CubeSats- *Some Observations From an Industry Perspective*

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A Little Background… Who We Are and What We Do

- Boeing Integrated Defense Systems (IDS)

Advanced Network and Space Systems

- **Produce Military Systems and Networking Technology**
  - World's largest designer and manufacturer of military aircraft
  - Provide services and support to governments worldwide
- **Provide Satellites and Launch Vehicles**
  - World's largest provider of commercial and military satellites; leading rocket manufacturer; NASA's largest contractor

- **Integrate Large-Scale Systems**
- **Develop Network-Centric Solutions**
- **Developing Advanced Technology that is Defining the Future of Aerospace**

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Industry and Academia Have Some Significant Differences

- Uses of CubeSats Seen Differently

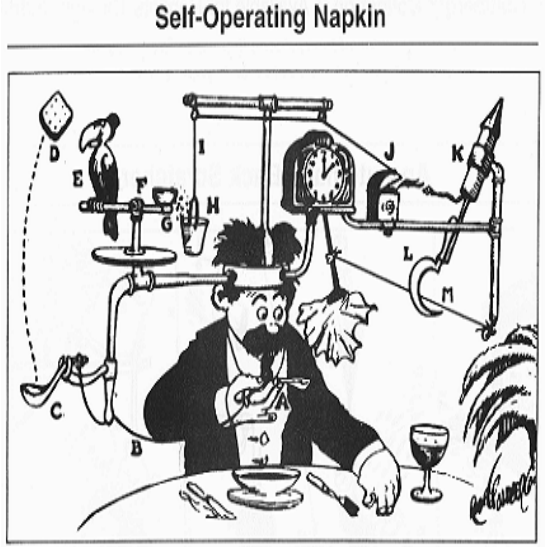
Industry 	**Academia** 
Goals / Motivations • Meet customer's mission requirements within budget and schedule • Generate mission data and deliverables • Represents a valuable endeavor	**Goals / Motivations** • Learning / training experience for students • To have "*University of >enter yours<'s first satellite*" • To communicate with the spacecraft, or to take pictures from space • General / theoretical research; e.g., test new sensor
Constraints / Negatives • Contractual obligation of financial, schedule, and performance goals • Higher cost of doing work • High reliability; it has to work • Competitive environment; need to protect intellectual property (IP)	**Constraints / Negatives** • Lack of funds (budgets in $10k-$100k's) • 'Churn' of students requires significant re-education • CubeSat project is secondary to classes • Generally, minimal compliance to US State Dept export regulations (exception: Cal Poly)
Advantages / Positives • Ability to focus on the project • Depth and breadth of experience • Rigorous compliance to US State Dept export regulations • Deep pockets and *ooh-aah* neat equipment • Budgets of $1Ms-$10Ms	**Advantages / Positives** • Inexpensive and motivated labor • Flexible performance goals • Open and information-sharing environment

What Key Lessons Observed

- We keep hearing from students ...

- **"We didn't think it would take this much work (or would be this hard) …"**
  - **There can be a lot of details in the most simple of problems**
  - **This <u>is</u> *"Rocket Science"***

- **Overly Complex Mission Objectives**
  - **If you can do one or two things and do them well, you're a Success**
  - **Often, teams try to do "advanced" projects**
    - **It is a natural tendency; makes for good reports and prestige**



- **Projects Have a Way of Getting Complicated on their Own… Don't Need to Add More to It**
  - **KISS; Design for integration and testability**
  - **Plan, think ahead, more planning…**

What Key Lessons Observed (continued)

- We keep hearing from students ...

- **Under-Estimating the Software Tasks**
  - **Software is often a long pole in system development**
    - **Need to solidify architecture and requirements early (sound familiar?)**
    - **Often attempt to correct hardware through software; "Software doesn't add weight"**
  - **Need to build in error handling and robustness**

- **Different Choices of Processor (or Comm) Systems**
  - **Have often heard… "after extensive review of requirements and survey of available options, we have selected (by far) the best option..." the PIC, the Rabbit, the Motorola HC12, the Atmel AVR, or > *enter your favorite* < …**
  - **Significant payoff within CubeSat community if some commonality were established; e.g., sharing software code**
    - **At the risk of too much standardization**

- **Communications System Frequency, Along With De-orbit / Lifetime Considerations Must be Considered From The Start**
  - **FCC Coordination normally takes a significant investment in time and coordination**
    - **Unless you have access to high-paid legal counsel ☺**
  - **Additionally, there is eventual need to get off Amateur Radio bands in order to perform industry-sponsored (& funded) missions**

What Key Lessons Observed (continued)

- We keep hearing from students ...

