Considerations when Designing a Mission Engineering Study

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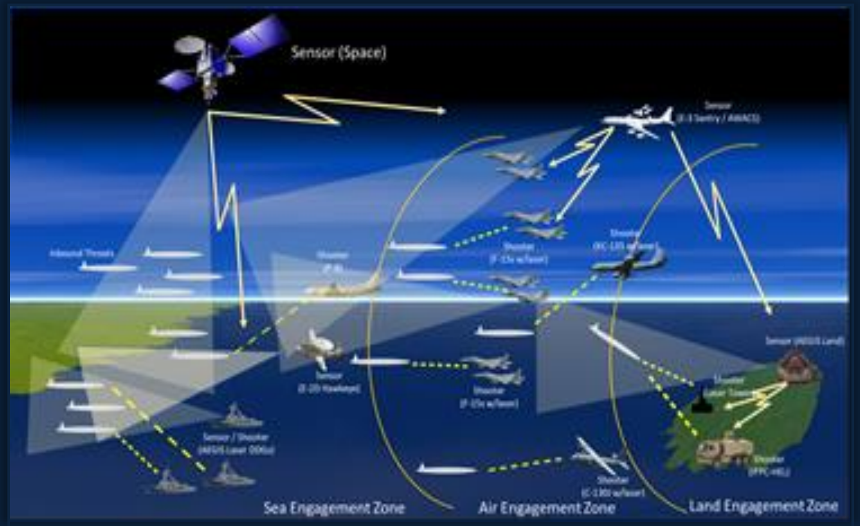
Motivation

- It may seem natural to analyze mission engineering trade studies using the same approaches used for a tradition engineering trade studies
- However, there are some special aspects of mission engineering studies that differentiate them from more traditional engineering trade studies
- Here we will discuss those differences and how they affect study design

What makes a mission engineering study different from a typical engineering trade study?

- Mission engineering studies seek to analyze a System of Systems (SoS)
- Systems of Systems tend to be more complex and unpredictable than a single engineered system
- They may exhibit
  - Many human actors that can behave unpredictably
  - Adversaries that can react and adapt to your moves
  - Systems in unknown configurations
  - A complex and ever-changing structure



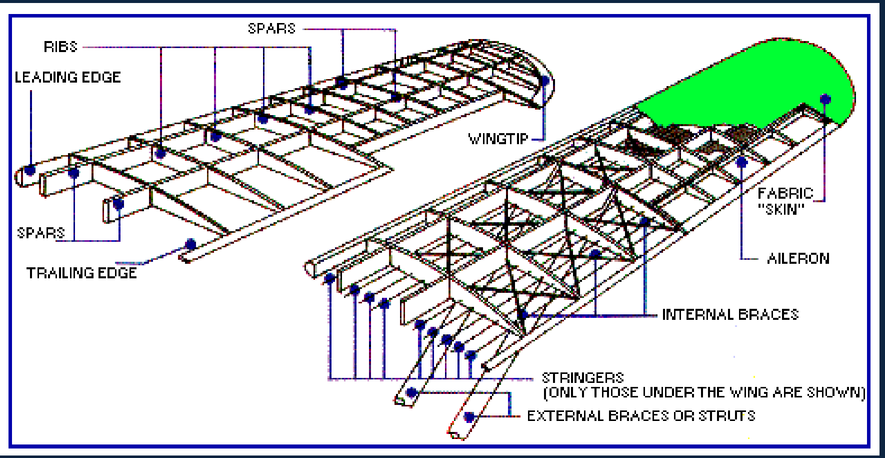
For Example

- Communications pathways will shift as units move and the battlefield situation evolves
- Fielding systems in a variety of configurations makes it challenging to maintain compatibility
- Adversaries may shift tactics to mitigate improved capabilities
- An improved engine may allow a fighter pilot to use different tactics, which may lead to different outcomes in air combat, which may lead to commanders to plan missions differently, and so on…

A typical engineering analysis alone may have trouble accounting for these types of factors

A Better Analogy

- A prototypical engineering trade study may ask “What type of wing design will give my aircraft the greatest range?”
- While likely important and challenging in its own way, this problem does not exhibit the challenges we just described
- A more instructive analogy for mission engineering is “How should I assemble a football team to maximize the chances of winning the Superbowl?”

