CubeSat Design and Optimization

For Live Presentation
- ▶ Software Developers Cartel (SDC)
- ▶ Downtown Bryan, TX
- ▶ Presentation & Demonstration

Recorded by SDC

July 2015

David Malawey
Texas A&M Mechanical Engineering

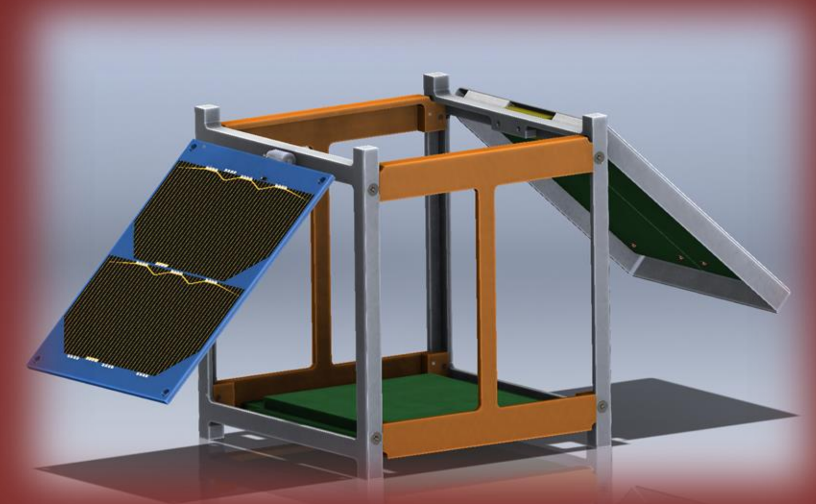
About Me:

- David Malawey
- St. Louis hometown
- A&M Mechanical Engineering
- Research topic:

Standardized Cubesat Design

Today's Talk:

1. What is *Multidisciplinary Design Optimization*?
2. The CubeSat Design Goals
3. Optimization demonstration



What is Multidisciplinary Optimization (MDO)?

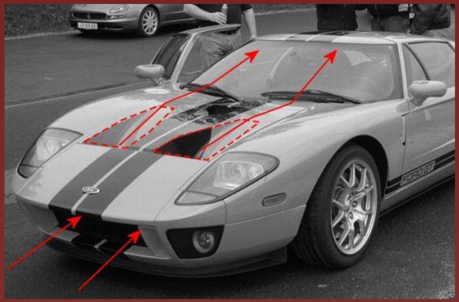
- Multiple disciplines, complex system.
- Experts know just 1 discipline!

Aesthetics → Aerodynamics → Powerplant → Cooling

Artists

Aerospace/structural

Mechanical/electrical



Heat transfer

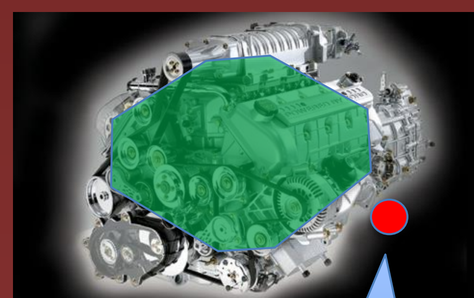
- Industry: design in sequence

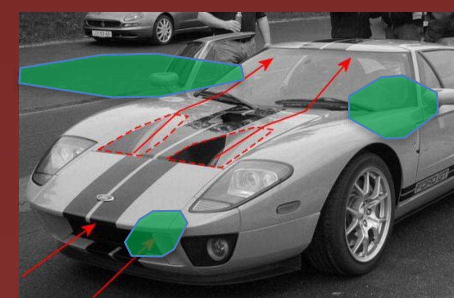
What is MDO? (2)

- Each designer is subject to previous decisions

Goals	Constraints
0-60 performance	Fits 2 humans
Visually pleasing	Physical envelope
Highly Comfortable	Runs on Gasoline
	Cost < $0.5m

