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History of *Boeing* (CMG) Control Moment Gyros (COFE7) Seventh International Conference On Future Energy

BOEING 15-00051-EOT

Mike Gamble
10/7/14

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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.

INTRODUCTION

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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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pg 1

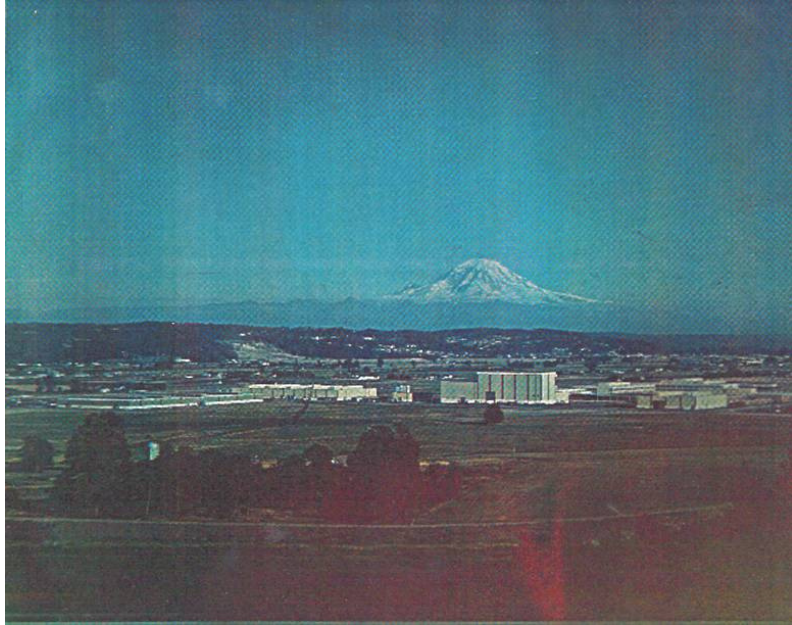
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This presentation is mainly a non technical pictorial history of Boeing's CMG work. The work started back in the 1960s and continued on into the 1990s. I got involved with it in 1995 when I took over operations of the (GN&C) Guidance, Navigation and 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.

BOEING (KSC) KENT SPACE CENTER

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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.



GYRO OPERATING PRINCIPLES

pg 3

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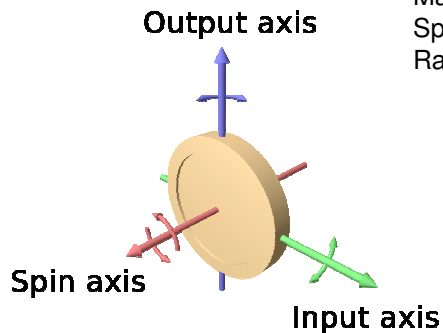
The next few charts show basic gyro operating principles and dual (or scissor) operations.

BASIC PRINCIPLES OF GYRO OPERATION

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- 1) Gyroscope has three (3) orthogonal (90deg) vectors
Rotor (spin axis - red)
Torquer (input axis - green)
Output (output axis - blue)

- 2) Gyroscope's output is proportional to three (3) things
Mass of rotor
Speed of rotor
Rate of torquing



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- 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

PRINCIPLES OF GYRO SCISSOR OPERATION

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Gyroscope scissor operation

Both gyros are the same

Mass (Rotor)

Spin (RPM)

Torqued in opposite directions

Grn = Input (Torquer)

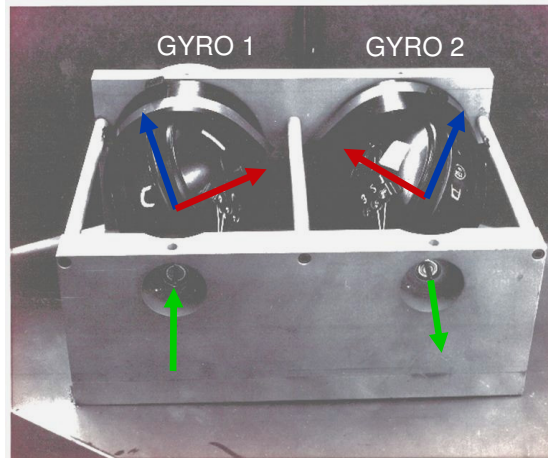
Red = Spin (RPM)

Blu = Output

Output = vector function (2x)

Torquer rate

Differential angle



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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