- **Documentation is Often an After-Thought**
  - **'The system is simple and doesn't require documentation'**
  - **'The code is so well coded, we don't need documentation'**
  - **Budget time for documentation since it may be the only legacy left after people leave the program**

- **Good/Excellent Work as Integrated Teams**
  - **Seen some high caliber of engineering**
  - **Use of Peer Reviews to check each others work**
  - **Like to see more use of external & industry reviews**

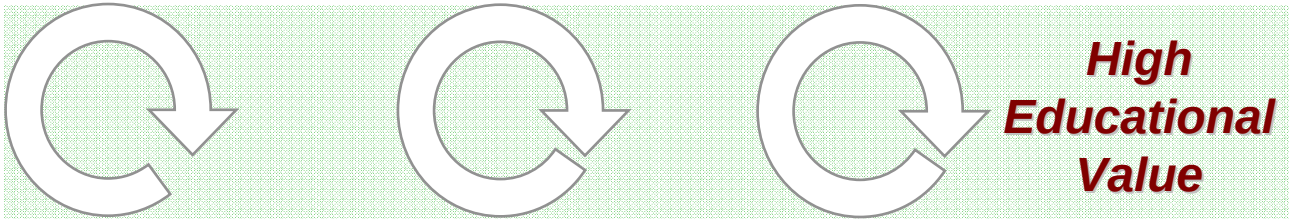
- **Margin, Robustness, Contingencies …**
  - **Compensate for uncertainties (environment, performance, design, schedule, costs, etc)**
    - **Don't assume things will work as planned**
  - **We are building systems which must operate for extended periods without physical human contact in an extremely harsh environment**

Growth Options Seen for University CubeSat Programs

- Once Initial Discovery Phase and Newness Wears Off

Cyclical Evolution

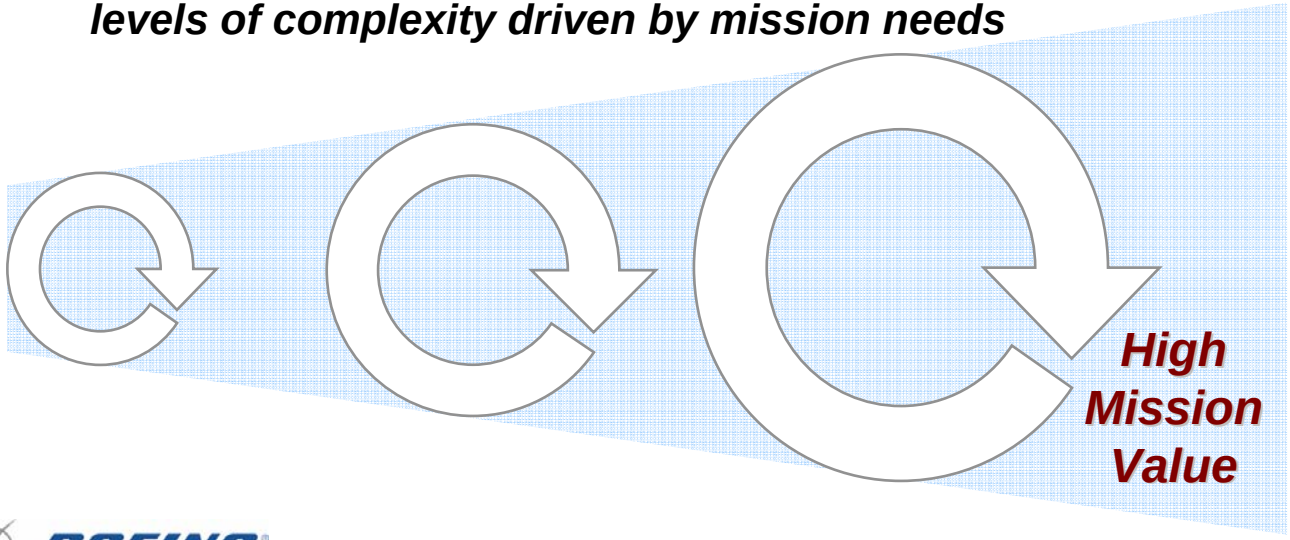
New starts leveraging some prior work, driven by educating new talent