Aesthetics → Structure/aero → Powerplant → Cooling

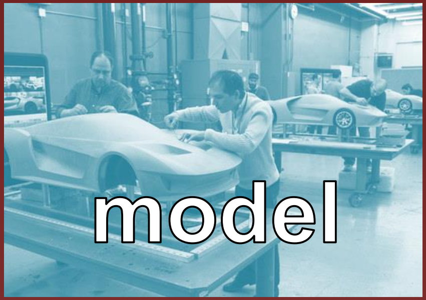




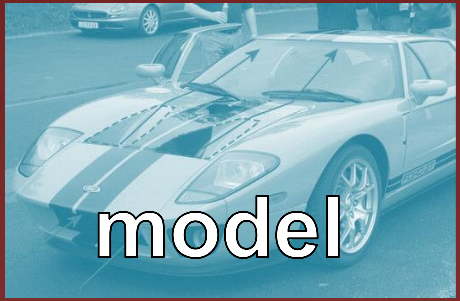
Most powerful

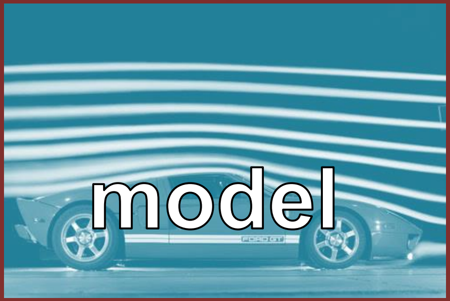
What is MDO? (3)

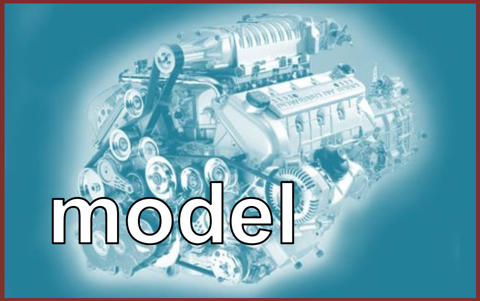
- MDO is a simultaneous design
  - Optimizer manipulates a “design vector.”
  - Optimizes objective function
  - Checks for feasibility

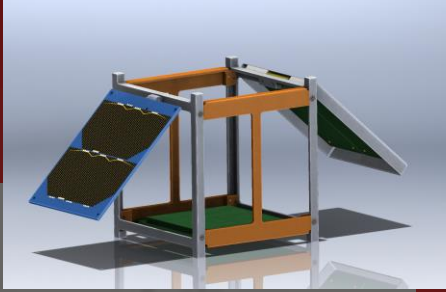


Optimizer:
- Goals (objective function)
- Constraints
- Parameters







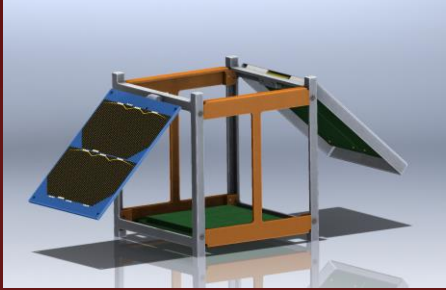


What is a Cubesat?

- Complex Multidisciplinary Satellite!
  – Carried by a rocket and launched to orbit
- Purpose:
  – Equip with sensors and send data to earth
- Base Functions:
  – Electrical Power -Structural system
  – Attitude sensing - Attitude Control
  – Communication
- Design Goals
  – framework can be reoptimized (different missions)
  – Adjust configuration as project moves forward
  – Take heuristic data from previous cubesats

Background Photo: *Planet labs Doves aim to create a constellation that images earth every 24 hours.*

Dwight Look College of
ENGINEERING
TEXAS A&M UNIVERSITY



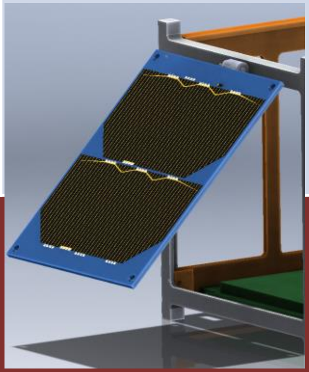
Problem Formulation

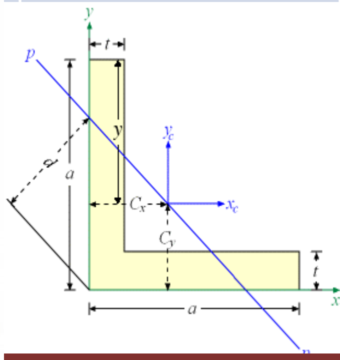
Objectives	Parameters	Constraints
Min Mass	Mission duration (60 days)	(1) Power required
Min Cost	Solar Panel Power (2 watts)	(2) Structure bending stiffness
	Battery Capacity (3200mAh)	(3) propellant sufficient
	Flight Disturbance (rotation /day)	
	Volume of a propellant tank	
	… (more)	

