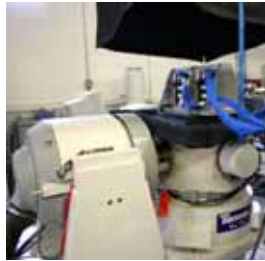


## Simultaneous Multiaxis Vibration Testing & Stress Screening

**Wayne Tustin**  
Equipment Reliability Institute  
Santa Barbara, California

Southern California Chapter  
Institute of Environmental Sciences  
January 9, 2008  
Anaheim, California



[www.equipment-reliability.com](http://www.equipment-reliability.com)

1

[tustin@equipment-reliability.com](mailto:tustin@equipment-reliability.com)

I hope I can get general agreement from this audience that "real world" vibrations are multiaxis.

Does everyone agree?

If not, let me remind you of a common multiaxis vertical, lateral and fore-and-aft experience .....

[www.equipment-reliability.com](http://www.equipment-reliability.com)

2

[tustin@equipment-reliability.com](mailto:tustin@equipment-reliability.com)

### Video Clip 20-6 Detroit Street



[www.equipment-reliability.com](http://www.equipment-reliability.com)

3

[tustin@equipment-reliability.com](mailto:tustin@equipment-reliability.com)

Some engineers have a need to strengthen the vehicle itself or some of its components or to make the passengers more comfortable. They need to measure the vehicle's

Vertical motion,

Lateral motion,

Fore-and-aft motion.

They could use three single-axis accelerometers or

[www.equipment-reliability.com](http://www.equipment-reliability.com)

4

[tustin@equipment-reliability.com](mailto:tustin@equipment-reliability.com)

### Figure 7-23 Triaxial Accelerometer

You know about this. Right?



courtesy Dytran

[www.equipment-reliability.com](http://www.equipment-reliability.com)

5

[tustin@equipment-reliability.com](mailto:tustin@equipment-reliability.com)

### Figure 7-23B Cable from triax accelerometer

You know about this. Right?



courtesy PCB

[www.equipment-reliability.com](http://www.equipment-reliability.com)

6

[tustin@equipment-reliability.com](mailto:tustin@equipment-reliability.com)

Figure 7-55 Torsional PE Accelerometer



Three can measure a vehicle's roll, pitch and yaw

courtesy Kistler

[www.equipment-reliability.com](http://www.equipment-reliability.com)

7

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

Why, then, knowing that the "real world" is multiaxis,

do test labs .....

shake hardware first in the hardware's X direction,

and then in the hardware's Y direction,

and finally in the hardware's Z axis?

Three tests, possibly three fixtures, much handling?

Specs and standards are usually way behind ....

[www.equipment-reliability.com](http://www.equipment-reliability.com)

8

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

*Military Standard 810* and subsequent revisions appeared.

- 810 14 June 1962
- 810A 23 June 1964
- 810B 15 June 1967
- 810C 10 March 1975
- 810D 19 July 1983
- 810E 14 July 1989
- 810F 1 January 2000

By late 2004, 810F had been downloaded 528,000+ times

810G is predicted for May, 2008.

[www.equipment-reliability.com](http://www.equipment-reliability.com)

9

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

I'm particularly interested in 810's *vibration* history.

The world of vibration testing commenced with mechanical shakers.

They were OK for short stroke, one-frequency-at-a-time, nominally sinusoidal shaking, up to 50 or perhaps 60 Hz.

Early vibration test standards, *circa* 1950, were written around those shakers and what they could do. 3 tests: specimen X, then specimen Y, then specimen Z axis.

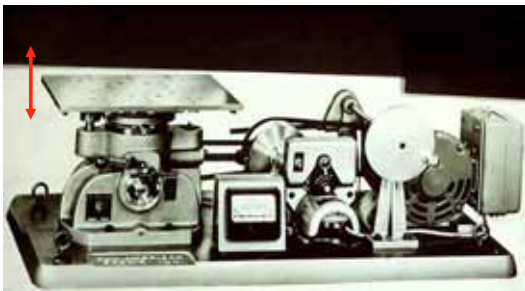
This single-axis-at-a-time idea, unfortunately, is still with us. It does **not** represent the "real world".

