Atmospheric Science

-*Measurements and Then Some*

E80
Fall 2011

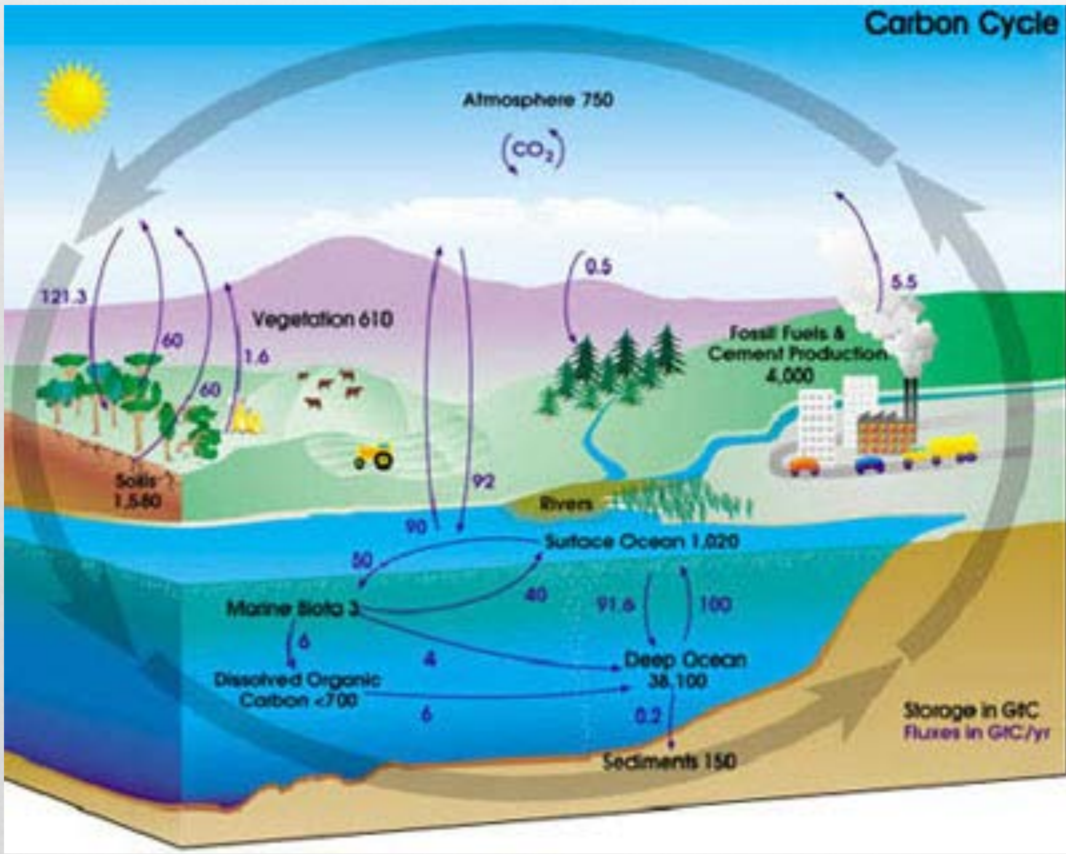
Lord Kelvin (1824–1907)

- "I often say that ***when you measure*** what you are speaking about and express it in numbers, ***you know something*** about it, but ***when you cannot measure it***, when you cannot express it in numbers, then ***your knowledge is*** of a ***meager*** and unsatisfactorily kind; it may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the stage of science, whatever the matter may be."

Atmospheric Measurements

- One of the most important functions of meteorological satellites is the measurement of the temperature and humidity of the global atmosphere on an operational basis.
- Over the past decade, satellite data have become increasingly important as a data source for Numerical Weather Prediction (NWP) models.
- Alternative measurements, such as those from meteorological balloons, cannot provide this global coverage as they are generally concentrated in the more developed parts of the world and are almost non-existent over oceans.

