Using Technology Readiness Level (TRL), Life Cycle Cost (LCC), and Other Metrics to Supplement Equivalent System Mass (ESM) in Advanced Life Support (ALS)

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Metrics overview

- Designing metrics for Advanced Life Support (ALS)
- Candidate metrics for ALS
  - Equivalent Mass (EM)
  - Equivalent System Mass (ESM)
  - Life Cycle Cost (LCC)
  - Performance score
  - Technology Readiness Level (TRL)
- Comments
- Recommended ALS metrics

Designing metrics for ALS

- What are the objectives of ALS?
  - The ALS project plan goals are reducing cost, improving performance, and achieving flight readiness.
- How are these objectives achieved?
  - ALS selects projects to advance the mission readiness of low cost, high performance technologies.
- What is the role of metrics?
  - Metrics can help select good projects and report progress.
  - A good set of metrics reflects all the ALS goals.
- ALS needs metrics for cost, performance, and readiness.

Equivalent mass (EM) definition

- The EM of a system is the sum of the estimated mass of the hardware, of its required materials and spares, and of the pressurized volume, power supply, and cooling system needed to support the hardware in space.
  - EM is the total payload launch mass needed to provide and support a system.
- EM is a cost metric.
  - EM is directly proportional to the launch cost.

Equivalent Mass (EM) metric

- EM includes mass, volume, power, cooling, and materials and spares logistics.
  - Volume, power, and cooling are converted to mass using conversion factors called mass-equivalents.
- EM is equal to the sum of the system mass, **m**, the equivalent mass of the required volume, EM(**v**), the equivalent mass of the required power supply, EM(**p**), the equivalent mass of the required cooling system, EM(**c**), and the mass (M) of the materials and spares logistics, M(**l**).
- $EM(system) = \mathbf{m} + EM(\mathbf{v}) + EM(\mathbf{p}) + EM(\mathbf{c}) + M(\mathbf{l})$

Equivalent System Mass (ESM)metric

- ESM was established by NASA Advanced Life Support (ALS) for use in the ALS reporting metric.
  - ESM is closely based on traditional EM.
- Unlike EM, ESM is not a weighable mass indicating the system launch cost.
  - The "equivalent mass of crew time" is an added penalty mass, sometimes very large.
  - The "other cost items" in ESM are unidentified.
  - Masses "not part of ALS," such as food, may be omitted.

EM and ESM metrics for ALS

- EM is a useful measure of system launch cost.
  - Launch cost is a major mission cost.
  - But development and operations costs can be larger.
  - And systems with equal EM have very different launch costs if they go to Earth orbit or beyond.
- ESM is a cost metric similar to EM.
  - But its "improvements" over EM make ESM too complex.
    - ESM uses massive supporting documents and programs.
    - ESM requires dedicated, skilled analysts.
    - Computing ESM is the subject of many papers.

Life Cycle Cost (LCC)

- Life Cycle Cost (LCC) is a total mission cost estimate.
- LCC includes Design, Development, Test, and Evaluation (DDT&E), launch, and operations costs.
  - Launch cost is usually <u>not</u> the dominant cost.
    - For Earth orbit rather than planetary missions, launch cost is less than DDT&E cost.
    - For long duration missions, launch cost is less than operations cost.

Design, Development, Test, and Evaluation (DDT&E) cost

- Parametric cost models use cost estimating relationships (CER's) to estimate DDT&E cost.
- NASA uses the Advanced Missions Cost Model (AMCM).
  - $Cost = 10.59\ Q^{0.59}\ M^{0.66}\ 80.6^{T}\ G^{-0.36}\ 1.57^{D}$
    - Cost of DDT&E in millions of 1999 dollars.
    - Q is quantity, M is mass, T is type of mission, G is hardware generation, and D is difficulty.
  - The DDT&E cost for human missions is typically \$100 k/kg.
  - For a planetary mission it could reach \$1,000 k/kg.

Launch and emplacement cost

- The Space Shuttle launch cost to Low Earth Orbit (LEO) is $25 k/kg.
- For a Moon or Mars mission, we must launch to LEO the payload, vehicle and propellant.
  - For a Moon landing, a Moon orbit and return to LEO, or a Mars landing, the initial/payload mass ratio is roughly 20.
    - The vehicle and propellant launch cost is $500 k/kg of payload.
  - For a Mars orbit and return to LEO, the initial/payload mass ratio is roughly 50.
    - The vehicle and propellant launch cost is $1,250 k/kg of payload.

Operations cost

- The operations cost includes ground systems, mission control and planning, data analysis, and crew training.
- For manned spacecraft, the operations cost per year is roughly 11% of the total DDT&E and production cost.
  - For human missions, this is typically $11 k/kg/year.
  - For a planetary mission it would be much larger.
  - Operations cost increases with mission duration.

A LCC metric for ALS

- LCC includes the costs of development, launch and emplacement, and operations.
  - For a ten year crewed mission to LEO, the largest costs are typically for DDT&E and operations.
  - For a crewed planetary mission, the largest costs are typically for DDT&E and launch.
  - LCC is a better estimate of mission cost than EM.
- The LCC of the proposed ALS system is a good measure of ALS progress in reducing cost.

Performance score

- The basic requirements for life support are defined by human needs for air, water, and food.
  - Systems can be designed to meet the same performance requirements and then compared using cost.
- But technology selection can not neglect performance issues.
  - These include safety, microgravity capability, contamination, noise, flexibility, commonality, maintainability, and reliability.
- Performance scoring using weights and exponents to combine multiple criteria can help select good technology.
  - But such a performance score is too arbitrary to be a good metric.

Technology Readiness Level (TRL)

- TRL 1 - Basic principles observed and reported
- TRL 2 - Technology <u>concept</u> formulated
- TRL 3 - Critical function proof-of-concept
- TRL 4 - Component or <u>breadboard</u> validated in laboratory
- TRL 5 - Components validated in a relevant environment
- TRL 6 - <u>Prototype</u> demonstrated in a relevant environment
- TRL 7 - Prototype demonstrated in a space environment
- TRL 8 - Design <u>flight qualified</u>
- TRL 9 - System flight proven in mission operations

A TRL metric for ALS

- Technology Readiness Level (TRL) measures a system's readiness for space flight.
  - Key factor in International Space Station (ISS) hardware selection
  - Used in defining Advanced Life support (ALS) research categories
- TRL reflects a technology's advance to flight readiness and potential for mission selection.
  - Our continuing investments in ALS technology increase TRL.
- The TRL of a candidate ALS system is a good measure of ALS progress.
  - The system TRL can be the mass or cost weighted TRL of its components.

Comments

- Systems are designed to achieve <u>competing objectives</u>.
  - Even overwhelming superiority in one area can not offset serious deficiencies in another.
- Cost, performance, and readiness are <u>independent factors</u>.
  - Cost and performance do not systematically increase or decrease as readiness is advanced.
  - The achievable flight cost and performance change only when a different technology is adopted.
- Cost, performance, and readiness <u>must be traded off</u>.
  - Using any single metric such as ESM, TRL, or LCC, tends to obscure this important truth.

Recommended ALS metrics

- The ALS goals are cost, performance, flight readiness.
  - The corresponding project selection metrics are LCC, a performance score, and TRL.
- ALS probably should report only one metric.
  - Either the cost weighted TRL of the recommended system.
  - Or the LCC of the best system with components at TRL 5 or higher.
- But we still need to use LCC, performance score, and TRL to reflect all the ALS goals.
  - Otherwise the one reported goal will be overemphasized.
- And we need to consider LCC and performance at all TRL's.
  - Otherwise reaching TRL 5 will be overemphasized.