Design Vector

X(1)	X(2)	X(3)	X(4)	X(5)	X(6)
Propellant	Thruster type	Structure material	Solar Panels	Batteries	Structure rail width
• Hydrogen • Helium • Neon • Nitrogen • Argon • Krypton • Xenon • Freon 14 • Methane • Ammonia	• Moog • Marotta • Lee LHDB	• 6061 T6 Aluminum • Titanium • A36 Steel	• Integers 0~4	• Integers 1~unlimited	3mm~inf

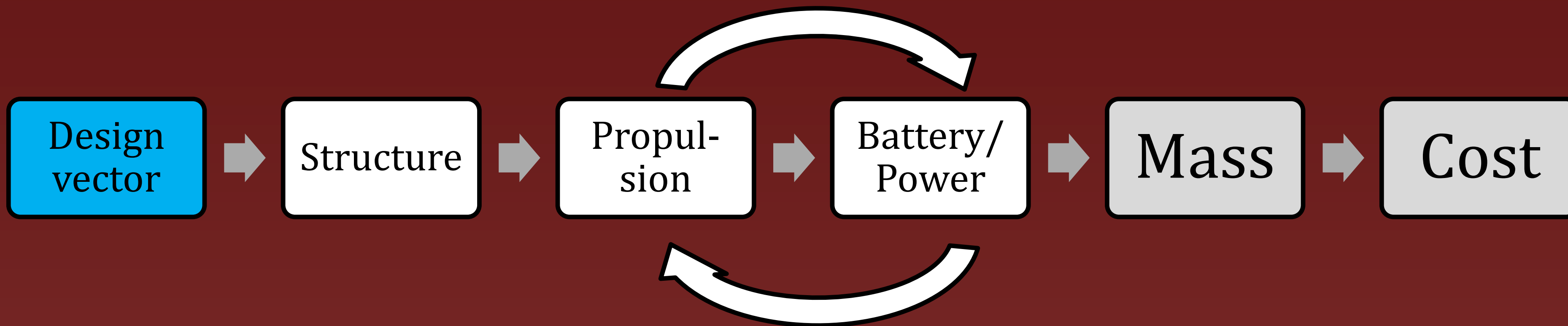
Marotta micro thruster





Model and Simulation

- Model Overview



  - Each module outputs a matrix of all variables

```
%---------LEVEL 1 VARIABLES--------------
global P
b101 = P(7); %battery capacity (mAh)
b102 = P(11); %factor of safety
b103 = P(1); %mission duration (days)
b104 = 300; % com power consumption (mA)
b105 = .10; % com duty ratio (ratio)
b106 = y(3); % prop power consumption (W)
b107 = .10;% prop duty ratio (ratio)
b108 = 44.5; %weight per battery (g)
b109 = P(8); % power of 1 solar panel (W)
%-------------LEVEL 2 VARIABLES------------
b201 =0; %total mAh drawn (mAh)
b202 =0; %batteries energy (Wh)
b203=0; % energy used in misison, raw (Wh)
%-------------LEVEL 3 VARIABLES------------
b301=0; % energy used in misison with FOS (Wh)
b302=0; % mass of batteries (g)
b303=0; % mass of solar panels (g)
b304=0; % mass, total power unit (g)
b305=0; % panels energy (Wh)
```

```
b=[b101 b102 b103 b104 b105 b106 b107 b108 b109...
    b110 b111 b112 b113 b114 b115 0.00 0.00 0.00;...
    b201 b202 b203 0.00 0.00 0.00 0.00 0.00 0.00...
    0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00;...
    b301 b302 b303 b304 b305 0.00 0.00 0.00 0.00...
    0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00];
```

```
%---recalculate all vars with final X-----
[j,s,p,b,y,c] = objective(X);
```