Carbon Cycle



Carbon is the 4th most abundant element, and is essential for life on earth. Every organism needs carbon for structure and/or energy – and we need it for both. The movement of carbon between the atmosphere, oceans, biosphere and geosphere is shown in Figure 1. The cycle consists of several storage pools of carbon and the processes by which carbon in exchanged.

Figure 1: A cartoon of the global carbon cycle.
Pools (in black) are gigatons ($1Gt = 1x10^9$ Tons) of carbon, and fluxes (in purple) are Gt carbon per year. Illustration courtesy NASA Earth Science Enterprise.

Relevant Measurements

- **Atmospheric Measurements of Co-variation Carbonyl Sulfide and Carbon Dioxide Provide Information on Carbon Cycle Processes** **Berry, J. A.; Campbell, J. E.; Montzka, S. A.; Kawa, S. R.; Baker, I.; Denning, A. S.; Wolf, A.** ***American Geophysical Union, Spring Meeting 2009, abstract #B13C-06***

- ***Carbonly sulfide (OCS), an analog of carbon dioxide, is emerging as a useful atmospheric tracer of the terrestrial carbon cycle. Previous studies have shown that OCS is taken up by leaves and soils. The principle source of OCS to the atmosphere is oxidation of sulfur compounds produced in the oceans. Over the continents there is strong depletion of OCS in the atmospheric boundary layer during the growing season.***