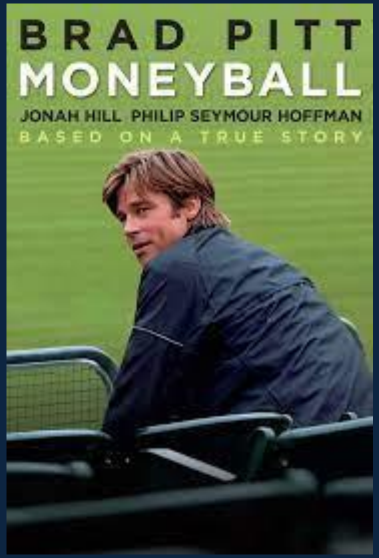


https://web.eng.fiu.edu/allstar/flight12.htm

https://dallasnews.com/high-school-sports/football/2022/11/06/final-2022-regular-season-dallas-area-high-school-football-rankings-the-teams-to-beat/

Some relevant aspects

- A set of players with complementary skills that work well together may be more effective than a group of uncooperative "all stars"
- Other teams will react to and attempt to counteract your decisions
- Need to plan for a whole season of games against many different teams that will evolve over the course of the season
  - Injuries, trades, shifts in performance
- Different teams may perform better under different conditions
- Players do not always behave as their coaches instruct them
- Different sets of players enable different game strategies



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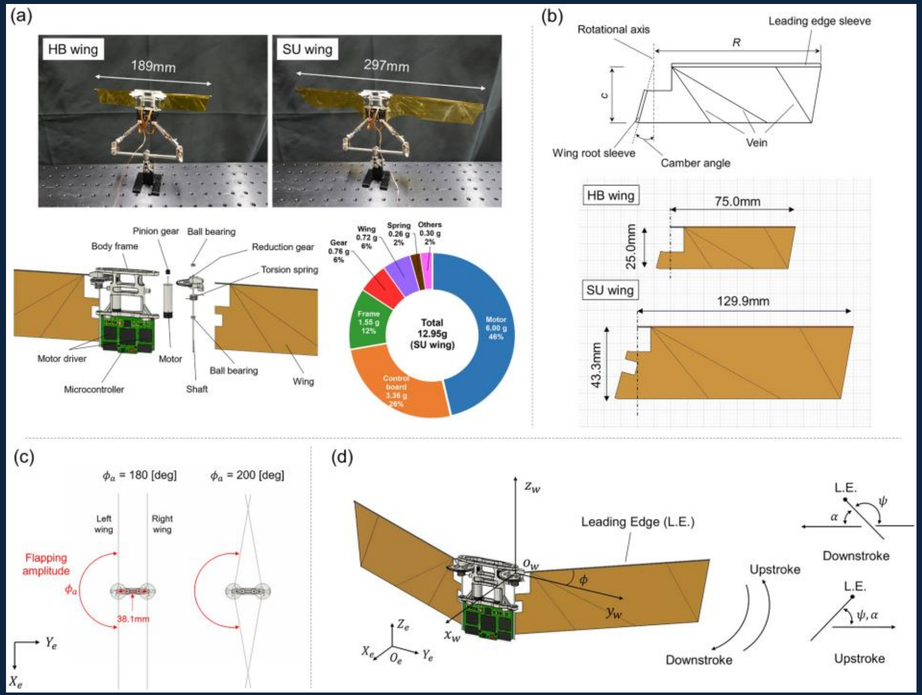
Would you be willing to adapt an engineering trade study approach to assemble your football team?

- The structure of a "prototypical" engineering trade study:
  1. Determine the question of interest
     - What type of wing design will give my aircraft the greatest range?
  2. Determine the experimental design
     - Identify a set of alternative wing designs that will be evaluated
     - Identify a set of contextual assumptions that will be varied to check sensitivity
  3. Collect authoritative data that describe the system
     - Collect detailed design characteristics of the aircraft
  4. Construct a simulation model of the system
     - Build a physics-based simulation of aircraft aerodynamics
  5. Run the simulation and collect results
     - Wing design B provides the greatest range



Tsuchiya, S., Aono, H., Asai, K. *et al.* First lift-off and flight performance of a tailless flapping-wing aerial robot in high-altitude environments. *Sci Rep* **13**, 8995 (2023). https://doi.org/10.1038/s41598-023-36174-5

This approach seems unlikely to be successful for the team assembly problem

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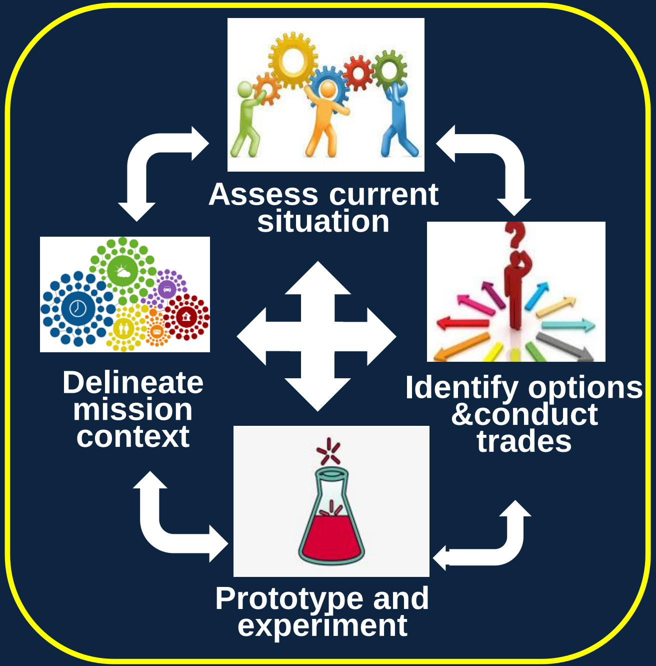
Employ the right mix of analysis approaches