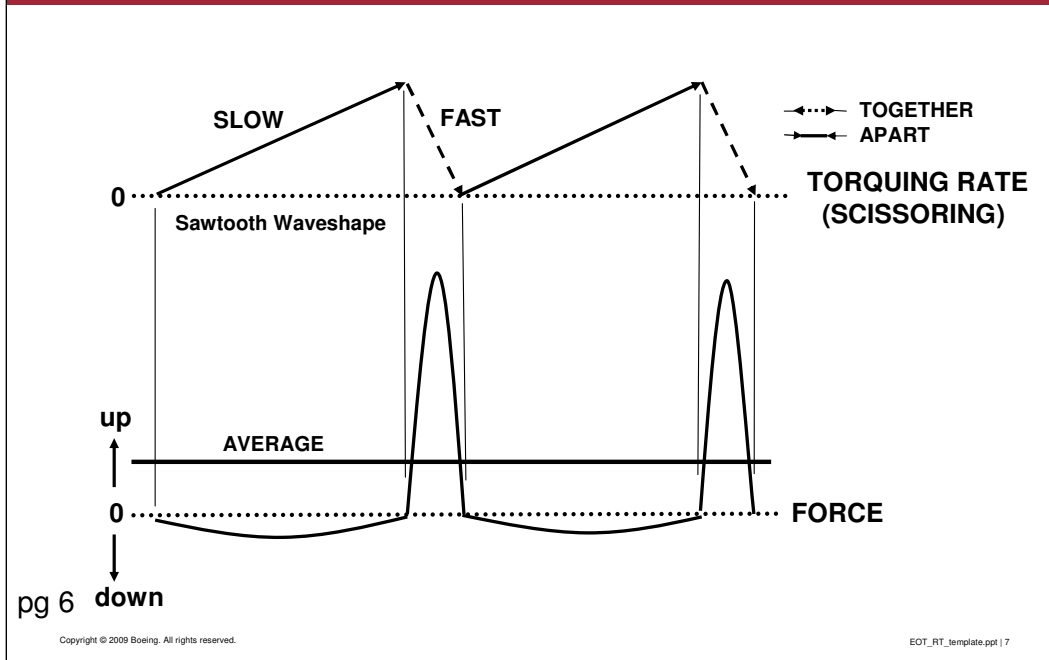
3) Making the Output = vector proportional to (2x) the:

Torquer rate and

Differential angle between them

PRINCIPLES OF GYRO SCISSOR OPERATION

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- 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.



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GYROSCOPES

pg 7

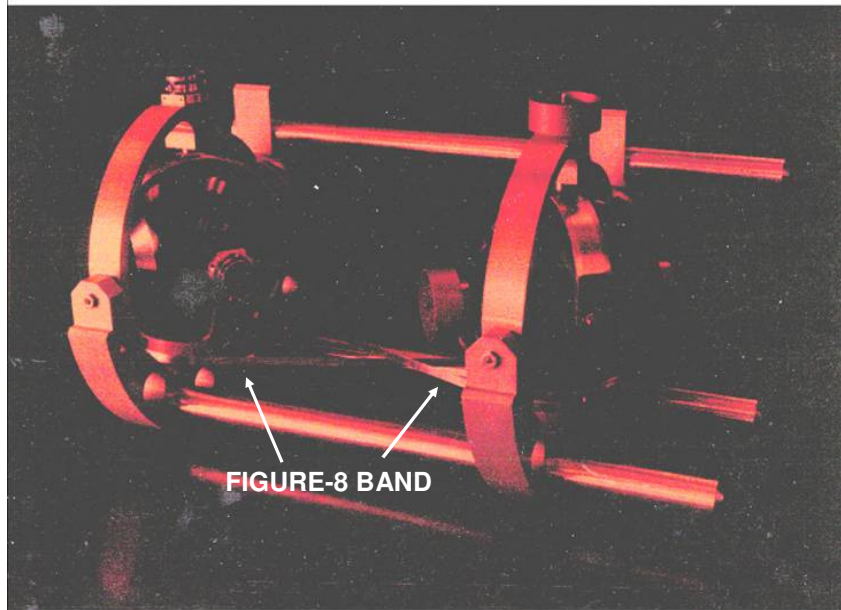
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The next few charts show some of the different type gyros Boeing used over the years. This CMG work started using small test articles and developed into large ones.

SMALL GYRO - FIRST TYPE

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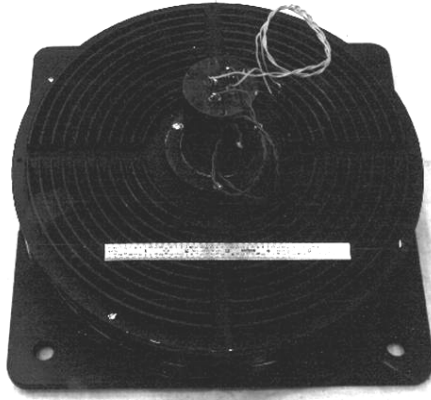
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- 1) Small gyro test article – first type
- 2) The gyros are operated pairs
- 3) and torqued in opposite directions (scissored)
- 4) By a figure-8 drive band at bottom
- 5) Torquer motor not shown