[www.equipment-reliability.com](http://www.equipment-reliability.com)

10

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

Figure 12-4 Direct-drive Mechanical Shaker



courtesy All-American

[www.equipment-reliability.com](http://www.equipment-reliability.com)

11

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

But mid-century field failures forced investigators to instrument air, land and sea vehicles.

Simulating some field conditions required longer strokes, and most required random vibration, leading to electrohydraulic (servohydraulic) shaker development.

[www.equipment-reliability.com](http://www.equipment-reliability.com)

12

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

Figure 14-16 "Four Poster" Shaking

Multiple shakers, but still single axis, vertical.



[www.equipment-reliability.com](http://www.equipment-reliability.com)

13

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

"Everyone knew" that road inputs to land vehicles were not 1-axis-at-a-time. Inputs were

- » Vertical
- » Fore-and-aft,
- » Lateral
- » Roll
- » Pitch and
- » Yaw,

occurring simultaneously.

You know this. Right?

[www.equipment-reliability.com](http://www.equipment-reliability.com)

14

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

Video Clip 14-6 Multi-axis shaking



courtesy Renault and MTS

[www.equipment-reliability.com](http://www.equipment-reliability.com)

15

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

Nonetheless, most test specifications and standards, including MIL-STD-810's current F revision, have called for single-axis-at-a-time shaking.

[www.equipment-reliability.com](http://www.equipment-reliability.com)

16

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

Meantime, simulating other inputs to hardware on land and sea (and especially flight) vehicles required higher frequencies, commonly 2,000 Hz, necessitating today's electrodynamic (ED) shakers.

Here a **single-axis** ED shaker is being assembled.

[www.equipment-reliability.com](http://www.equipment-reliability.com)

17

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

Figure 15-11 ED Shaker Assembly



[www.equipment-reliability.com](http://www.equipment-reliability.com)

18

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

Shaker armatures look very stiff.

And they are stiff, but only at relatively low test frequencies, up to perhaps 1000 Hz.

Some suspicious test engineers have investigated shaker armature behavior.

Figure 15-9A Instrumenting a Shaker Armature

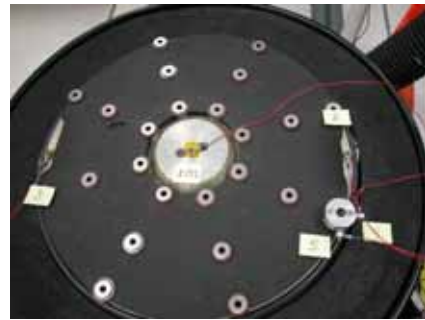


Figure 15-8 Wanted And Unwanted Shaker Motions

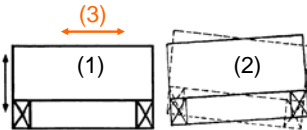
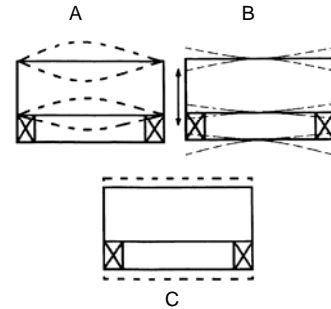


Figure 15-9 More Unwanted Shaker Motions



Difficulties are exacerbated by head expanders and slip plates.

Figure 27-5 Head Expander for Greater Area

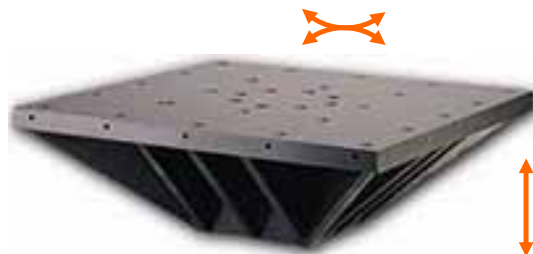


Figure 15-13 Shaker drives Slip Plate



courtesy LDS

www.equipment-reliability.com

25

justin@equipment-reliability.com

You know all this. Right?