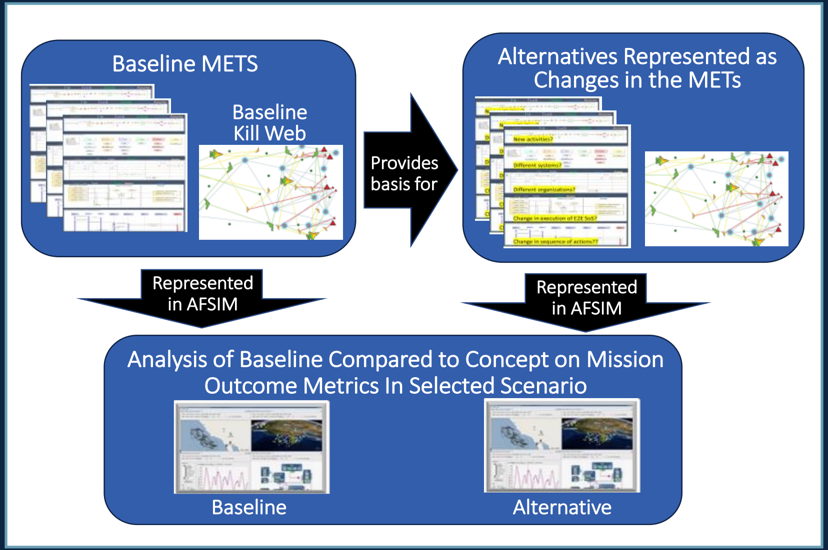
- A typical mission engineering problem is a really a hybrid of the football team problem and the traditional engineering problem
  - Many of the systems we employ can be simulated
  - But the human factor can be critical
- Consequently, any mission engineering study needs to determine the right mix of approaches that account for both
- As a result, mission engineering studies may be iterative and exploratory



Mission Engineering Playbook
Modular Open Online SE (MOOSE)
https://mitre.tahoe.appsembler.com/

A possible sequence

1. Subject matter experts identify gaps in current or anticipated mission execution
2. Mission threads (MTs) and mission engineering threads (METs) are constructed across one or more scenarios and vignettes to understand the gaps in context
3. METs are integrated to derive one or more SoS architectures that perform the mission. These are analyzed to determine to which key aspects should be modeled to quantify the gaps
4. A simulation model of the key aspects of the SoS architecture is constructed to quantify the gaps
5. Gaps that are determined to be significant are targeted for further analysis
6. A simulation experiment (SIMEX) with human operators in the loop is conducted to validate and better understand the gaps
7. SMEs identify candidate solutions potentially including changes to systems, doctrine, or technologies
8. Alternative METs are developed for candidate solutions and the process repeats until viable solutions are found



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Some things to consider

- When faced with many unknowns, it may be beneficial to reverse the direction of the question of interest:
  - Instead of asking, “What is the mission performance when we make this change?”
  - Ask “How much better would the change need to be to make a difference in mission performance?”
- Run screening and/or scoping experiments to avoid expending time and effort on irrelevant factors
  - Properly structured simulations can by used to screen for important factors and rule out irrelevant ones
  - Go only as deep as you need, more fidelity is not always better
  - Only use high-fidelity models, human-in-the-loop simulations, or prototyping to deep dive into critical areas

Some things to consider (continued)

- Focusing on a single, demanding scenario/vignette may lead to a brittle mission solution
  - The likelihood of any given scenario happening is quite low and the best solution for one scenario may be a poor solution for another
- Computer simulations are not good at modeling human behavior
  - Wargaming, tabletops, or simex may be useful to identify adaptive behavior and inform the representation of human behavior in the simulation
- Standard models and analysis approaches may implicitly contain “business as usual” assumptions, and in ME you often want to consider cases where business is not as usual
  - Probe and challenge assumptions in models and analysis techniques
  - Sometimes the assumptions may be necessary to perform the analysis, but understand the implications

https://www.seawarstore.com/NavalGames.htm

Recommended Reading

- Bankes, S. (1993). Exploratory modeling for policy analysis. *Operations research*, 41(3), 435-449.
- Bryant, B. P., & Lempert, R. J. (2010). Thinking inside the box: A participatory, computer-assisted approach to scenario discovery. *Technological Forecasting and Social Change*, 77(1), 34-49.
- Lempert, R. J. (2019). Robust decision making (RDM*). Decision making under deep uncertainty: From theory to practice*, 23-51.
- Pennock, M. J., & Bodner, D. A. (2020). A methodology for *modeling sociotechnical systems to facilitate exploratory policy analysis. Systems engineering*, 23(4), 409-422.