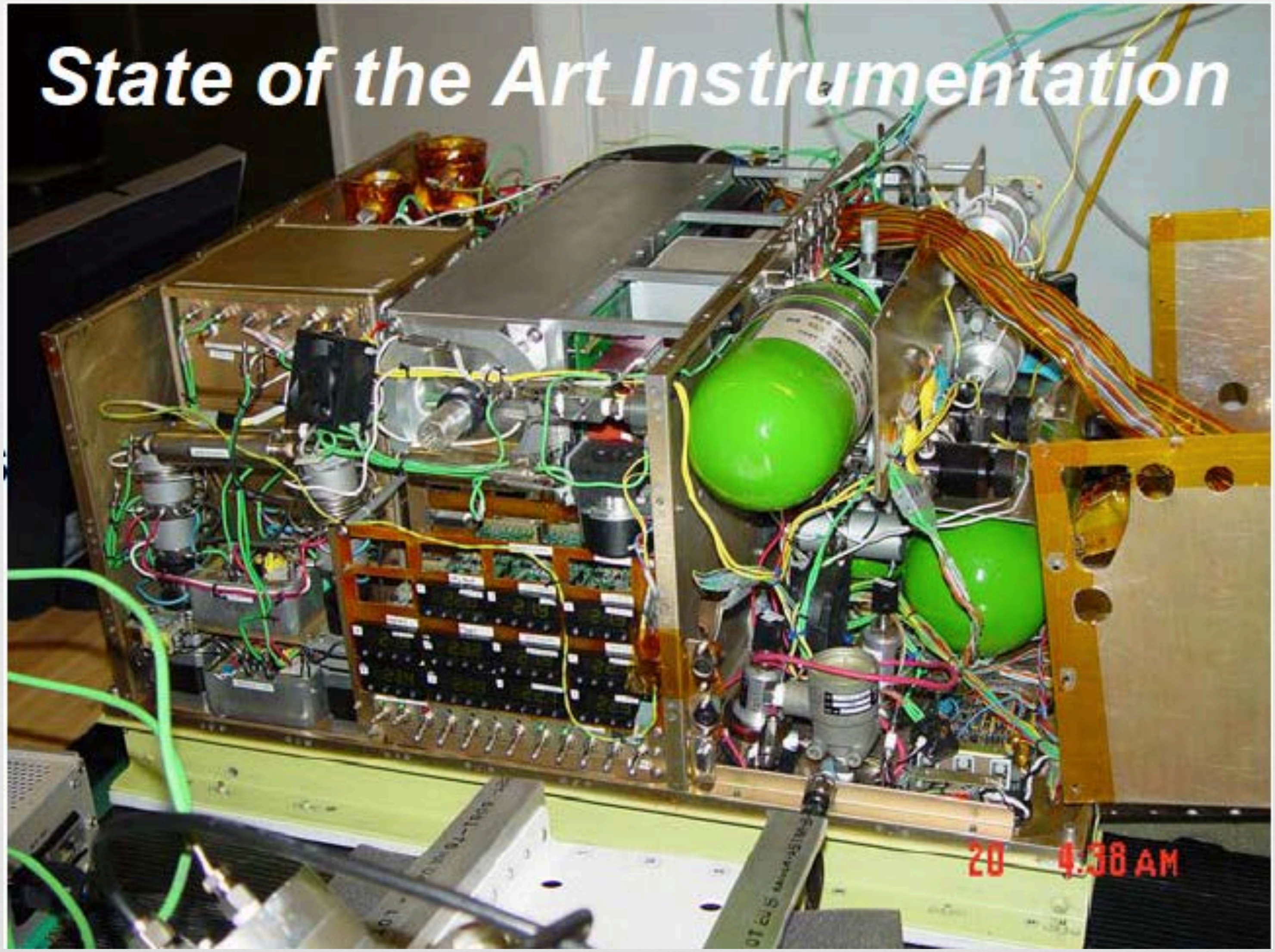
Aerosols in the Atmosphere

- *Suspended particles in the air create aerosols that are important to the behavior of whole atmosphere and play a role in determining human disease.* Natural sources of atmospheric particles are volcanoes, dust storms, spontaneous forest fires, tornadoes and hurricanes. Clouds are a product of aerosols that seed the formation of water droplets. *Human air pollution now dominates aerosol production over cities with negative health effects.* Thick aerosols are obvious as haze and contain a complex system of particles with adherent toxic gases such as sulfur dioxide.

Greenhouse Gases

- The first-ever, global, real-time sampling of carbon dioxide and other greenhouse gasses across a wide range of altitudes in the atmosphere, literally from pole-to-pole occurred in 2008. Previous measurements of global atmospheric greenhouse gasses had been acquired from distant satellites, balloon launches.
- HIAPER's pole-to-pole mission gave scientists real-time global observation data to verify climate models with.
- *HIAPER is short for the National Science Foundation's High-performance Instrumented Airborne Platform for Environmental Research.*

Complicated…



National Centre for Atmospheric Science

- The National Centre for Atmospheric Science (NCAS) is a world leader in atmospheric science that conducts research on
  - *The science of climate change, including modeling and predictions*
  - *Atmospheric composition, including air quality*
  - *Weather, including hazardous weather*
  - *Technologies for observing and modeling the atmosphere*

Facility for Ground based Atmospheric Measurements
NATURAL ENVIRONMENT RESEARCH COUNCIL

NCAS conference 2010

The Facility for Ground based Atmospheric Measurements: highlights and activities

Jim Hopkins, University of York
representing FGAM

www.ncas.ac.uk/fgam/

FGAM provides observations of atmospheric processes within the National Centre for Atmospheric Science (NCAS)

It comprises four inter-linked areas:

- Atmospheric observatories
- Laboratory studies
- Ground-based / Field observations
- Airborne observations

Facility for Airborne Atmospheric Measurements

- Objective - to gather the data required by the UK 's meteorology and atmospheric science communities - continuously improving understanding of weather, global warming, pollution and climatology.

FGAM instruments are operated aboard the FAAM 146 and other aircraft to measure aerosol size and composition, cloud and ice microphysics and a range of trace gases and free radicals

Ground-based and airborne instruments have common methodologies - an effective use of expertise.

