rt} = 18.84 \quad \bar{w}/l_r = 0.0232$

$\alpha = \frac{0.70}{(0.1 + 0.01R/t)^{1/2}} = 0.455 \quad$ FOR $\bar{w}/l_r = 0.01$

$\alpha = .5 \times .455 = 0.227 \quad$ FOR $\bar{w}/l_r = 0.02$

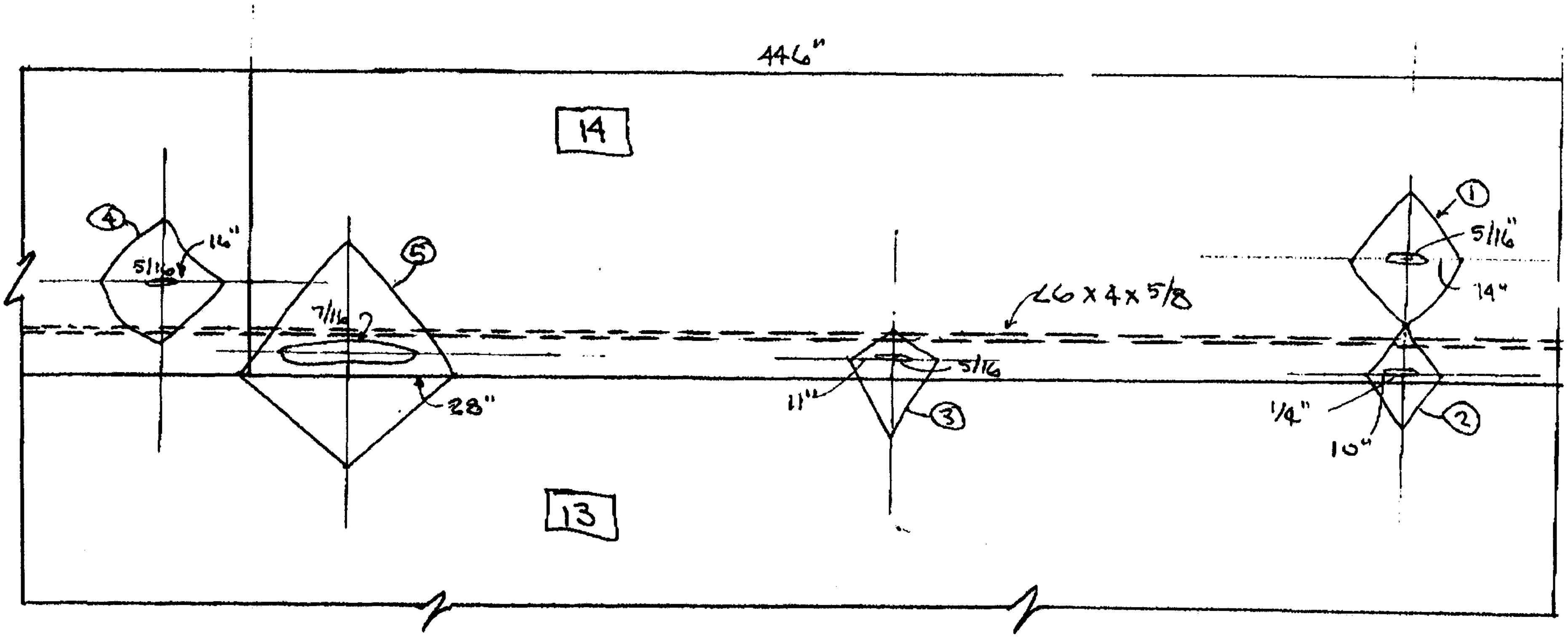
$\alpha' = 0.154 \quad \frac{\alpha'}{\alpha} = 0.338 \quad$ FOR $\bar{w}/l_r = 0.0232$

$F_{xc} = \frac{3}{4} 0.154 \times 0.605 \times 29000 / 227 = 8.91$

$F_a = \frac{F_{cn}}{1.5} = \frac{8.83}{1.5} = 5.89 \quad \lambda = 0.190 \quad F_{cn} = [1 - 0.74(\lambda - 0.15)]^{0.3} F_{xc} = 8.83$

$P_a = 2\pi \times 71 \times \overset{139.4}{} .3125 \times 5.89 = 820$ Kips

SHT. 1
CDM
RDE
6-17-93



LENGTH OF BUCKLES = 69" $\frac{446-69}{446} = 0.845$

DENT LOCATIONS AND SIZES.

