

A photograph of a Space Shuttle External Tank (ET) being mated to the orbiter and solid rocket boosters on the Mobile Launcher Platform. The ET is the large, orange, cylindrical structure in the center. The orbiter and boosters are white. The background is a clear blue sky. The text is overlaid on the image.

Flexible Design of Space Shuttle External Tank

Application Portfolio
Engineering Systems Analysis for Design
Massachusetts Institute of Technology
December 5th, 2005
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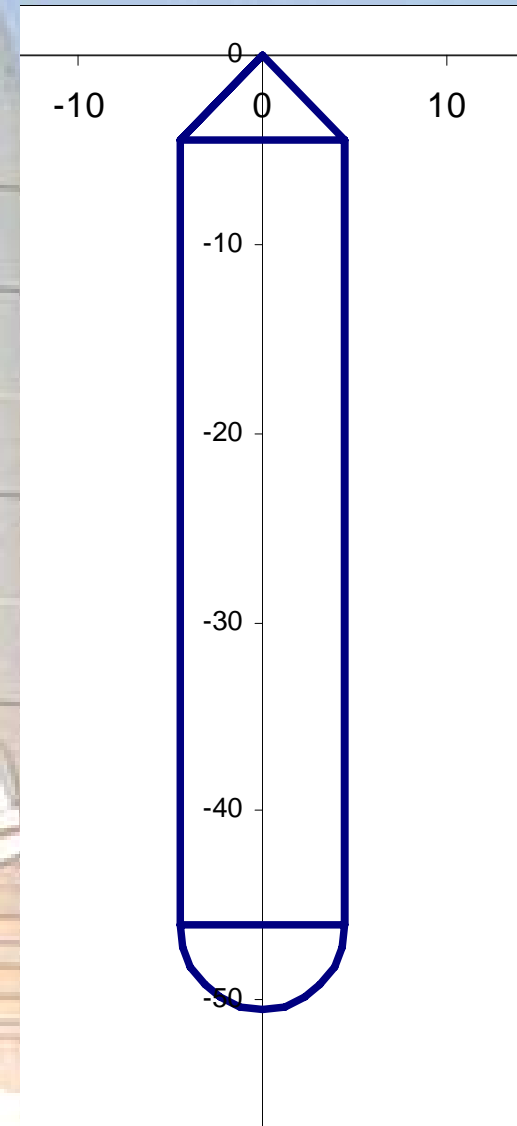
Space Shuttle External Tank

- Contains H_2 and O_2 for main engines
- Jettisoned
- Contains adequate fuel to lift itself, space shuttle and payload



Tank Model

- Cylinder with cone on top and hemisphere on bottom
- Stress and vibration constraints
- Design variables: radius, lengths of cylinder and cone, wall thicknesses

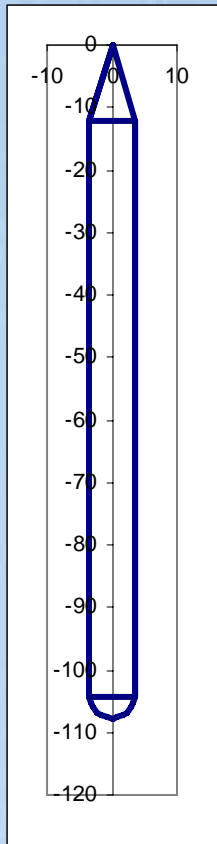


Payload Uncertainty Modeling

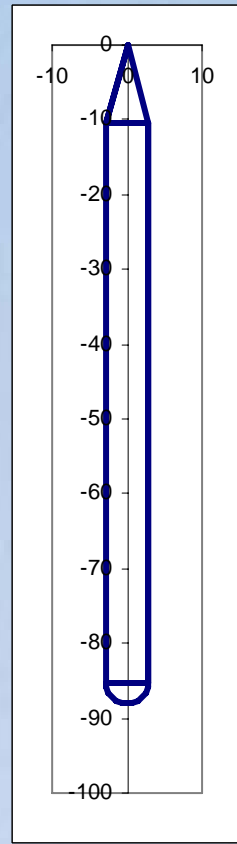
A photograph of a Space Shuttle Columbia on the Mobile Launcher Platform being mated to the External Tank and Solid Rocket Boosters on the Vehicle Assembly Building. The shuttle is white with black and orange stripes, and the external tank is orange. The boosters are white with black segments. The background is a clear blue sky.