Close working links with FAAM, ARSF and international scientific aircraft operators (established during collaborative projects)

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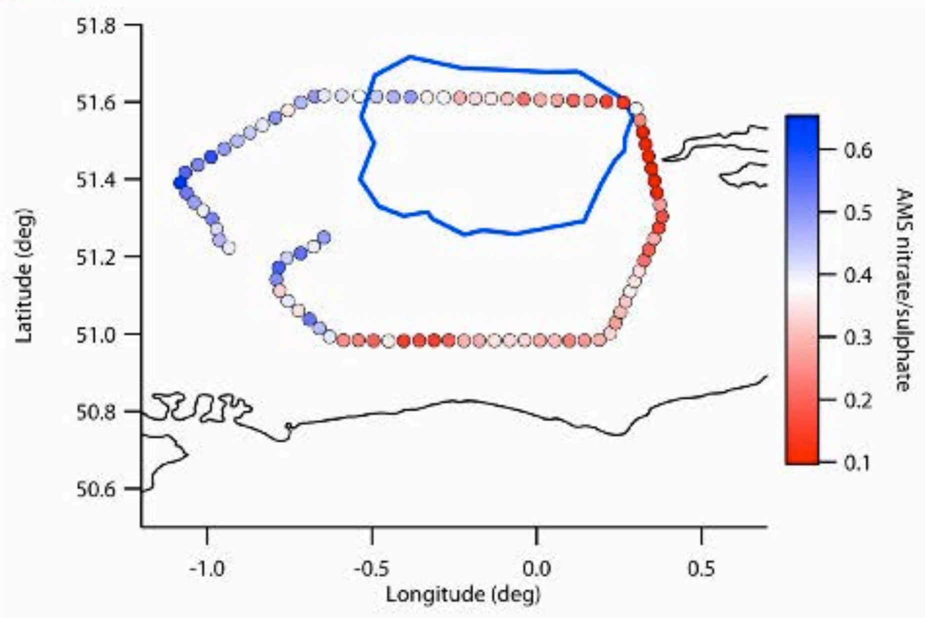
Airborne observations - M25 flights – nitrate aerosols



Around London (M25) flights to investigate emissions from London

Data collected from the FGAM-AMS during an easterly flow across London

The ratio of nitrate to sulphate is clearly observed to increase downwind indicating that London is a major source of nitrate aerosol, compared to the background sulphate.

Understanding the sources and origins of nitrate aerosols is important as it is poorly accounted for in global climate models.

The flights were led by Jim Haywood, UK Met office and Gavin McMeeking, University of Manchester

Instrument operation, characterisation and maintenance performed by FGAM

Gas Emissions

Facility for Ground based Atmospheric Measurements
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Airborne observations - CalNex 2010

CalNex 2010

Aim: To determine greenhouse gas emissions and maintain an accurate inventory using both models and measurements

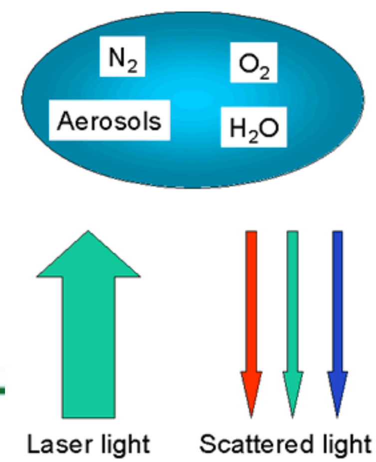
Collaboration with Prof Mike Hardesty (NOAA), Dr Guy Pearson (Halo-Photonics), Dr Christoph Senff (NOAA), Dr Alan Brewer (NOAA) and Dr Raul Alvarez (NOAA)

Initial proof of concept study – Boulder 2009

FGAM Halo lidar installed alongside the TOPAZ Ozone lidar, sharing same aperture.

Test robustness of lidar in the high vibration NOAA Twin Otter

Concurrent ozone and doppler lidar measurements to determine ozone flux



www.ncas.ac.uk/fgam/

Rocket Instrumentation

- Rockets are instrumented for a variety reasons having to do with
  - *Design and performance verification*
  - *Feedback Control and Operations*
  - *Numerical model validation*
  - *Development of Payload design specifications*
- ***To properly instrument a rocket (any system) you need to understand the (dynamic) loading environment.***

