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Optimizing Spacecraft Lifespan: Balancing Mass and Propellant Fraction

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Abstract: Over the decades, scholars and data scientists have extensively explored the correlation between satellite mass and its impact on satellite reliability—an essential consideration for satellite manufacturers and space agencies [1]. Initially, a conceptual notion, a group of statisticians has now rigorously defined the reliability parameter of spacecraft across different mass categories, utilizing a survival analysis algorithm pioneered by Kaplan & Meier in 1958 [2]. J.H Saleh's analysis reveals that spacecraft in the medium-range category (with mass ranging from approximately 500-1000 kilograms) exhibits maximum reliability and a longer lifespan. This statistical model has provided a foundation for the next generation of data scientists to redefine satellite reliability models [3].

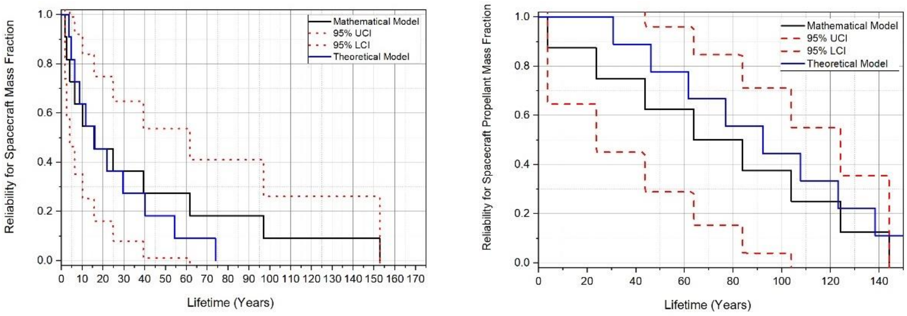

Figure-1: (left) Spacecraft Mass Fraction versus reliability & Spacecraft propellant mass fraction versus reliability (right) [Note: These graphs were generated using Kaplan-Meier estimation method, whereas the figure graph were estimated from Weibull probability estimation]

Examining mass parameters such as spacecraft dry mass, propellant mass, and payload mass, the role of propellant mass emerges as crucial in determining spacecraft survival in various planetary orbits. Propellant facilitates trajectory raising maneuvers, course corrections, and orbital stabilization (e.g., ESA's Cassini's final plunge due to propellant exhaustion). Therefore, integrating a larger propellant tank into a relatively small spacecraft may not extend its lifespan; in fact, it could lead to spacecraft destabilization. Maintaining an optimal propellant and spacecraft mass ratio becomes paramount for effective operations. Addressing this, an innovative mathematical and statistical model has been introduced and validated, defining a propellant mass fraction limit of 0.2 to 0.6 as optimal for longer survivability [4-5].

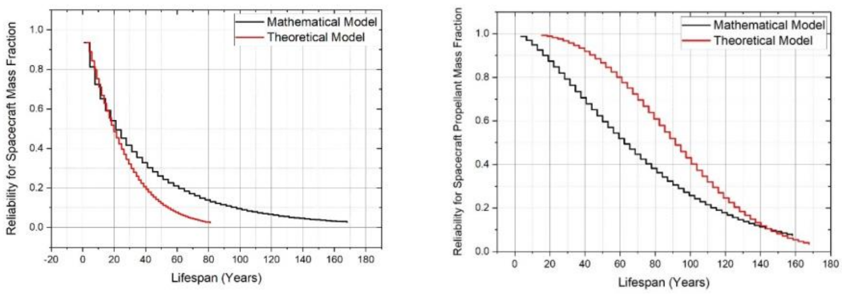

Figure-2: Spacecraft Mass and Propellant mass fraction versus reliability.

In conclusion, the various masses of a spacecraft significantly impact its lifespan and reliability. Satellite manufacturers must carefully consider mass and mass fraction parameters during the design and validation phases to ensure the spacecraft's optimal performance before deploying it into any interplanetary orbit. This consideration remains a critical task, especially as recovering a spacecraft beyond low-earth orbit poses significant challenges.

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