SMALL GYRO - SECOND TYPE

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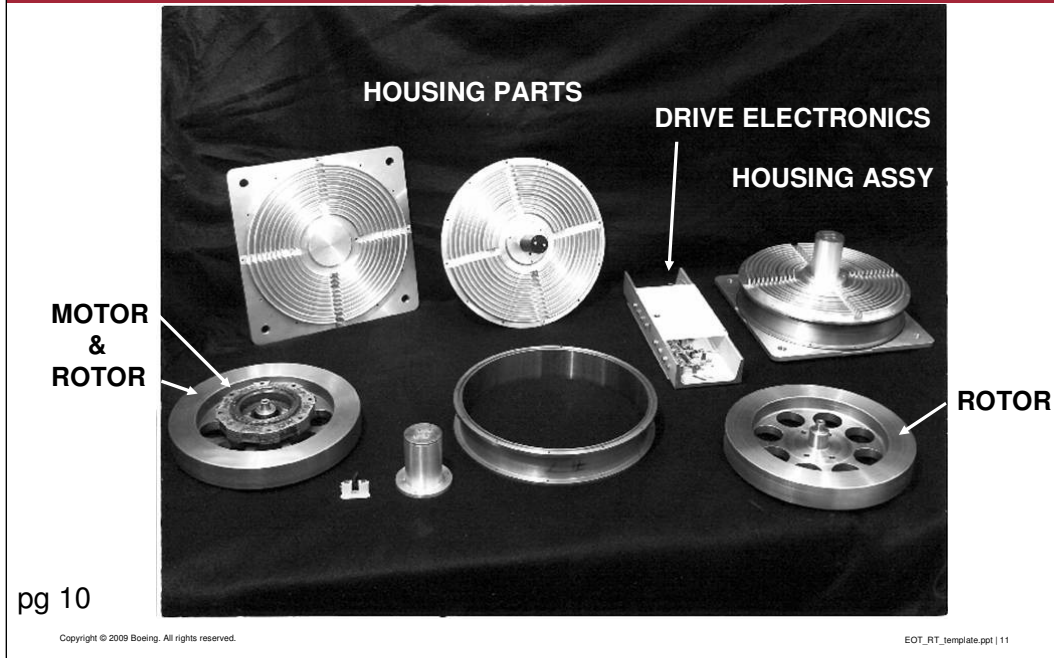
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- 1) Small gyro – second type
- 2) Black color makes it difficult to see the details
- 3) However, the following exploded view shows it much better

SECOND TYPE GYRO - DISSEMBLED VIEW

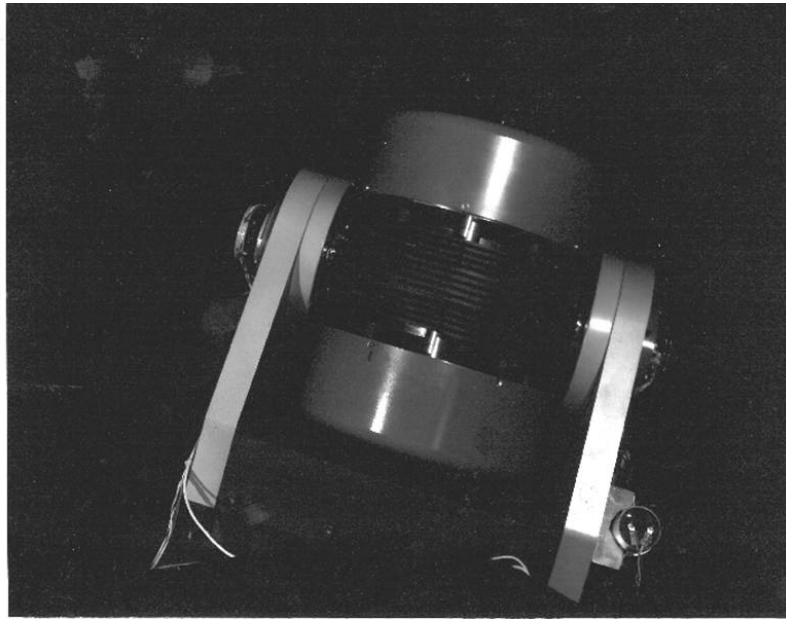
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- 1) Disassembled view of previous gyro (second type)
- 2) Showing the individual parts

MEDIUM GYRO AND GIMBALS

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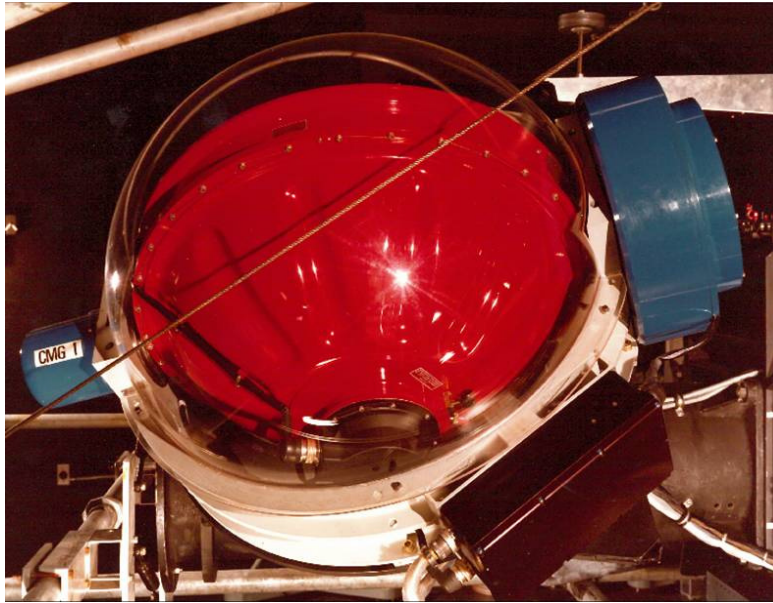
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- 1) Medium size gyro and gimbals
- 2) Rotor (Flywheel) is in the middle
- 3) Motor and position sensor are on opposite ends

LARGE (SPERRY) GYRO AND GIMBALS

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- 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



GN&C Lab Facility

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The following charts show some pictures of the Boeing CMG test facility (GN&C lab)

AIR PAD CONSTRUCTION

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- 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.