Dynamic Environments

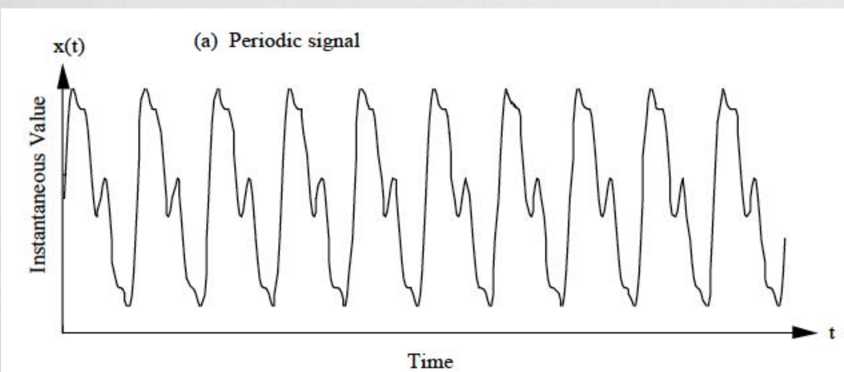
- ***Dynamic environments*** include all phenomena that ***produce fluctuating excitations*** (also called forcing functions or dynamic loads) that act on a launch vehicle or spacecraft and its constituent components.
- The ***excitations may occur physically*** as either an ***applied force or an input motion***, and may be either internally or externally induced.

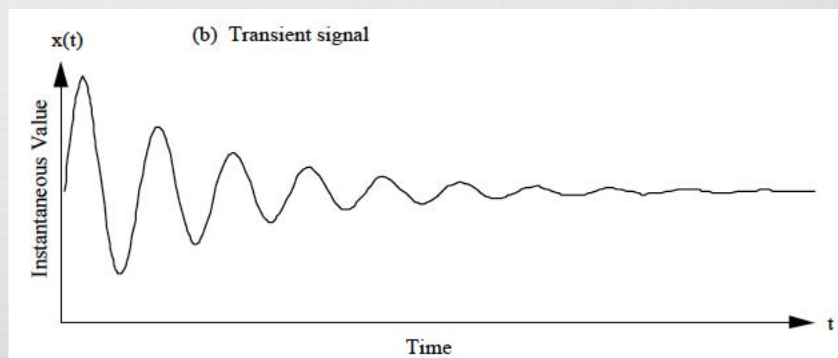
Excitations

- Examples of internally induced excitations include, (a) imbalance of rotating parts, (b) operation of mechanisms, (c) coupling misalignment in the assembly of hardware, (d) magnetic, aero- or hydrodynamic forces within the unit, (e) sloshing of liquid propellants in tanks, and (f) torque variations due to an uneven supply or demand of power.
- They also are usually classified as being ***stationary, nonstationary, or transient in character.***

Deterministic Environments

- A *deterministic* dynamic environment is one that produces an excitation with the *same time history each time the environment occurs*. They are generally produced by relatively well understood and well-characterized physical processes.





