For those of you that haven’t met me, I am Mike Gamble. Presently working for the Flight Sciences division of (BR&T) Boeing Research and Technology. I was requested by the conference chair to give this historical presentation of Boeing’s CMG work. The following pictures are all that is left of this gyro effort.
This presentation is mainly a non technical pictorial history of Boeing’s CMG work. The work started back in the 1960s and continued on into the 1990s. I got involved with it in 1995 when I took over operations of the (GN&C) Guidance, Navigation and Controls lab at the Boeing Kent (WA) Space Center. This lab and the building that housed it were badly damaged in the 2001 Seattle earthquake and later demolished. The pictures show many of the different types of test articles built and used along with some of the lab facilities. As this facility and equipment no longer exist it’s now possible to talk about it.

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This is the Boeing Kent (WA) Space Center with Mt Rainer in the background. On a historic note Boeing built the first stage of the Apollo moon rocket; which was developed and tested here. Also, the lunar rover (moon buggy) was developed in the GN&C lab (before my time). It’s presently on display at Boeing’s “Museum of Flight” (Seattle). The following CMG work was done in the GN&C lab located at this facility.
The next few charts show basic gyro operating principles and dual (or scissor) operations.
1) A gyroscope has three (3) orthogonal (90deg) vectors:
   - Rotor (spin axis - red)
   - Torquer (input axis - green)
   - Output (output axis - blue)

2) Making the gyroscope’s output proportional to three (3) things:
   - Mass of rotor
   - Speed of rotor
   - Rate of torquing
Gyroscope’s dual (or scissor) operation:

1) Both gyros are the same:
   - Mass (Rotor)
   - Spin (RPM)

2) However, they torqued in opposite directions:
   - Grn = Torquer (see vectors)
   - Red = Spin
   - Blu = Output

3) Making the Output = vector proportional to (2x) the:
   - Torquer rate and
   - Differential angle between them
1) This chart shows the sawtooth input torquing rate waveshape (scissoring) for generating the pulsed output force:
   - slow together and fast apart = force in one direction
   - fast together and slow apart = force in other direction
2) By torquing fast in one direction and slow in the other, a pulsed (average) output force is generated.
The next few charts show some of the different type gyros Boeing used over the years. This CMG work started using small test articles and developed into large ones.
1) Small gyro test article – first type
2) The gyros are operated pairs
3) and torqued in opposite directions (scissored)
4) By a figure-8 drive band at bottom
5) Torquer motor not shown
1) Small gyro – second type
2) Black color makes it difficult to see the details
3) However, the following exploded view shows it much better
1) Dissembled view of previous gyro (second type)
2) Showing the individual parts
1) Medium size gyro and gimbals
2) Rotor (Flywheel) is in the middle
3) Motor and position sensor are on opposite ends
1) Large Sperry CMG gyro and gimbals
2) One of four (4) used on the big test article
3) Big blue cylinder on right is the torquer motor
4) Small blue cylinder on left is the position sensor
5) Red housing is a vacuum chamber around rotor (flywheel)
6) Clear plastic bubble is a safety shield
The following charts show some pictures of the Boeing CMG test facility (GN&C lab)
1) Air pad (isolation slab) construction
2) was a 20’ square reinforced concrete slab (70K lbs)
3) and floated on air cylinders (seismic isolated down to uGs)
4) with the air bearing pedestal in the middle (center) of pad
5) I happened to be standing on this air pad when the earthquake hit
   didn’t feel a thing – worked perfectly! It was only when the overhead crane
   started dancing, I got concerned.
1) Door into “space” - (black room) simulator
2) This black room could simulate most “space” conditions except for vacuum (air drag)
3) The chamber was EMI, Thermal, Optical and Acoustic shielded
4) Control console for air pad (left), air bearing (center) and test article (right) operation
5) Note viewing peep hole (window into space); no one was allowed in when the test article was running (doors interlocked for safety)
6) Floor (square) in front of peep hole was part of air pad so exact measurements could be taken (referenced to test article)
3-D Helmholtz [six (6)] coils could be placed around test article to generate any required (simulated) EM fields.
1) Sun simulator
2) Brightness and size (number of lights) could be adjusted to simulated any distance from the sun
3) Note honeycomb lens assembly
4) There were also small star pattern simulator lights (no pictures)
1) GN&C test control room (early 70s)
2) All the data was collected/recorded on strip chart recorders
3) No digital computers to be seen
The following charts show some of the sensors on the test article
1) Sun sensor on the test article that tracked the (simulated) sun’s position
2) Light intensity and position was used for navigation and control
1) Star sensor on the test article tracked (simulated) star patterns
2) Different star patterns were used for navigation and positioning
1) Test article’s DAQ computer system
2) 16bit address, 8bit data buss (one antique machine)
3) It’s many battery packs were used as ballast and counter weights
4) Today, one laptop could easily replace it
The following charts show some of the different CMG test articles Boeing built
1) Early CMG test article on a stand
2) This was a circular unit with small gyros
3) Note white shirt, narrow tie and (analog) VOM - mid 60s
1) Same test article on the air pad
2) Bowling ball size air bearing
3) Floated on high pressure N2 gas
4) and heavy duty support structure
5) Note white shirt and bow tie – mid 60s
1) Time laps picture of the test article showing its range of movement  
2) Also the test stand could rotate (locked for picture)  
3) All Movement was generated by it’s gyros
1) Another early type test article
2) Heavy duty tripod stand supporting air bearing and test article
3) Gyros (right) were counter balanced by the DAQ system and battery packs (left)
4) Note mini skirt - late 60s
1) Test article’s calibration and range of movement (degrees)
2) being measured with protractors and pointers
3) Note sun simulator in the background
1) Right side view of medium gyro test article
2) showing four (4) gimbaled medium CMGs
3) Note hairdo - early 70s
1) Left side view of same medium gyro test article
2) Note colored shirt and lamb chops - early 70s
1) Later version medium gyro test article
2) Showing dish antenna and counterweights
3) Note color picture - late 70s
1) Large gyro test article (front view) showing two of the four gyros (80s – 90s)
2) Looks like the head of an insect (nickname “old bug eyes”)
3) Note sun simulator in the background
4) This test article was in use when I came into the group in 1995
1) Rear view of the same test article showing the other two gyros and counter weights
2) If you put a seat on top it would beat any mechanical bull in town
3) However, no one was allowed in the “space (black) room” when it was running
4) Note scratch marks on the air pad (floor), sometimes it got out of control (crashed)
Same test article (front view) with balance beam frame for making inertial measurements. Once a satellite achieved orbit it must maintain a stable reference platform.
1) Side view of same test article showing the balance beam
2) The balance beam is centered (leveled) on top of test article
3) Note scratch marks on air pad (floor), it did not always work the way it should
1) This building and GN&C lab (upper left corner) were damaged in the Seattle (2001) earthquake and demolished
2) All the labs and their test equipment were scraped/surplused
3) The rust colored scrap pile (upper left corner) is sitting where the “space (black) room” used to be
4) Because it does not exist any more I can talk about it. Presently, “Amazon.com” has a big warehouse at this exact location
Hope I have not bored you with too many details – It’s a flaw of engineers! Here’s where you can find me or just catch me in the hall if you have questions.