SHT. 2
CDM
RDE
6-17-93

REFS: MILLER: (1) EFFECT OF IMPERFECTIONS ON BUCKLING OF AXIALLY COMPRESSED CYLINDRICAL SHELLS. (2) CBT 5349

MAX. DENT = 0.4375 = w_o $\quad$ $w_o/t = 1.40$

$U = \frac{w_o/t}{4R/t} = 0.00154$ $\quad$ $U\frac{R}{t} = \frac{w_o/t}{4} = 0.35$

$c = -0.025 - 0.286 \log (UR/t)$
$= .0.1054$

$F_{xe} = cEt/R = .1054 \times 29000/227 = 13.46$ $\quad$ $\lambda = 0.233$

F.

?

$F_{cn} = .981 \times 13.46 = 13.21$ $\quad$ $F_a = \frac{13.21}{2} = 6.60$

$P_a = 139.4 \times 6.60$ KSI = 920 KIPS

$\overset{?}{SPO, u}$

CYLINDER - NORMAL FABRICATION

$\frac{W_o}{t} = 4 \times \boxed{0.00050} \times 227 = 0.454$ IN.

$c = \boxed{\overset{?}{0.919}} - 0.286 \log \boxed{\overset{?}{227}} = 0.245$ $\quad$ $F_{xe} = 31.3$

$F_{xc} = \left[0.45 + 0.18 \frac{31.3}{36.0}\right] 36 = 21.8$ ksi

2U

$c = \alpha C_x = \frac{169}{195 + 227} \cdot .605 = 0.242$ $\quad$ $F_{xe} = 30.9$

$F_{xc} = \frac{233 F_y}{166 + R/t} = \frac{233 \times 36}{166 + 227} = 21.3$ KSI

$\frac{F_{xc}\text{ (DENTED)}}{F_{xc}\text{ (NORMAL)}} = \frac{13.46}{21.3} = 0.632$

ECCS $\quad$ $\alpha \sigma_{cr} = .455 \times .605 \times E\,t/R = 35.2$

$F_{xc} = \left[1 - 0.4123 \left(\frac{36}{35.2}\right)^{0.6}\right] 36 = 21.0$

$\frac{F_{xc}\text{ (DENTED)}}{F_{xc}\text{ (NORMAL}} = \frac{11.90}{21.0} = 0.567$

SHT. 3
CDM
RDE
6-17-93

Tutorials for Tuesday - Rooms 4, 5, and 6

8:30 - 12:00, Tuesday, Room 4

401 C: Integration of GPS with Inertial Navigation Systems III

In 401 C & D, current activities in GPS/INS integration will be discussed, including new approaches to decentralized filter design. Applications of low cost integrations will be considered, as will the benefits of integration for GPS integrity enhancement. The inertially aided GPS concept and techniques will be analyzed.

Design of Centralized Filters for GPS/INS Integration — **Mr. G. Jeffrey Geier**, ***Motorola***
- Dynamic modeling; F, Q matrices
- Measurement modeling; H, R matrices
- New approaches to centralized filter design

Integration of Existing Receiver Designs with Inertial Platforms
- The cascaded filter design problem
- Existing and new cascaded filter designs
- Analysis of performance

Receiver Aiding
- Carrier, code loops
- Simplified error analysis
- Partitioned design, integrated design
- Simulation results; agreement with practice

Level: Familiarity with INS and GPS technology is assumed in 401C, as well as knowledge of matrix theory.