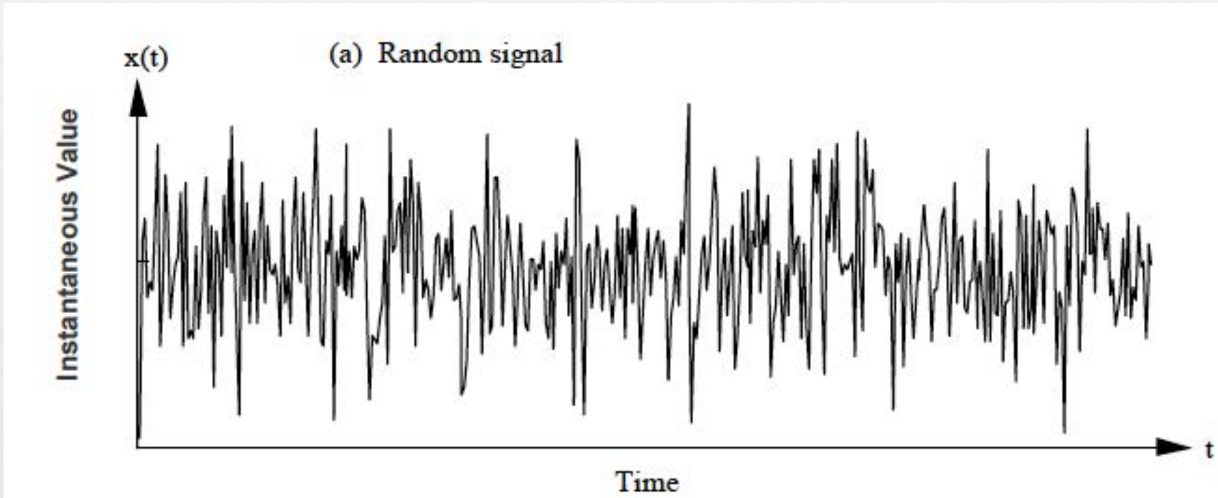
Random Environments

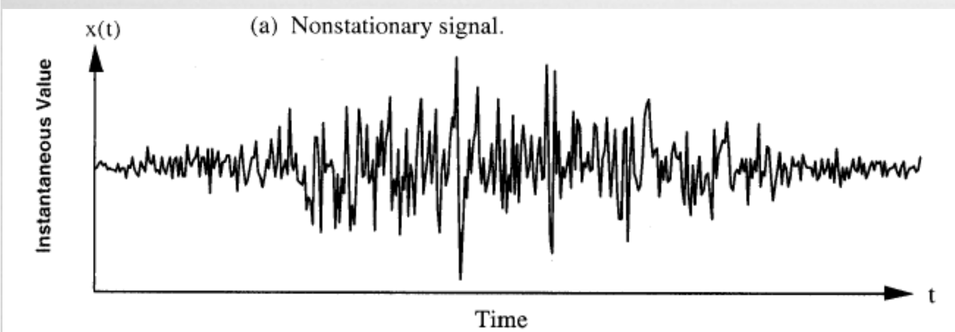
- A ***random*** dynamic environment is one where the ***average properties*** of the time history signal characterizing the environment (e.g., the mean and standard deviation) might be the ***same each time*** the environment occurs, ***but the exact time history signal is not the same*** and, hence, the exact value of the signal at a specific time t cannot be predicted in advance based upon a previous measurement of the environment.

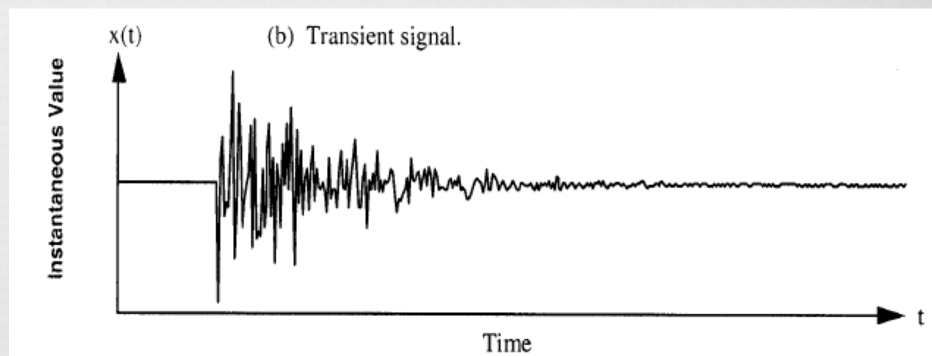
Time (In) Variance

- A random dynamic environment is said to be either ***"time-invariant" or "time-varying,"*** depending on whether the average properties of all time history signals representing the environment ***do*** or ***do not vary*** with time, ***at least over the time interval of interest.*** Time-invariant random signals are usually referred to as "stationary" signals. When one or more of the average properties of the random signal representing the environment varies with time, the environment is said to be time varying.

