Right-sizing Small Satellites

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Introduction

- Fundamental question: “what is the right size for a small satellite?” (< 200 kg)
- Three proposed design factors:
  - Spacecraft Utility (*ScU*)
  - Mission Utility (*MU*)
  - Optimum Cost
- Motivation
  - *Provoke thought, not discredit prior work*
  - *Develop comparison metrics for decision-makers*

SmallSat Momentum

- First satellites were SmallSats!
- Re-birth in 1980s
- CubeSats/containerization early 2000s
- US Government CubeSat interest late 2000s
- Recent major findings/publications
  - NASA Ames “Small Satellite Technology State of the Art” (< 180 kg)
  - *USAF SAB “Microsatellite Mission Applications” (< 300 kg)*

SmallSat Community Focus

- Lowering launch costs through containerization
  - NASA's Payload Ejection System (PES)
  - Orbiting Picosat Activated Launcher (OPAL)
  - P-POD
- Standardized bus designs
  - STP-SIV – 180 kg ESPA configuration
  - 3U CubeSats – 4.5 kg – such as NRO's Colony
- Plug-and-play architecture
- *Little work in quantitative assessments*

Theoretically Perfect Satellite

- Firstly, we must define the “perfect” satellite
- Payload consumes 100% of resources
  - Power
  - Volume
- Infinite power available
- Volume is unconstrained (infinite)
- Mass is zero
- *Impossible to approach, but helps us model*

Spacecraft Utility (*ScU*)

- Proposed mathematical model:

$$ScU = \eta\left(\frac{P}{P+100}\right)\left(\frac{V}{V+1}\right)$$

- η = aggregate payload volume & power efficiency
- *P* = OAP in Watts (∞ = ideal)
- *V* = spacecraft volume in m^3 (∞ = ideal)
- Initial weighting factors: 100 Watts $\approx$ 1 m^3

ScU Examples

Mission	Bus Cost ($K)	Mass (kg)	η	OAP (W)	Volume (cm^3)	ScU
SpaceChip	2.7	0.01	0.01	0.001	2×2×0.3	1.2×10^{-13}
MCMSat	24	0.170	0.1	0.88	10×10×1	8.4×10^{-8}
PCBSat	13	0.25	0.05	0.88	10×10×2.5	1.2×10^{-7}
$50Sat	0.25	0.22	0.3	0.55	5×5×7.5	3.1×10^{-7}
1U CubeSat	75	1	0.1	1.6	10×10×10	1.6×10^{-6}
Colony I	250	3	0.4	8	10×10×30	8.9×10^{-5}
Colony II	250	3	0.4	10	10×10×30	0.0001
FS-2	1,500	19.5	0.2	10	32×32×32	0.0006
FS-3	2,100	54.3	0.21	18.9	45×45×63	0.004
DMC	-	88	0.5	30	64×64×68	0.025
FS-5	2,400	137.7	0.51	38	61×72×97	0.043
DMC-2	15,000	96	0.5	50	63×66×84	0.043
SIV	-	181	0.35	**225**	61×72×97	**0.07**
FS-6	2,600	164.3	0.48	102	61×72×97	0.07

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Mission Utility (*MU*)

- Proposed mathematical model:

$$MU = 1 - \left(1 - ScU\right)^{n}$$

- Similar to parallel reliability equation
- *n* = number of spacecraft in mission architecture
- *MU*, like *ScU*, approaches unity (1)

MU Examples (apples to oranges)

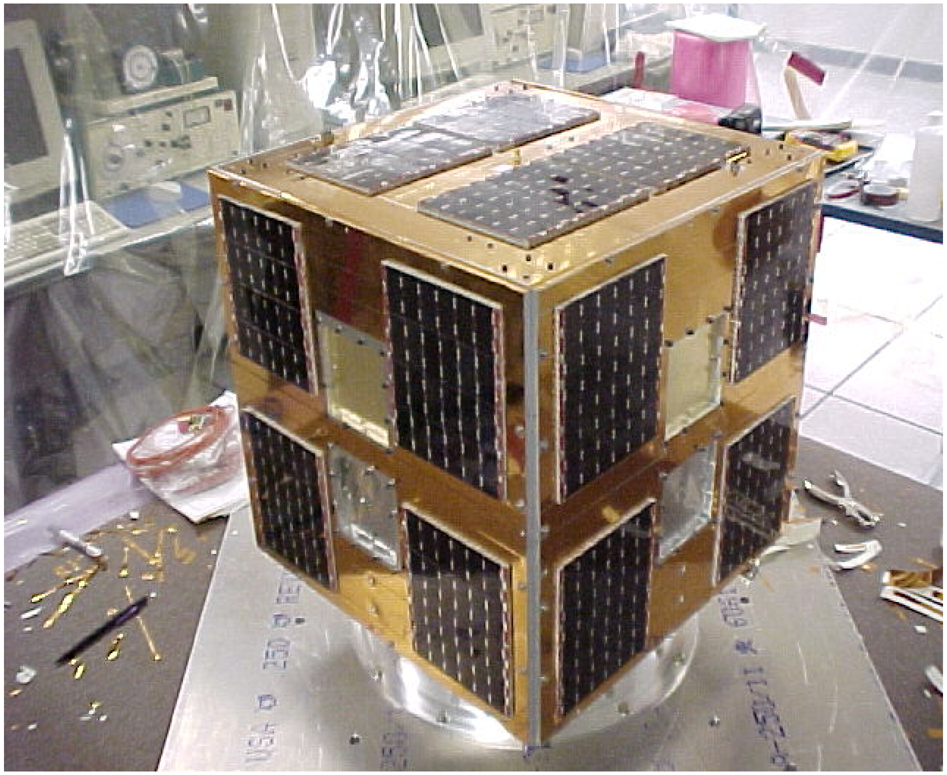
- Disaster Monitoring Constellation (DMC)
  - 88 kg bus mass, 64×64×68 cm bus volume
  - η = 0.50, OAP of 30 W; results in an *ScU* of 0.025
  - Five satellites in architecture yields <u>*MU* of 0.12</u>
- Space Weather
  - 1 kg 1U CubeSat, 10×10×10 cm bus volume
  - η = 0.1, OAP of 1.6 W; yields *ScU* of 1.6×10^{-6}
  - Ten satellites in architecture yields <u>*MU* of 1.6×10^{-5}</u>
  - 100 satellites yields <u>*MU* of 1.6×10^{-4}</u>