DOOR INTO “SPACE” (BLACK ROOM)

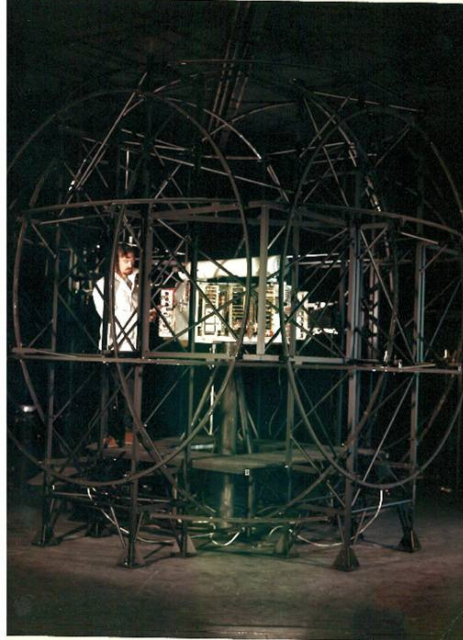
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- 1) Door into “space” - (black room) simulator
- 2) This black room could simulate most “space” conditions except for vacuum (air drag)
- 3) The chamber was EMI, Thermal, Optical and Acoustic shielded
- 4) Control console for air pad (left), air bearing (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 COILS

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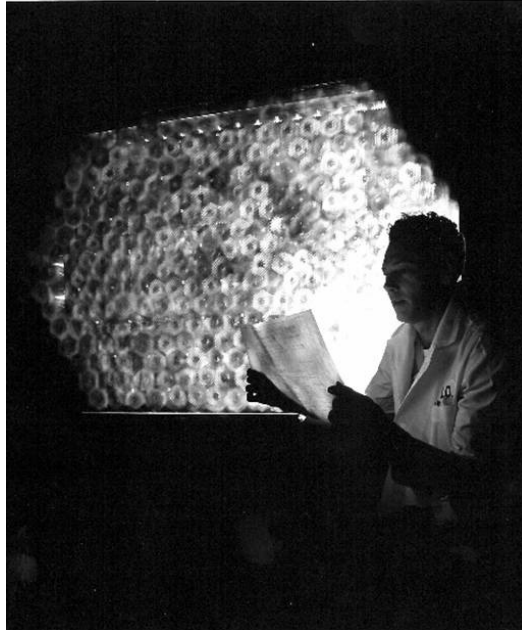
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3-D Helmholtz [six (6)] coils could be placed around test article to generate any required (simulated) EM fields.

SUN SIMULATOR

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- 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)

TEST CONTROL ROOM

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- 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



Test Article Sensors

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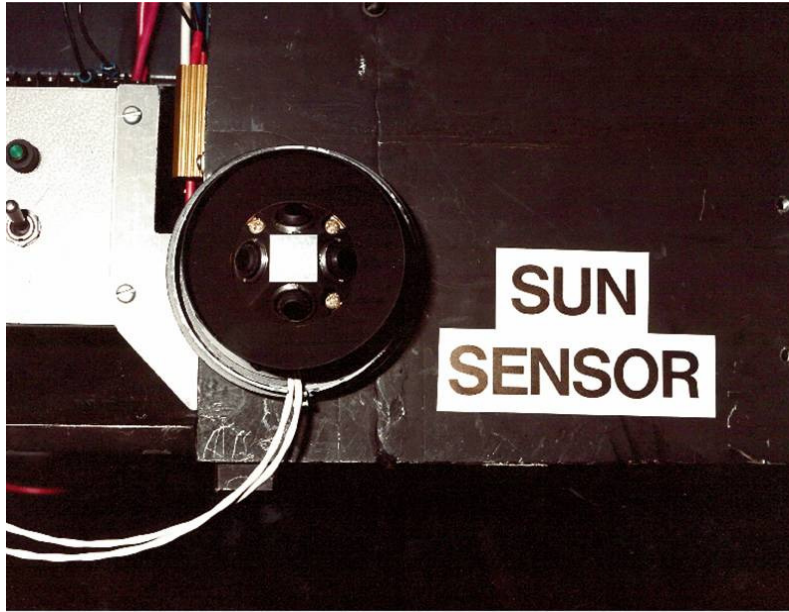
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The following charts show some of the sensors on the test article