- Flights divided into “light” and “heavy” categories
- Light: up to 15000 kg
- Heavy: up to 30000 kg
- Modeled parameter: percentage of flights in heavy category

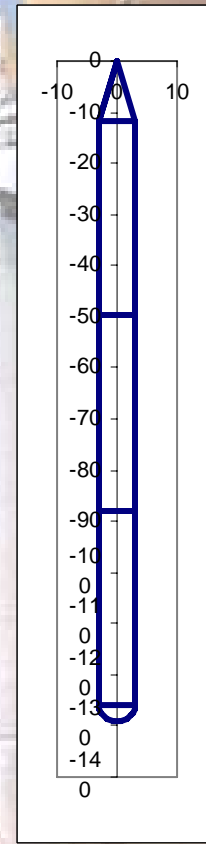
Designs Under Consideration



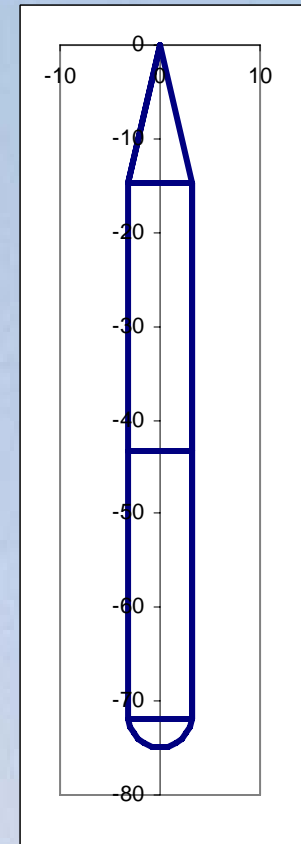
Large
fixed



Small
fixed



Large
flexible



Small
flexible

Scenarios for Decision Analysis

	%light	%heavy	Initial chance	Chance A next	Chance B next	Chance C next
Scenario A	90%	10%	50%	85%	10%	5%
Scenario B	70%	30%	30%	15%	80%	5%
Scenario C	50%	50%	20%	10%	15%	75%

	Average Profit Scenario A		Average Profit Scenario B		Average Profit Scenario C	
Large fixed	\$	516,508,880	\$	520,508,880	\$	524,508,880
Small fixed	\$	639,706,468	\$	497,549,475	\$	355,392,482
Flexible	\$	586,830,750	\$	550,937,538	\$	515,044,326

Two-Stage Decision Analysis

A background image of the Space Shuttle Columbia on the launch pad, with the orbiter and external tank visible against a blue sky.

- Optimal initial decision is to use flexible design for first period
- If first period is Scenario A, use small fixed design for next period
- If first period is Scenario B or C, use flexible design for next period
- Expected value using this strategy is \$1.14 billion dollars

Lattice Design

A background image of the Space Shuttle Columbia on the launch pad, viewed from a low angle looking up. The shuttle is white with orange external tank and white solid rocket boosters. The launch pad structure is visible at the bottom.

- Each stage is one year
- Consider a total of five years
- At time 0, 20% of flights are heavy
- Geometric Brownian motion problematic in this case; used anyway
- Growth $v=0$, volatility $\sigma=28\%$
- Thus $u=1.32$, $d=0.76$, $p=0.5$

Resulting lattice

OUTCOME LATTICE: FRACTION OF SHUTTLE FLIGHTS IN HEAVY CATEGORY

0.200	0.265	0.350	0.463	0.613	0.811
	0.151	0.200	0.265	0.350	0.463
		0.114	0.151	0.200	0.265
			0.086	0.114	0.151
				0.065	0.086
					0.049

PROBABILITY LATTICE

1.000	0.500	0.250	0.125	0.063	0.031
	0.500	0.500	0.375	0.250	0.156
		0.250	0.375	0.375	0.313
			0.125	0.250	0.313
				0.063	0.156
					0.031

Decision Analysis Using Lattice

- Can go from flexible to fixed, not vice versa

Best Decision (if arriving in a state with a flexible design)

1	2	3	4	5	6
flexible	flexible	flexible	flexible	large	large
	small	flexible	flexible	flexible	large
		small	small	flexible	flexible
			small	small	small
				small	small
					small

- Flexibility valued at \$0.9 million

Summary

A photograph of the Space Shuttle Columbia on the launch pad, viewed from a low angle looking up. The shuttle is white with orange external tank and white solid rocket boosters. The background is a clear blue sky.

- Design of space shuttle with payload uncertainty
- Considered two fixed and one flexible design
- Two-stage decision analysis showed that best strategy started with flexible design
- Lattice analysis valued flexibility at \$0.9 million