Random and Transient Signals

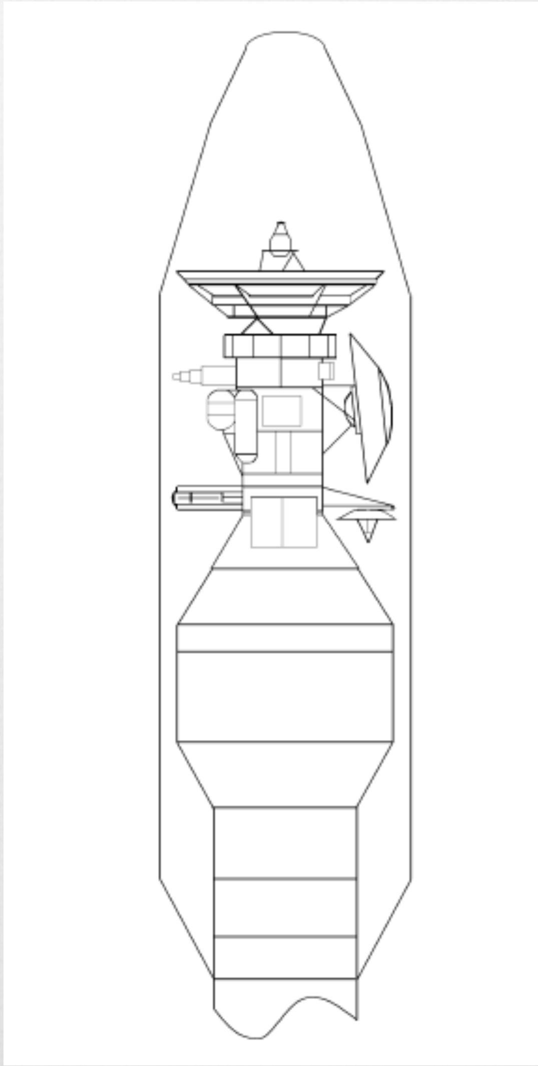




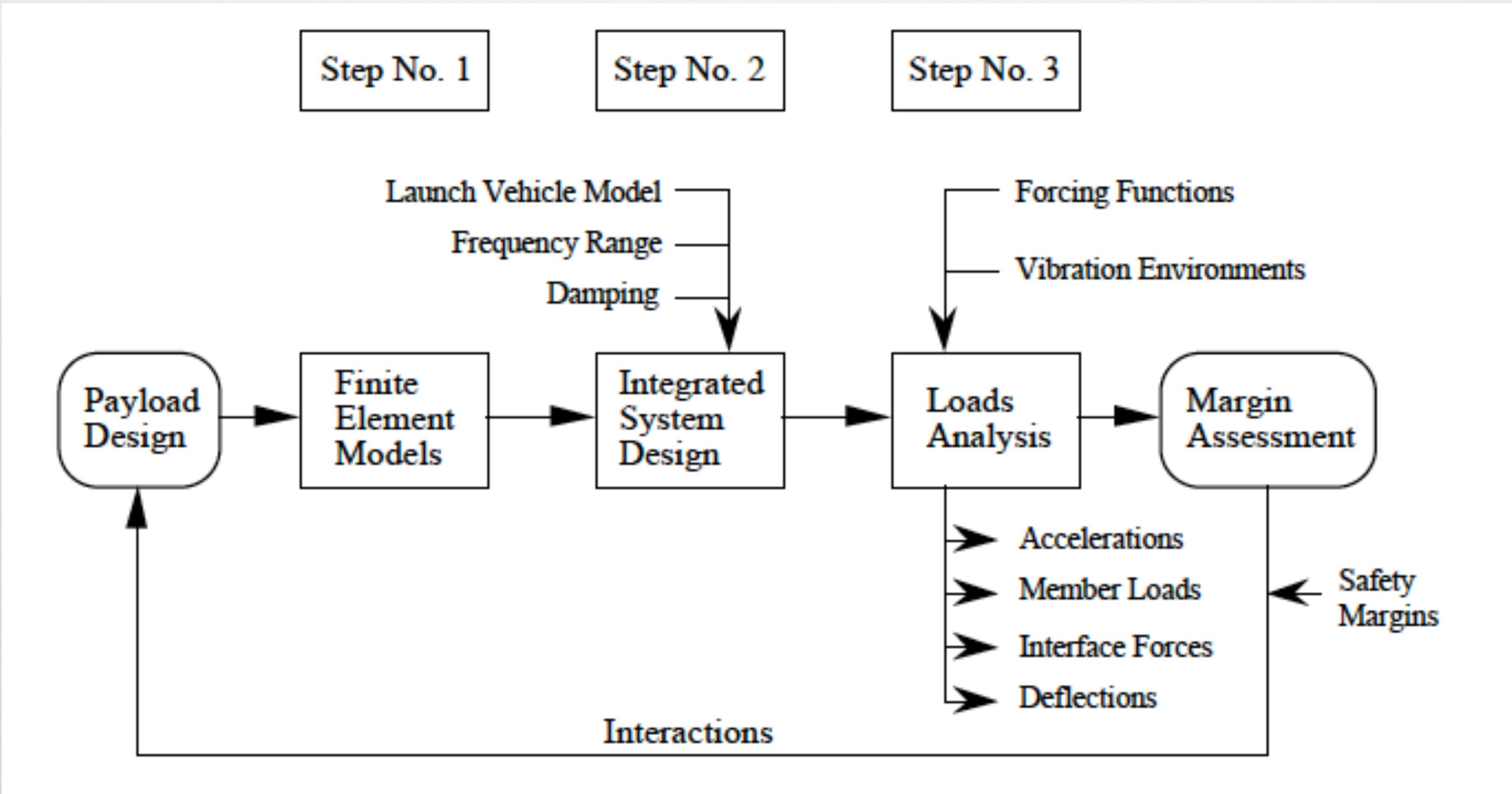


Why these signals matter

- Payload must withstand acoustic loads inside the fairing.
- Payload designers must be able to count of some degree of certainty when estimating maximum loads.
- Launch vehicle performance equates to dollars.
  - Cost to lift one pound into orbit - $10k
  - SpaceX (others) - $4k, and could drop to $.5k



Analysis Flow



Events and Loads

Event	Source of Dynamic Load	Basic Characteristics of Dynamic Load	Details (Section)
Pre-Flight	Transportation**	Various	3.1
	Seismic loads**	Low frequency mechanical transient	3.2
	Wind on launch pad	Low frequency fluctuating pressure	3.3
Liftoff	Motor ignition overpressure*	Low frequency pressure transient	3.4
	Liftoff release*	Low frequency mechanical transient	3.5
	Engine/motor acoustic noise*	Broadband random acoustic pressure	3.6
Ascent	Wind during ascent	Low freq. random fluctuating pressure	3.3
	Structureborne noise	Broadband random mechanical vibration	3.7
	Aerodynamic noise (including vent noise)*	Broadband random fluctuating pressure and possible periodic pressure	3.8
	Engine/motor thrust transients	Low frequency mechanical transient	3.9
	Thrust vector loads	Low frequency mechanical transient	3.10
	Pogo**	Low freq. periodic mechanical vibration	3.11
	Motor resonant burning**	Mid freq. periodic mechanical vibration	3.12
	Fuel slosh in tanks	Low freq. random fluctuating pressure	3.13
Staging	Stage and fairing separations*	Low frequency mechanical transient	3.14
	Pyrotechnic events*	High frequency mechanical transient	3.15
Free-flight	In-flight operations	Low frequency mechanical transients	3.16
	Onboard equip. operations	Various	3.17
	Meteoroid impacts**	High frequency mechanical transients	3.20
Entry	Wind during entry	Low freq. random fluctuating pressure	3.3
	Aerodynamic noise	Broadband random fluctuating pressure	3.8
	Planetary descent and entry**	Broadband random fluctuating pressure	3.18
	Soil penetration**	Low frequency mechanical transient	3.19

* Usually the dominant excitations for a normal flight.

** Could be the dominant excitations if they occur.

Picking Your Sensors

- Think about the various events you want to monitor during flight and the analyses that you will need to do in order to extract meaningful information.
- The sensor packages you assemble will likely provide "low" frequency data, allowing you to focus on trends and some oscillatory response.
- Think about the time response of your sensors. Will the sensor(s) package actually measure what you want within your flight time?
- Think about how to protect and ensure your data are sampled for accurate reconstruction.