

Flexibility for in-Space Propulsion Technology Investment

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ESD.71 Engineering Systems Analysis for Design
Application Portfolio



Slide 1

Background

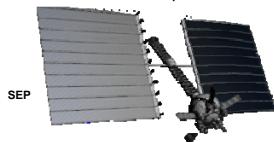
- Problems in previous program led to review of human spaceflight.
- NASA human spaceflight revamped in April 2010.
- New technology required for new exploration goals.
- There is lots of turmoil and debate among industry and politicians.
- This leads to uncertainty in the way forward...



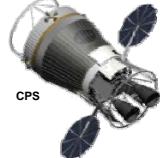
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Scope of Project

- 2 in-space propulsion technologies:
 - Solar Electric Propulsion (SEP)
 - Chemical Propulsion Stage (CPS)
- 2 exploration destinations:
 - Near-Earth Asteroid (NEA)- current target
 - Mars (NEA develops technology for Mars)
- 2 design alternatives:
 1. A combination of SEP and CPS are used to transport crew and cargo to the NEA. (works for Mars or NEA)
 2. Only CPS is used to transport crew and cargo to the NEA. (NEA only)



SEP



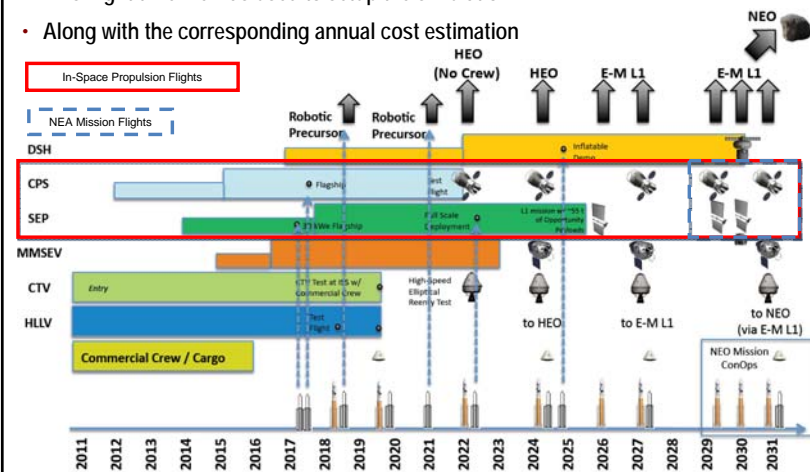
CPS



Slide 3

DRM from HEFT I Closeout Charts

- This flight timeline was used to setup the simulation
- Along with the corresponding annual cost estimation



Slide 4

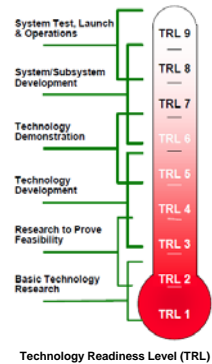
Simulation Setup

- Assumptions from HEFT I Closeout DRM

- Costs over time assumed to be correct
- Precursor flight manifest assumed to be correct (to develop technology readiness)

- My assumptions

- SEP is currently at TRL 6
- CPS is currently at TRL 7
- Each successful precursor flight raises the TRL by 1
- There is a 50/50 chance (uncertainty) of each precursor flight being successful

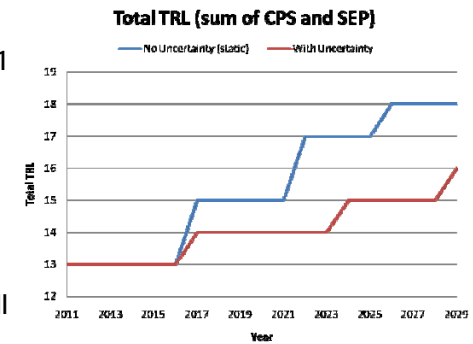


Uncertainty of Mission Success

- According to the # of flights (and my assumption of 1 flight = 1 increase in TRL) both SEP and CPS reach TRL 9 before the NEA campaign in 2029.

- However with a 50/50 chance of each flight being successful this will not always be true.