When is Wayne going to tell me something I don't already know?

Well, maybe you don't already know that .....

www.equipment-reliability.com

26

justin@equipment-reliability.com

Occasionally, subassembly failures on US Army land vehicles could not be duplicated on existing shakers at any frequency or any force level.

Investigators questioned single-axis-at-a-time lab shaking.

Fortunately, the lab was funded to try *simultaneous* multiaxis testing, which they found was far more effective.

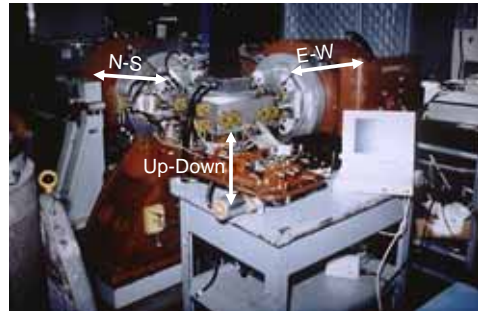
And faster.

www.equipment-reliability.com

27

justin@equipment-reliability.com

Figure 16-8 Three-shaker 3DoF realization



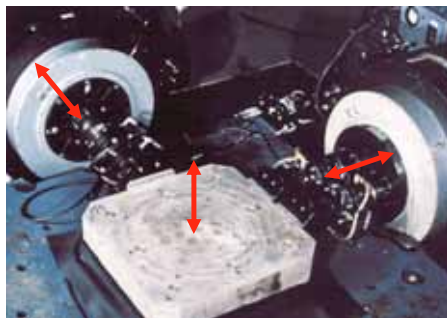
courtesy Army Research Lab, Adelphi, MD

www.equipment-reliability.com

28

justin@equipment-reliability.com

Figure 16-8A Three-shaker 3DoF realization



courtesy Team Corporation and White Sands Proving Ground

www.equipment-reliability.com

29

justin@equipment-reliability.com

Figure 16-8D Three-shaker Navy 3DoF realization



Courtesy US Navy Keyport

www.equipment-reliability.com

30

justin@equipment-reliability.com

Figure 16-8E Three-shaker Navy 3DoF realization



Courtesy NUWC Keyport and Baughn Engineering

[www.equipment-reliability.com](http://www.equipment-reliability.com)

31

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

Figure 16-9 Three-shaker 3DoF concept



courtesy NUWC Keyport

[www.equipment-reliability.com](http://www.equipment-reliability.com)

32

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

Figure 16-10 USAF Multi-Axis Test Equipment



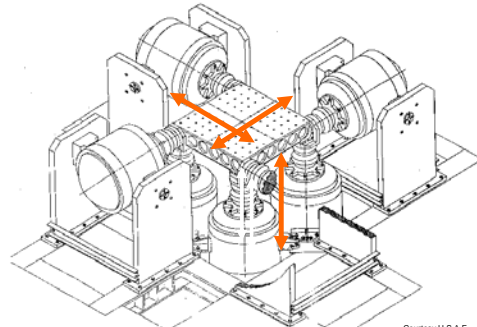
Courtesy U.S.A.F.

[www.equipment-reliability.com](http://www.equipment-reliability.com)

33

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

Figure 16-11 USAF Multi-Axis Test Equipment



Courtesy U.S.A.F.

[www.equipment-reliability.com](http://www.equipment-reliability.com)

34

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

MIL-STD-810G finally recognizes,

as did these few generously funded US military installations

and the Japanese automobile industry,

that laboratory shaking should be *simultaneous* (not sequential) multiaxis.

[www.equipment-reliability.com](http://www.equipment-reliability.com)

35

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

But what about *suppliers* to the military?