TEST ARTICLE SUN SENSOR

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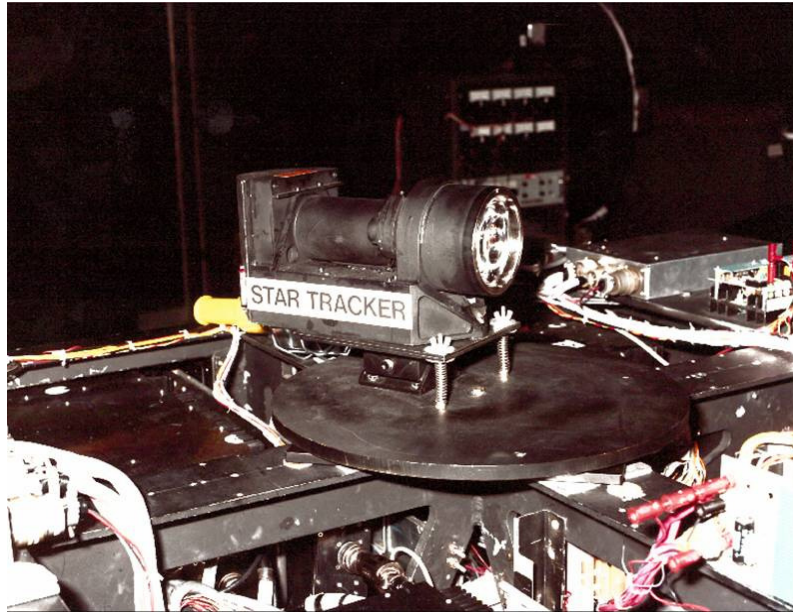
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- 1) Sun sensor on the test article that tracked the (simulated) sun's position
- 2) Light intensity and position was used for navigation and control

TEST ARTICLE STAR SENSOR

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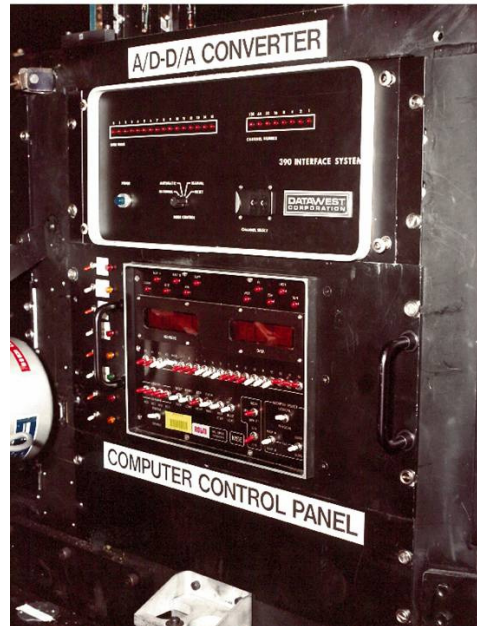
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- 1) Star sensor on the test article tracked (simulated) star patterns
- 2) Different star patterns were used for navigation and positioning

TEST ARTICLE DAQ COMPUTER

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- 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



CMG Test Articles

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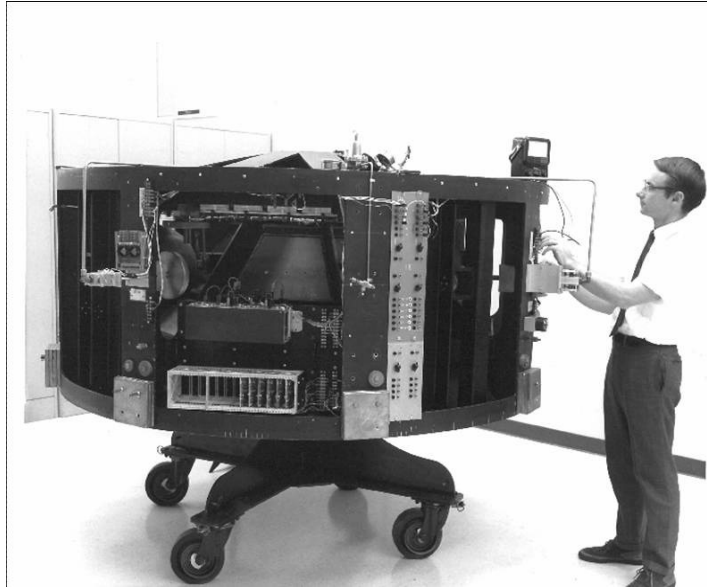
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The following charts show some of the different CMG test articles Boeing built

EARLY CMG TEST ARTICLE – FIRST TYPE

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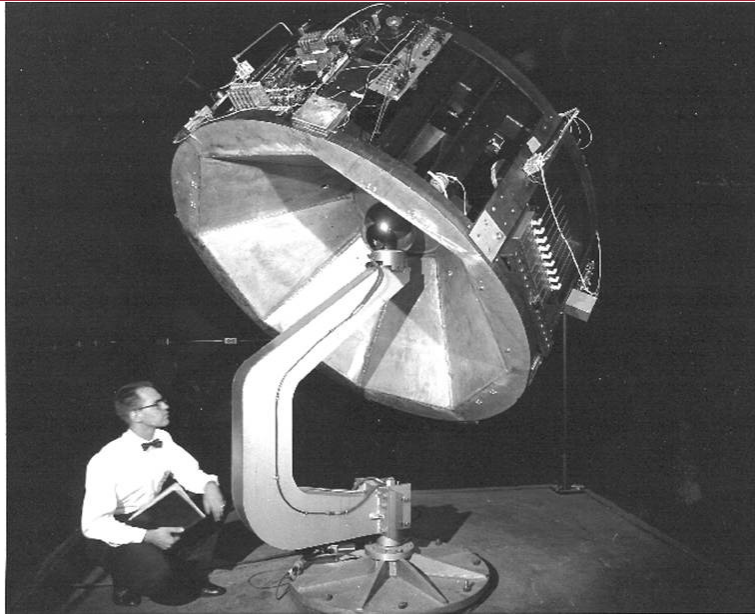
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- 1) Early CMG test article on a stand
- 2) This was a circular unit with small gyros
- 3) Note white shirt, narrow tie and (analog) VOM - mid 60s