1:30 - 5:00, Tuesday, Room 4

401 D: Integration of GPS with Inertial Navigation Systems IV

Case studies, current activities in the field, and new areas of research are emphasized in this half day.

Mr. Geier

GPS/INS Case Studies I
- GPS/AHRS/Doppler for helicopter applications
- Equipment configuration with filter design options
- Simulation results

GPS/INS Integration Case Studies II
- Aircraft integration: low cost, moderate performance
- Aircraft high performance, maximum jamming environment
- Low cost guided weapon integration

Current Activities and Research
- Very low cost GPS/INS integrated systems
- Jamming resistant GPS receiver
- GPS/INS Integrity Monitoring: benefits of integration
- Inertially aided GPS and performance enhancement
- GPS/INS national meetings, publications and references

Level: Familiarity with INS and GPS technology is assumed, as well as knowledge of integration techniques (401 A-C desirable).

8:30 - 12:00, Tuesday, Room 5

501 C: High Accuracy GPS Positioning Techniques and Survey Applications III

This half day addresses methods for achieving high accuracy positioning measurements for moving platforms using the latest differential GPS techniques.

✓

GPS Point Positioning — **Dr. Gérard Lachapelle**, ***University of Calgary***
- Effect of selective availability (SA)
- Use of post-mission orbit and timing information

Differential GPS (DGPS) Techniques
- Differencing coordinates
- Code DGPS
- Carrier smoothed code DGPS

RTCM SC-104 differential corrections
- Basic code-based DGPS corrections
- Carrier phase differential corrections

Monitor Stations
- Communications links; latency

Applications and Case Studies
- Geographic Information Systems (GIS)
- Vehicle positioning
- Attitude reference systems
- Airborne photogrammetry
- Marine

Level: Basic knowledge of the GPS system is assumed as well as familiarity with engineering analysis methods.

1:30 - 5:00, Tuesday, Room 5

501 D: High Accuracy GPS Positioning Techniques and Survey Applications IV

This final half day addresses precise positioning techniques particularly as they relate to surveying - both in the static and kinematic modes.

✓

Dr. M. Elizab[illegible] Cannon, ***Univers[illegible]gary***

GPS Static Positioning
- Conventional static surveying pr[illegible]es
- Rapid static methods, stop and [illegible]niques
- Impact of rcvr technologies, acc[illegible]s a[illegible]elevat[illegible]

High Accuracy GPS Kinematic Positioning
- Known baselines; antenna swapping
- On the fly (OTF) ambiguity resolution methods
- Single versus dual frequency observables
- Effect of carrier phase noise and multipath

Static and Kinematic Case Studies
- Integer vs. float ambiguity solutions
- Stop and go positioning
- Low cost receiver vs. geodetic receiver results; trades
- Single & dual frequency OTF results; land, marine & airborne
- Effect of cycle slips and propagation biases

Intro to GPS Surveying Specifications and Guidelines
- Federal Geodetic Control Committee standards, reports
- Survey validation concept

Level: Basic knowledge of the GPS system is assumed as well as familiarity with engineering analysis methods.

Tuesday Morning Tutorials

[illegible]

This course brings attendees up to date on developments in differential techniques, achieving high accuracies in real time on dynamic platforms. Addresses the concepts, implementations, capabilities and performance of both code and carrier (kinematic) DGPS techniques.

Differential Code and Carrier Phase Measurement Concepts — **Dr. M. E. Cannon**, ***University of Calgary***
- Code correlation vs. carrier phase meas.techniques
- Measurement errors
- Impact of narrow correlator spacing code technology
- Differencing techniques
- Achievable accuracies; effect of dynamics

Ambiguity Resolution Methods
- Static vs. kinematic; carrier cycle ambiguity
- Relationship between various methods
- Testing criteria; multipath & other errors
- Single vs. dual frequency resolution; processing
- Attitude determination case

Real Time Issues and Emerging Trends
- Implementation; techniques, concerns
- Data links; requirements
- Effect of satellite constellation build-up
- Ionospheric and tropospheric effects

Level: 631A is an advanced course which assumes attendees have a good understanding of GPS and its signal processing.