1-Objective Optimization

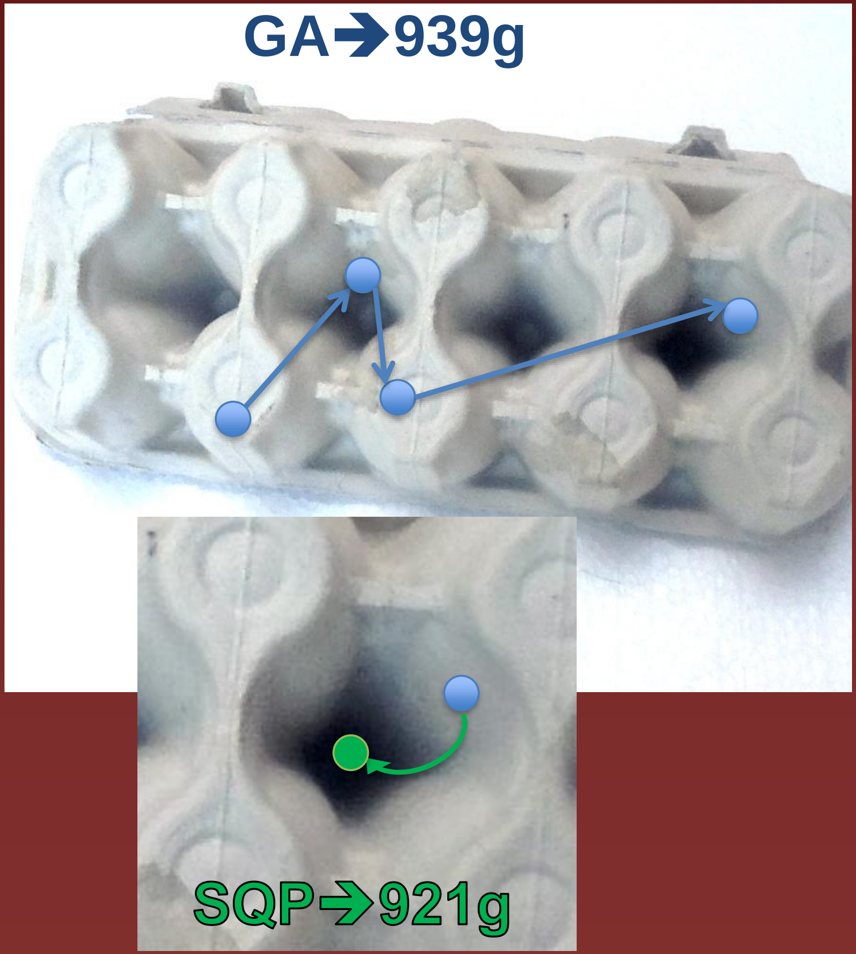
Coupled analysis

- Genetic Algorithm (GA)
  - finds global area of interest

X(1)	X(2)	X(3)
Propellant	Thruster type	Structure material

- Sequential Quadratic Programming (SQP)
  - Local analysis (refines the design)

X(4)	X(5)	X(6)
Solar Panels	Batteries	Structure rail width



Validating the Design

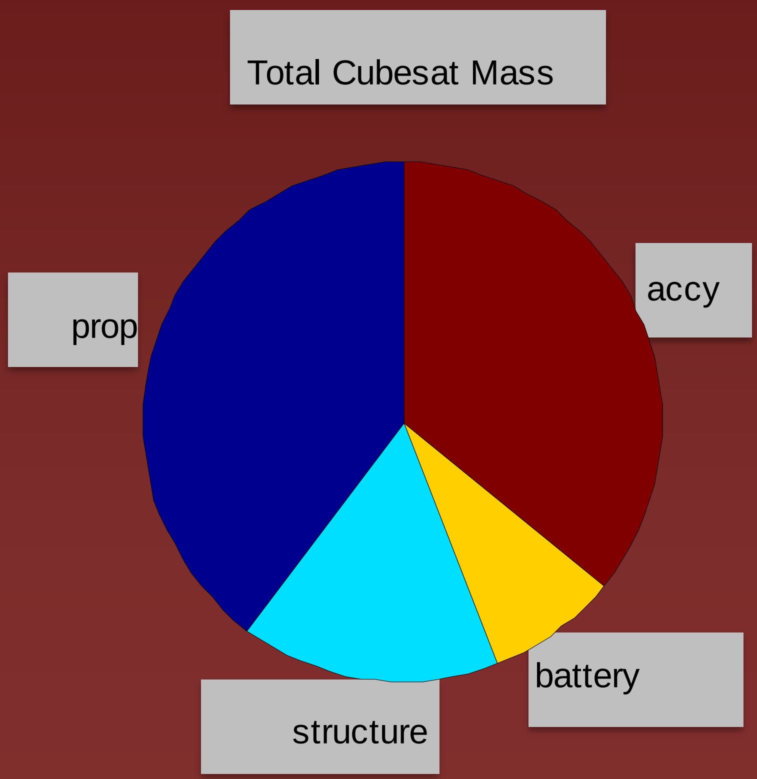


Table A: Design Vector

	Value
total mass (g)	921
propellant	Xenon
thruster	lee LHDB054...
material	Al 6061 T6
solar panels	0.6905
batteries	1
structure width(mm)	6.3537