SAME TEST ARTICLE ON AIR BEARING PAD

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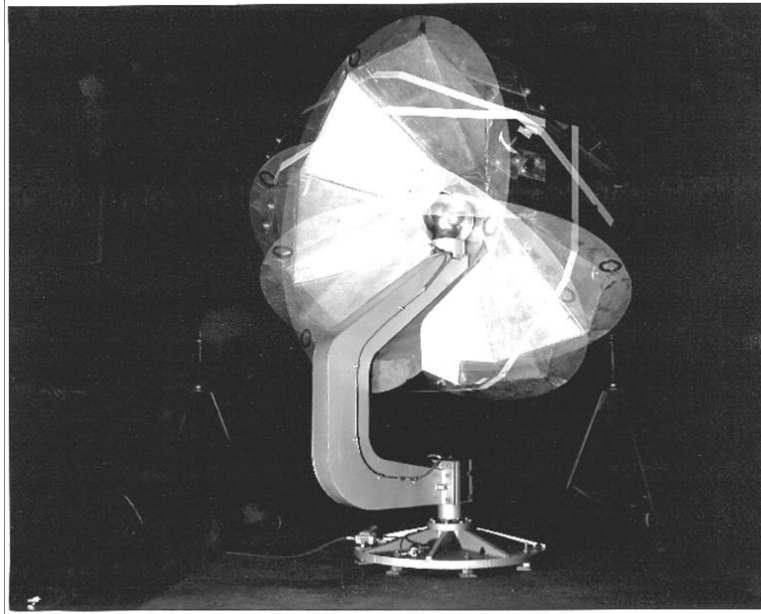
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- 1) Same test article on the air pad
- 2) Bowling ball size air bearing
- 3) Floated on high pressure N2 gas
- 4) and heavy duty support structure
- 5) Note white shirt and bow tie – mid 60s

TEST ARTICLE SHOWING RANGE OF MOTION

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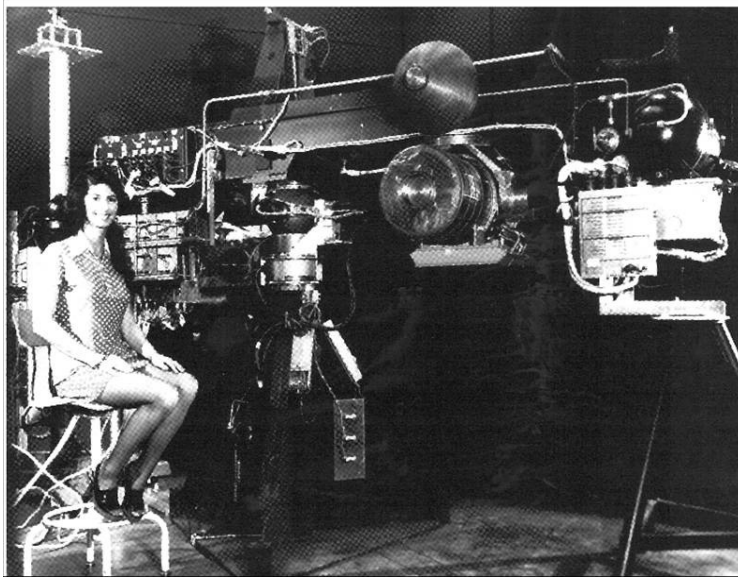
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- 1) Time laps picture of the test article showing its range of movement
- 2) Also the test stand could rotate (locked for picture)
- 3) All Movement was generated by it's gyros

EARLY CMG TEST ARTICLE – SECOND TYPE

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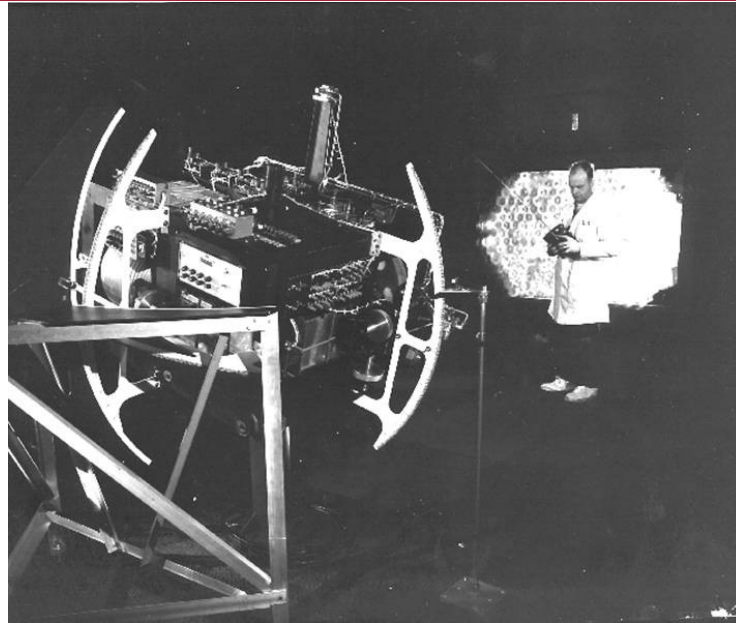
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- 1) Another early type test article
- 2) Heavy duty tripod stand supporting air bearing and test article
- 3) Gyros (right) were counter balanced by the DAQ system and battery packs (left)
- 4) Note mini skirt - late 60s