Optimum Cost

- Bus cost (drives *ScU*)
  - Invest in raising *ScU*
- LVI costs (drives *MU*)
  - CubeSat mass overhead 40-55%
  - ESPA mass overhead 13%
  - *Launch opportunity cost not yet considered*
- Potential revenue
  - A commercial issue in general
  - Academic programs typically not concerned

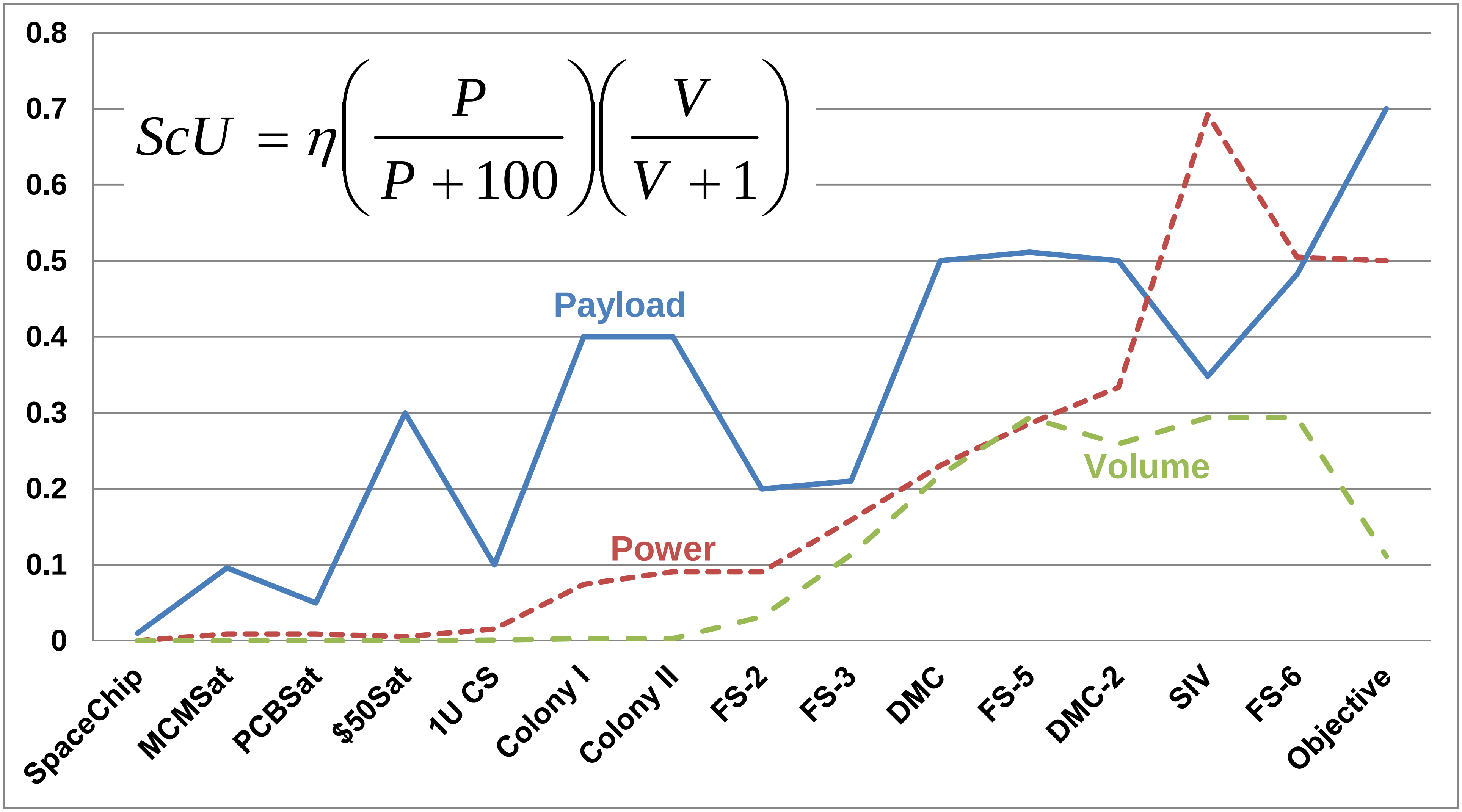
Proposed Objective Design

- 50×50×50 cm
- η = 70%
- OAP = 100 W
- Target cost of $1M
- Mass of 30 kg
- Non-containerized