- Provides more students with end-to-end experience
- Similar missions and payloads each cycle
- Short-term or mission-specific funding

Spiral Evolution

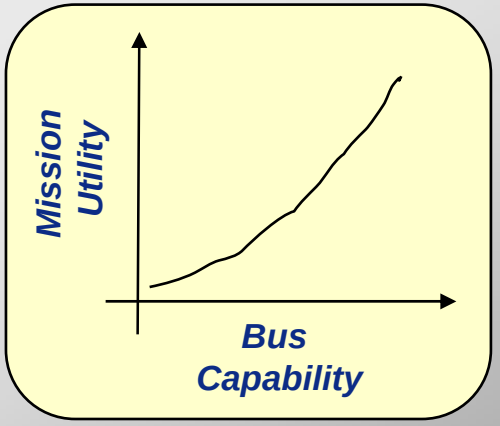
Building on previous work in direction of higher levels of complexity driven by mission needs

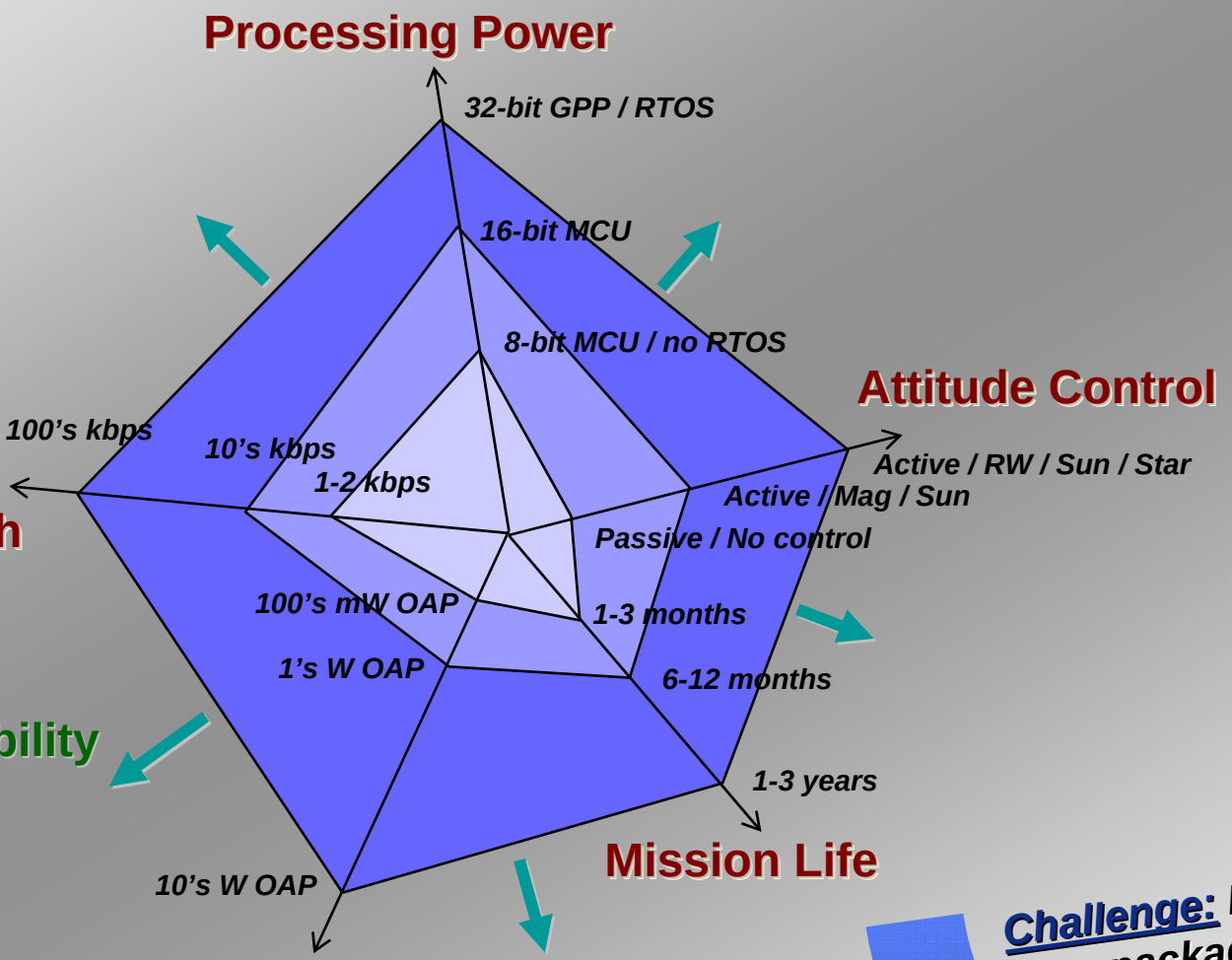


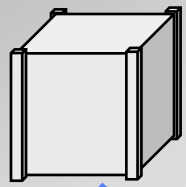
- Utilizes knowledge legacy from previous cycles
- Increased capability each cycle
- Standard & modular bus
- Missions and payloads of interest to Industry & Government
- Can leverage deeper pockets of Industry / Government partners

Spacecraft Performance Growth is Inter-Dependent

- Driven by Needs of More Advanced Missions and Payloads







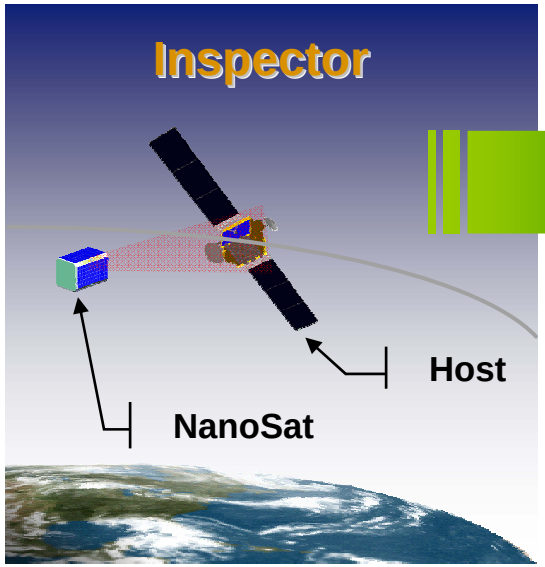
Challenge: How to package more capability into CubeSat envelope

Representative NanoSat Missions

- Why Industry is Interested in NanoSats

NanoSats Can Perform Unique Missions

– **Several Current Missions Being Developed**



Inspector Mission:
- Anomaly Resolution and Assessment
- Additional Camera View During On-Orbit Operations

Other Missions Identified:
- Space Situational Awareness
- Sparse Arrays / Formations

- Low Cost Launch [e.g., $/kg]
- Frequent Launch Opportunities