- This is one sample simulation to show uncertainty is important (eventually a Monte Carlo sim with 10k iterations was executed).



Measure of Effectiveness

$$\text{Cost Effectiveness} = \frac{\text{TRL}_{\text{SEP Final}} + \text{TRL}_{\text{CPS Final}} - \text{TRL}_{\text{SEP Initial}} - \text{TRL}_{\text{CPS Initial}}}{\text{Cumulative Cost}}$$

- Since there is no revenue or profit, I created a measure of effectiveness that is essentially $\Delta\text{TRL}/(\text{billion } \$)$
- This MoE is designed to maximize overall HSF capability.
- If only looking at cost for the NEA mission, there is no incentive to pursue SEP. (CPS dominates in cost alone).
- Look for an investment strategy that seeks to maximize overall increase in TRL per unit cost while ensuring that there is a feasible in-space propulsion alternative to execute the NEA mission.
- Maximizing technology readiness rather than minimizing cost can also be seen as a form of flexibility given the uncertainty of mission goals (which have already changed in the past).



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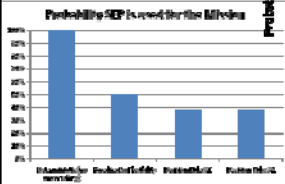
Decision Rules

- Decision Rules give flexibility to abandon SEP.
- The idea is to maximize the MoE while not spending money on a system that CAN NOT be used for the mid term goal of the NEA
- Basically if there are not enough flights to increase the TRL of SEP to 8 to be ready for human spaceflight as time goes on (and some precursors fail) you can abandon the SEP research (not spend that money) with the intent that you would then reopen that research once the NEA mission is complete.
- Two decision rules were implemented:
 - Decision rule #1: If the first SEP flight fails, shut down. If it succeeds, this brings SEP from TRL 6 to 7. One of the next 2 SEP flights must then succeed to proceed to the NEA mission including SEP (SEP reaching TRL 8), otherwise shutdown SEP and continue with CPS only.
 - Decision rule #2: One of the first two SEP flights must succeed. Only one or the other may fail. This will make SEP at least a TRL 7 (could be 8). However the next flight must then succeed to achieve TRL 8 (or 9) before the NEA mission. If not, then shut down SEP and continue with CPS only.



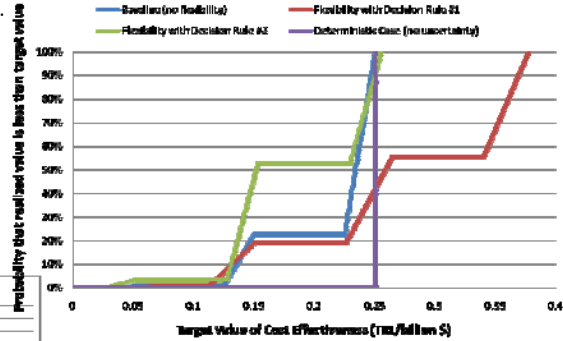
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- Decision Rule #1 is the most interesting option.
- Upside of Cost Effectiveness is dramatically increased
- SEP is used less often w/ put option- but money is not spent on lacking capability



Results

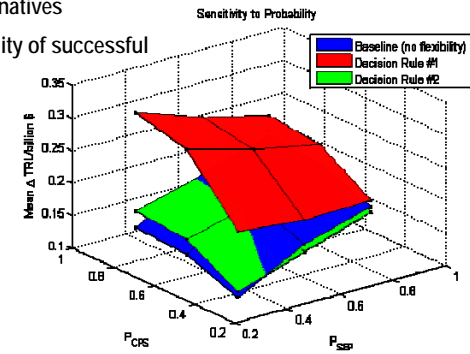
CDF Cost Effectiveness



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Next Steps

- Compare to NASA TRL roadmaps
- Define and include uncertainty on cost
- Include other technology alternatives
- Define uncertainty on probability of successful flights in more detail



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Thank You!

- Thanks for listening.
- Special thanks to Prof. de Neufville and Michel for taking time to discuss my project.