MEASURING TEST ARTICLE RANGE OF MOTION

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- 1) Test article's calibration and range of movement (degrees)
- 2) being measured with protractors and pointers
- 3) Note sun simulator in the background

MEDIUM GYRO TEST ARTICLE (right side)

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- 1) Right side view of medium gyro test article
- 2) showing four (4) gimbaled medium CMGs
- 3) Note hairdo - early 70s

MEDIUM GYRO TEST ARTICLE (left side)

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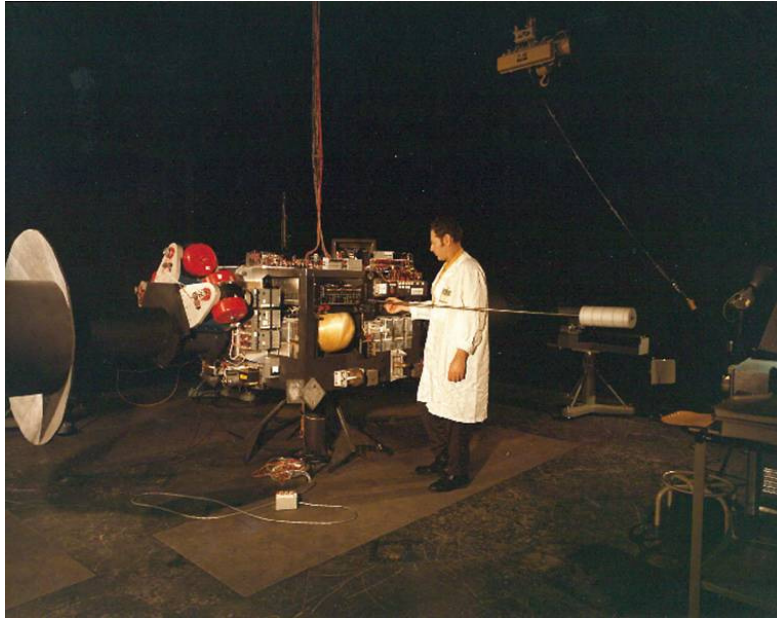
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- 1) Left side view of same medium gyro test article
- 2) Note colored shirt and lamb chops - early 70s

LATER VERSION OF MEDIUM GYRO TEST ARTICLE

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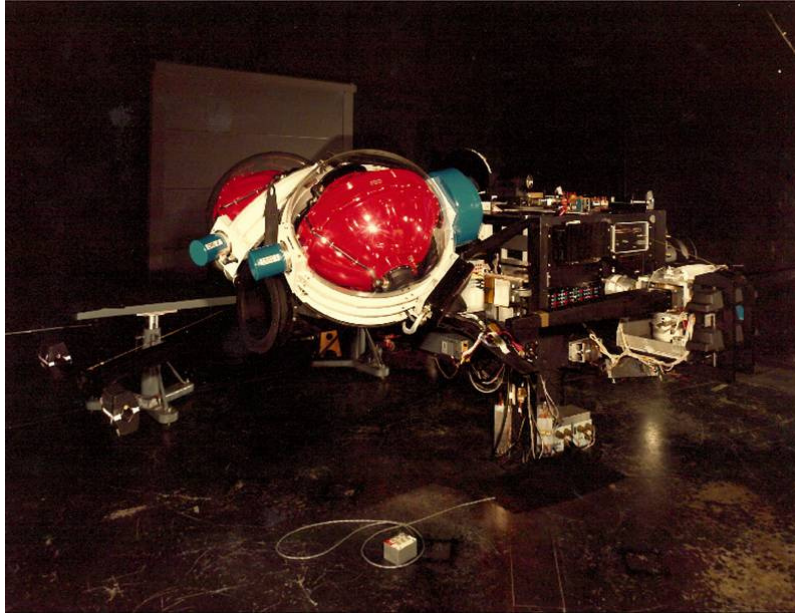
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- 1) Later version medium gyro test article
- 2) Showing dish antenna and counterweights
- 3) Note color picture - late 70s

LARGE GYRO TEST ARTICLE (front view)