Advertisement

Tuesday Afternoon Tutorials

[illegible]

This half day addresses some of the advanced techniques, experimental results and real time applications currently supported by code and carrier phase differential measurement technologies.

Case Study I: Land and Marine Positioning — **Dr. Gérard Lachapelle**, ***University of Calgary***
- Effect of ambiguity resolution algorithm
- Use of multi-receiver configurations
- Ionospheric code-carrier divergence
- Multipath effects and ground planes
- P-code vs. codeless processing

Case Study II: Airborne Positioning — **Dr. Herbert Landau**, ***terraSat GmbH***
- Applications and associated accuracy requirements
- Error components; iono, tropo, multipath
- Use of carrier phase, OTF ambiguity resolution, performance
- Receiver/IMU/computer mechanization
- Experimental and production flight results

Case Study III: Attitude Determination with GPS — **Dr. Clark Cohen**, ***Stanford University***
- Principles; error sources
- GPS errors, multipath, refraction effects
- Structural flexing, geometry • Performance envelope
- Static and dynamic flight test results

Level: 631B is an advanced course which assumes attendees have a good understanding of GPS signal processing.

Turn the page for evening events and [illegible]al registration form

Tutorials for Monday - Rooms 4, 5, and 6

8:30 - 12:00, Monday, Room 4

401 A: Integration of GPS with Inertial Navigation Systems I

GPS and INS complement each other to achieve continuous high accuracy and reliability. GPS provides precise position and velocity fixes at discrete points in time; the INS provides precise interpolation between fixes. 400A and 400B lay the groundwork for understanding current integration methods, and lead to tutorials 400C and D.

Dr. R. Grover Brown
Consultant

Integration Principles for Navigation Systems
- System integration problems
- Filter theory perspective: classical, Wiener and Kalman
- Integrated INS/GPS -- optimal configuration

Kalman Filter Basics
- Discrete process and measurement models
- Key filter parameters • Recursive equations
- Examples: bias, random walk, Markov process
- Guarding against divergence

Additional Topics on Kalman Filtering
- Alternative recursive algorithms • U-D factorization
- Processing measurements one at a time
- Error covariance analysis • Least squares
- Linearization • Extended Kalman filter

Level: **Familiarity with INS and GPS operation, as well as the fundamentals of matrix theory is assumed.**

1:30 - 5:00, Monday, Room 4

401 B: Integration of GPS with Inertial Navigation Systems II

The sessions in this half day tie together the Kalman filtering concepts covered in the morning with their basic uses in GPS/INS integrations.

Mr. G. Jeffrey Geier
Motorola

Application of Kalman Filtering to GPS
- Why Kalman filtering with GPS?
- Overview of hierarchy of GPS/INS Kalman filter models
- Stand-alone GPS Kalman filter model
- Overview of cascaded filter problem

Inertial Navigation Topics
- INS components, sensor characteristics
- Gimballed and strapdown system configurations
- System comparisons and performance analysis

Introduction to GPS/INS Integration
- Performance synergy
- Predicting uncalibrated and calibrated INS error growth
- Classification of integration levels
- Centralized vs. decentralized filter design

Level: **Familiarity with INS and GPS operation, as well as the fundamentals of matrix theory is assumed.**

(Normal sequence is to proceed to 401C and D.)

8:30 - 12:00, Monday, Room 5

501 A: High Accuracy GPS Positioning Techniques & Survey Applications I

High accuracy positioning users have found great benefit in employing GPS to achieve a variety of accuracies (down to the centimeter level) in far less time than by conventional methods. This first half day addresses the basic principles involved.