Nano-Satellite Technologies:
- Development of Miniature Components
- Application to all Space Vehicles; not just NanoSats

Why CubeSats are Great !!!

- From an Industry Perspective

- **Training New Spacecraft Engineers**
  - Graduate with 1 or 2 flight programs under their belt
  - Come see me… ☺
- ***"Out of the Cube"* Thinking**
  - Has many good points (and some bad)
- **Quick Response Test Beds**
  - "Relatively" rapid spacecraft development programs
- **Established and Low Cost Infrastructure for Launches**
  - Significantly reduces non-recurring costs
- **Lower Cost of Failure; *Risk Tolerant***
  - Promotes Innovation
  - Lower threshold of risk
  - Oh &%$#*!!, the LV just cratered… …let's launch our back-up CubeSat
- **Most Teams Utilizing Commercial ("COTS") Components in their CubeSats**
  - Demonstrating that Spacecraft don't need "space-rated" parts to perform useful missions
  - Would like to see more collaborations to promote use of commercial components

Future CubeSat Capabilities I'd Like to See:

- Propulsion System with Reasonable Delta-V (10's m/s)
- Higher Precision Attitude Control (<1.0 deg) and Determination (<0.1deg)
- Higher-Bandwidth Comm (>10's kbps)
- And Others…

Questions?