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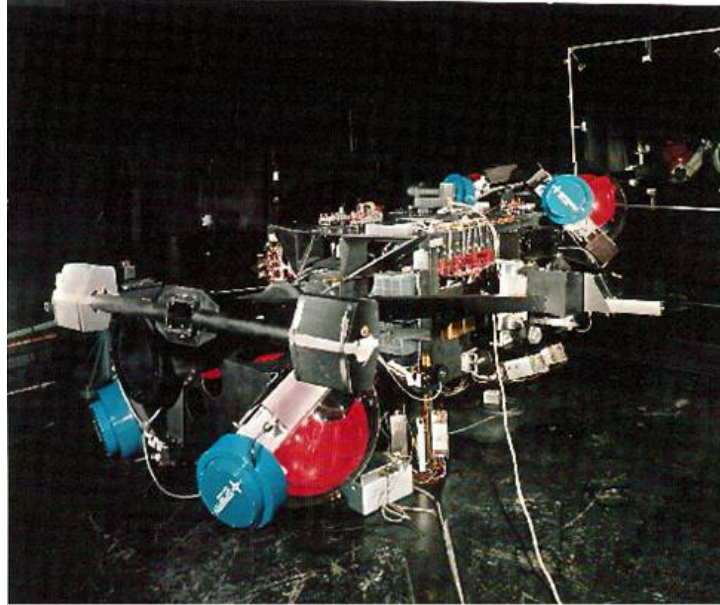
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- 1) Large gyro test article (front view) showing two of the four gyros (80s – 90s)
- 2) Looks like the head of an insect (nickname “old bug eyes”)
- 3) Note sun simulator in the background
- 4) This test article was in use when I came into the group in 1995

LARGE GYRO TEST ARTICLE (rear view)

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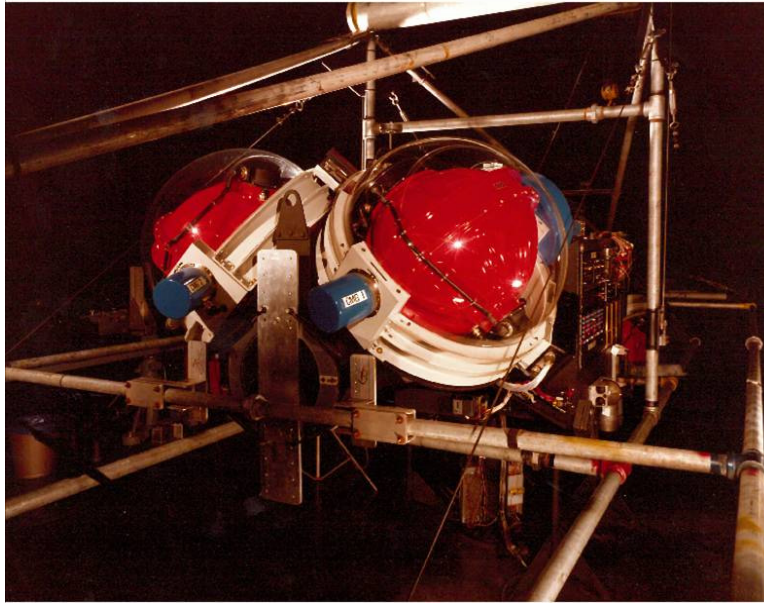
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- 1) Rear view of the same test article showing the other two gyros and counter weights
- 2) If you put a seat on top it would beat any mechanical bull in town
- 3) However, no one was allowed in the “space (black) room” when it was running
- 4) Note scratch marks on the air pad (floor), sometimes it got out of control (crashed)

BALANCE BEAM TEST ARTICLE (front view)

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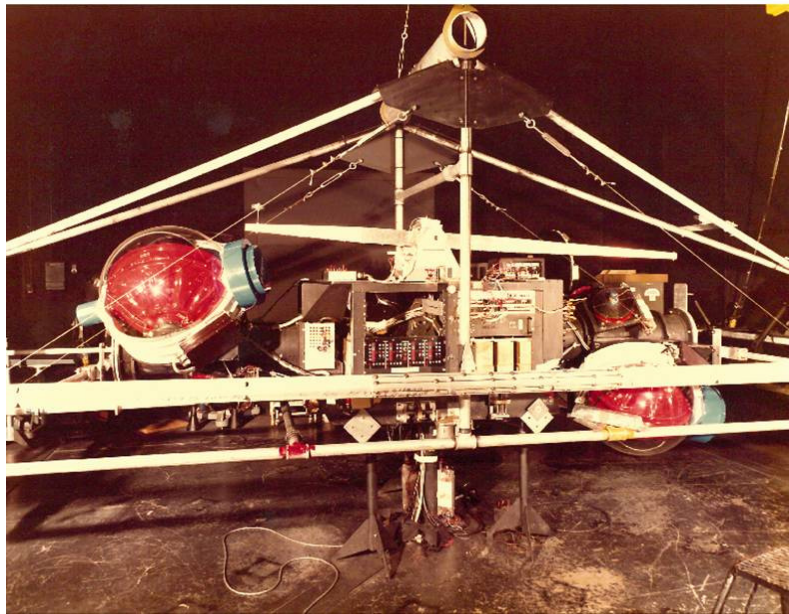
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Same test article (front view) with balance beam frame for making inertial measurements. Once a satellite achieved orbit it must maintain a stable reference platform.

BALANCE BEAM TEST ARTICLE (side view)

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- 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

THE END

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- 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

THANK YOU

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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.