FalconSAT-1 was about this size

ScU Component Analysis



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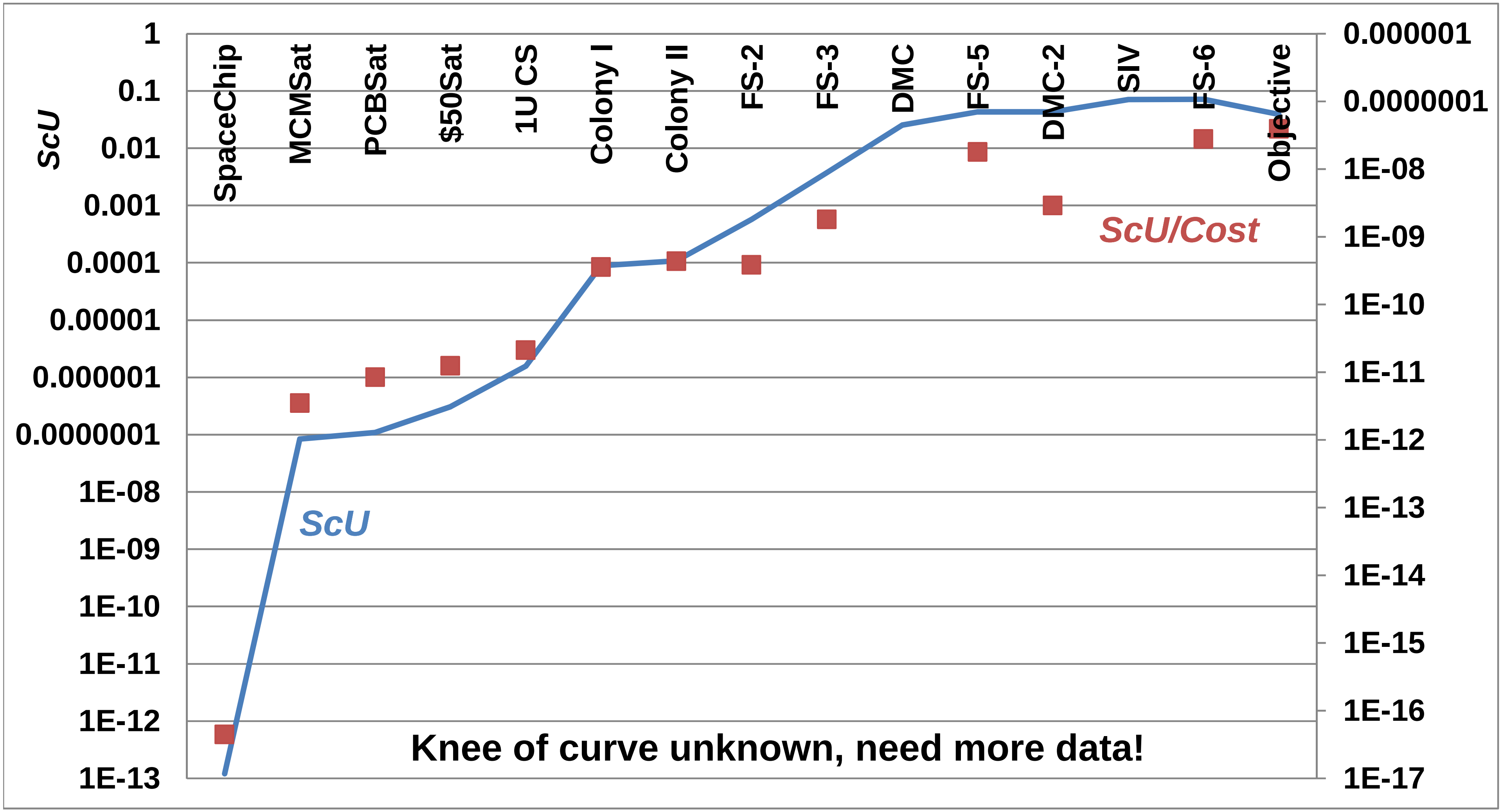
ScU/Cost



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Conclusions

- Theoretically perfect satellite proposed
- First step in quantifying the "utility" of spacecraft and mission capabilities
- Much more work to be done
  - *Need more data, extend to all satellite classes*
  - *Develop ScU and MU standard reference points*
- Career lessons learned in the community
  - *Miniaturizing payloads to fit is costly*
  - *Overselling SmallSats reduces credibility*
  - *Decision-makers need metrics for comparison*
  - *SmallSat potential barely tapped…*

Questions?

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