Dr. Gérard Lachapelle
The University of Calgary

High Accuracy Receivers and Antennas
- Single and dual frequency receivers
- Correlation, squaring and codeless receivers
- Narrow correlator spacing receiver technique
- Effect of SNR losses on codeless receivers

GPS Observation Equations
- Code and carrier phase measurements
- Integer nature of carrier cycle ambiguity
- Cycle slips and detection
- Doppler frequency
- Widelane observables

GPS Errors and Biases
- Timing and orbital biases, Selective Availability
- Atmospheric propagation errors, receiver noise
- Code, carrier phase multipath errors

Level: **A basic knowledge of the GPS system operation is assumed in 501A, as well as familiarity with engineering analysis methods.**

1:30 - 5:00, Monday, Room 5

501 B: High Accuracy GPS Positioning Techniques & Survey Applications II

This half day focusses on how GPS measurements can be used with coordinate systems and reference networks to obtain consistent, high accuracy results.

Dr. Lachapelle

Use of Differencing Techniques to Reduce Biases & Errors; Assessment of Rcvr. Noise and Multipath Effects
- Numerical results using various receivers
- Impact of various errors on positioning accuracy

Reference: Survey of GPS Receivers

Coordinate Systems and Reference Networks
- Cartesian and ellipsoidal coordiante systems
- NAD27, NAD83, WGS72 and WGS84
- National networks
- Satellite orbit determination networks
- IGS and ITRF

Computing Positions
- Satellite position information
- Least squares solutions
- Constrained solutions
- Sequential solutions
- Kalman filter solutions

Level: **A basic knowledge of the GPS system operation is assumed, as well as familiarity with engineering analysis methods.**

(Normal sequence is to proceed to 501C and D.)

[illegible]

This course addresses the use of hazard tree analysis and risk allocation methods for the determination of RNP for each phase of flight. Navigation sensors evaluated on GNSS, LORAN, DME, IRS & INS. Introduces new concept of aircraft navigation performance (ANP) relationship.

Dr. Robert Kelly
Consultant

Principles of RNP
- Risk analysis background
- Design of aircraft containment surface using risk tree
- Derivation of RNP parameters: accuracy, integrity, continuity and availability • Relationship of RNP to target level-of-safety

Principles of the Tunnel in Space Concept
- RNP development for approach and landing phase of flight
- Derivation of approach & landing system characteristics using four RNP parameters
- Applications to DGNSS Special Cat I MASPS

Principles of ANP (Aircraft Nav Perf.): Oceanic & En Route
- ANP assesses in real time A/C capability to fly in RNP airspace
- Develops methodology using accuracy, continuity and integrity risk allocations for determining the MTBO of avionics and the capability of the monitoring system
- Emphasis on inertial aided GNSS and DME nav systems

Level: **621 is an advanced course which assumes familiarity with navigation and landing systems and basic statistical techniques. (Normal sequence is to proceed to Course 625 and 631 A & B.)**

[illegible]

Multipath is the dominant error source in both code and carrier DGPS. A thorough understanding of the causes, effects and methods for mitigating multipath is essential in order to achieve the full potential of GPS and DGPS.

Dr. Michael Braasch
Ohio University

The Multipath Problem and Its Analysis
- Multipath sources, L-band reflection and diffraction
- Effects on GPS, DGPS and kinematic use
- Impact on airborne, land and marine users
- Multipath environment, modeling and analysis
- Code and carrier phase error characteristics

Reducing the Effects of Multipath
- Receiver architecture considerations: correlator spacing, coherent vs. non-coherent processing, carrier-aiding vs. carrier-smoothing, Maximum Likelihood Estimation (MLE) separation of direct and multipath signals
- Receiver autonomous multipath monitoring
- Antenna design and siting considerations

DGPS Signal and Multipath Modeling
- Signal model data requirements and applications
- Real-time and fast-time considerations
- Hardware vs. software simulations, algorithm testing
- Receiver architecture modeling
- Error sources, models and analysis results

Level: **Assumes a basic understanding of GPS operation and measurements, also familiarity with signal theory & engineering analysis. (Normal sequence is to proceed to 631A and B.)**