And what about automotive and other commercial shaking?

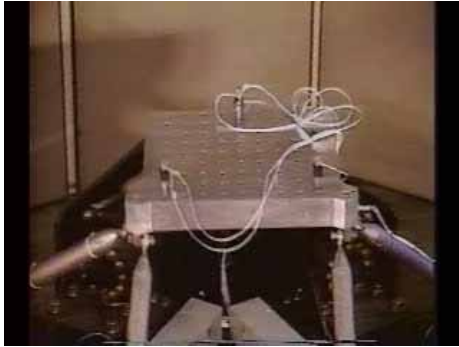
Instead of at-the-site assembling 3 shakers on a foundation, might 3-shaker arrays be factory assembled at lesser cost?

[www.equipment-reliability.com](http://www.equipment-reliability.com)

36

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

Video Clip 16-2 Six-Axis ANCO ED Shaker

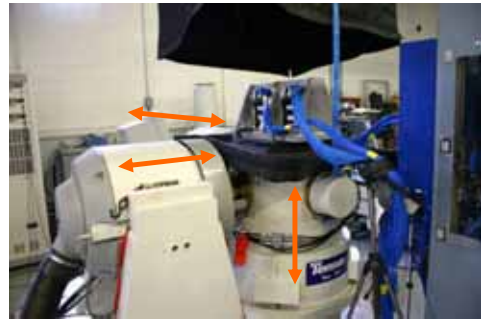


[www.equipment-reliability.com](http://www.equipment-reliability.com)

37

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

Figure 16-11A Tri-axial automotive electronics shaking



courtesy IMV, Viateon and Spectrum Technologies.

[www.equipment-reliability.com](http://www.equipment-reliability.com)

38

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

Video clip 16-2A Random vibration



courtesy Spectrum Technologies

[www.equipment-reliability.com](http://www.equipment-reliability.com)

39

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

Video Clip 16-2B Sine vibration



courtesy Spectrum Technologies

[www.equipment-reliability.com](http://www.equipment-reliability.com)

40

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

Most long-stroke simultaneous seismic simulation uses EH shakers.

However, long-stroke ED shakers are preferred by some seismic test labs.

[www.equipment-reliability.com](http://www.equipment-reliability.com)

41

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

Video Clip 16-4 X, Y and Z Motion



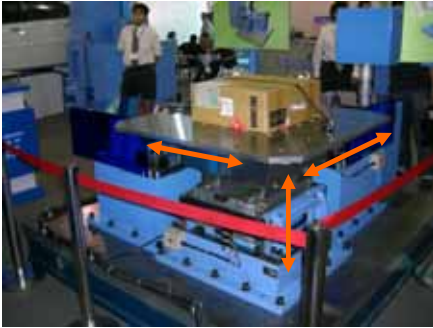
courtesy IMV

[www.equipment-reliability.com](http://www.equipment-reliability.com)

42

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

Figure 12-15A Three mechanical axes?



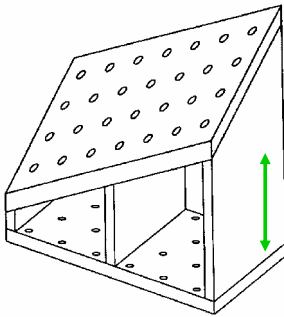
courtesy Kokusai Katsokuki

So ---- what will MIL-STD-810G say about simultaneous multiaxis shaking?

We'll have a new Multiexciter Test Method 527, presently 22 pages long.

I'm confident it will NOT call for .....

Figure 16-14 "Tilted" Fixture does not Multi-axis Test



One (fortunately rare) lab attaches customer DUTs to a single-axis shaker via a "tilted" fixture.

**To me, the vibration is still single-axis,** even though there is a component of that vibration is each of the DUT's axes.

Figure 25-15A "Tilt" (not Multi-Axis) Fixture



courtesy Hong Liu

Thanks for listening to me talk about my favorite subject.