Table B: Relevant Data

	Value
algorithm run time (s)	6.6184
prop tanks (qty)	2
propellant mass (g)	85.2459
pwr consumption (Wh)	327.6000
solar pwr produced(Wh)	313.2000

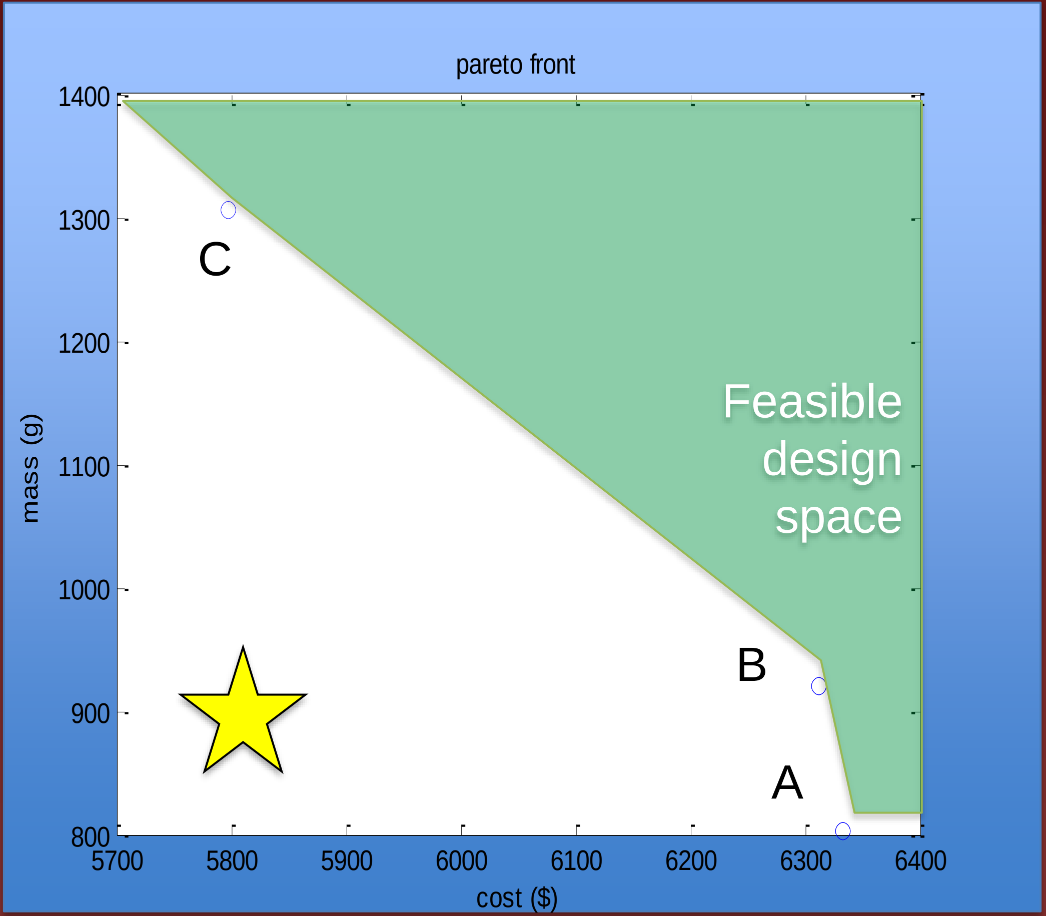
	prop	structure	battery	accy
mass (g)	366	149	76	330

Demonstration

- (Matlab) Optimization based on *MASS*

Multi-objective Optimization

- Adjusted Weighted Sum (AWS) Pareto Front



	Prop	Thruster	Material	S.Panel	Battery	Rail (mm)	Cost	Mass (g)
A	Freon	Lee	Titanium	0.690	1	3.04	$6,333	802
B	Xenon	Lee	Aluminum	0.690	1	6.354	$6,312	921
C	Methane	Marotta	Steel	0.760	1	3.00	$5,798	1,293

Special Thanks:

MECHANICAL ENGINEERING
TEXAS A&M UNIVERSITY

- Dr. Douglas Allaire
- Dr. Joseph Morgan

ELECTRONIC SYSTEMS ENGINEERING TECHNOLOGY
TEXAS A&M UNIVERSITY

TSTAR
TEXAS SPACE, TECHNOLOGY, APPLICATIONS & RESEARCH

- Matt Leonard
- NASA personnel

NASA

Questions?

July 2015

David Malawey
Texas A&M Mechanical Engineering