Most of the figures I've just used are in my 2005 text, soon to be used at Santa Barbara, Huntsville, College Park, Toronto and in Europe. Video clips are on a CD inside the back cover.



A message from ERI's Webmaster:

If any of Wayne's fellow IEST members wants to access the January 9 presentation from his/her home or office, it will be available on line in about two weeks.

Go where?



## Simultaneous Multiaxis Vibration Testing & Stress Screening

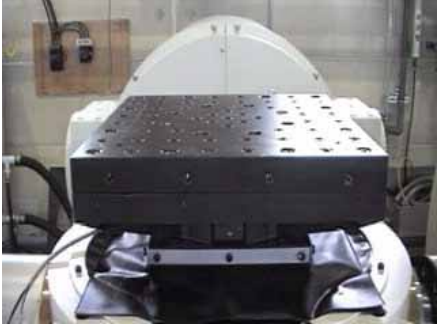
**Wayne Tustin**  
Equipment Reliability Institute  
Santa Barbara, California

Southern California Chapter  
Institute of Environmental Sciences  
January 9, 2008  
Anaheim, California



[www.equipment-reliability.com](http://www.equipment-reliability.com) 51 [tustin@equipment-reliability.com](mailto:tustin@equipment-reliability.com)

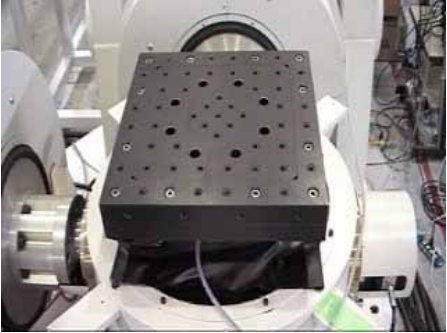
## Extra Videos



courtesy IMV

[www.equipment-reliability.com](http://www.equipment-reliability.com) 52 [tustin@equipment-reliability.com](mailto:tustin@equipment-reliability.com)

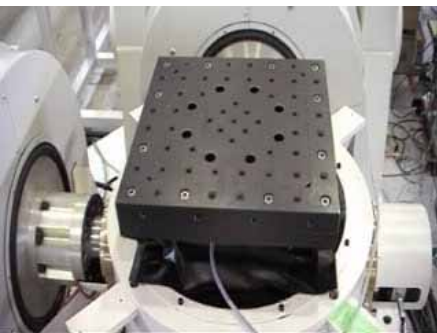
## Extra Videos



courtesy IMV

[www.equipment-reliability.com](http://www.equipment-reliability.com) 53 [tustin@equipment-reliability.com](mailto:tustin@equipment-reliability.com)

## Extra Videos



courtesy IMV

[www.equipment-reliability.com](http://www.equipment-reliability.com) 54 [tustin@equipment-reliability.com](mailto:tustin@equipment-reliability.com)

Extra Images



courtesy IMV

[www.equipment-reliability.com](http://www.equipment-reliability.com)

55

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

Extra Images



courtesy IMV

[www.equipment-reliability.com](http://www.equipment-reliability.com)

56

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

Extra Images



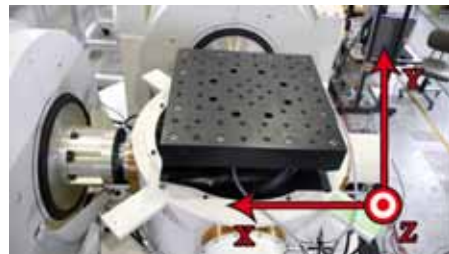
courtesy IMV

[www.equipment-reliability.com](http://www.equipment-reliability.com)

57

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

Extra Images



courtesy IMV

[www.equipment-reliability.com](http://www.equipment-reliability.com)

58

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)

Extra Images



courtesy Shinken

[www.equipment-reliability.com](http://www.equipment-reliability.com)

59

[justin@equipment-reliability.com](mailto:justin@equipment-reliability.com)