Satellite System Engineering

-- Budget & Margin

Prof Dr Shufan Wu
Chinese Academy of Science (CAS)
Shanghai Engineering Centre for Microsatellite
Haike Road 99, Shanghai, China
Email: shufan.wu@mail.sim.ac.cn

Main System Budgets

Overall System synthesis is based on budgets:

- Mass budget
- Delta-V and Propellant budget
- Power/Energy budget
- Data budget
- Link budget
- Pointing error budget
- Cost

Mass Budget

Main purposes of mass budget:

- Ensure mission is launchable with a given margin
- Provide reference total mass for subsystem analyses

Element 1 Ocean Earth Watch

						Target Spacecraft Mass at Launch		950.00	kg
						Below Mass Target by:		920.00	kg
	Input Mass	Input Margin	Dry mass contributions	Without Margin		Margin %	Margin kg	Total kg	% of Total
EL			Structure	0.00	kg	-	-	-	-
EL			Thermal Control	0.00	kg	-	-	-	-
EL			Mechanisms	0.00	kg	-	-	-	-
EL			Communications	0.00	kg	-	-	-	-
EL			Data Handling	0.00	kg	-	-	-	-
EL			AOCS	0.00	kg	-	-	-	-
EL			Propulsion	0.00	kg	-	-	-	-
EL			Power	0.00	kg	-	-	-	-
DI			Harness	0.00	kg	0.00	0.00	0.00	0.00
EL			Instruments	0.00	kg	0.00	0.00	0.00	0.00
			Total Dry(excl.adapter)	0.00				0.00	kg
			System margin (excl.adapter)			20.00	%	0.00	kg
			Total Dry with margin (excl.adapter)					0.00	kg
			Other contributions						
			Wet mass contributions						
EL			Propellant	0.00	kg	-	-	-	-
			Adapter mass (including sep. mech.), kg	30.00	kg	0.00	0.00	30.00	1.00
			Total wet mass (excl.adapter)					0.00	kg
			Launch mass (including adapter)					30.00	kg

Mass Budget (cont.)

- A bottom-up exercise from unit to subsystem to system
- Subsystem breakdown is arbitrary but a convention needs to be fixed
- Requires a preliminary design; however a starting point needs to be given (first guess)
- Margins shall be explicit at all levels
- Launcher adapter mass shall be taken into account as it subtracts from the available launcher performance

Need for Margins

- Mass is usually a driving parameter for all space missions. It can make the mission unfeasible
- Just about everything else can be somehow negotiated (except at times cost and in rarer cases launch date)
- During the development of a project, the value of every early mass estimation tends to increase due to several reasons:
  - Change of requirements
  - Unforeseen design issues (e.g. under-evaluation of environmental factors, etc.)
  - Poor knowledge of technology performance (low TRL)
  - Optimism (need to "sell" the mission)
- To cope with this critical uncertainty, margins are introduced

Margin Approach

- In theory, margins could be defined statistically by assessing the possible range of variations of all the mass drivers (e.g. delta-V, radiation dose, disturbance torque, etc.) and running a Montecarlo analysis to find the overall ΔM corresponding to all possible combinations of variations
- This requires the availability of a reliable system model and it is very complex unless only few drivers can be identified. Therefore this approach is implemented only in special cases (e.g. launchers, landers, etc.)
- In practice, a more simplistic approach is followed using a cascade of coefficients σ so that: $M^* = M + \sigma M$

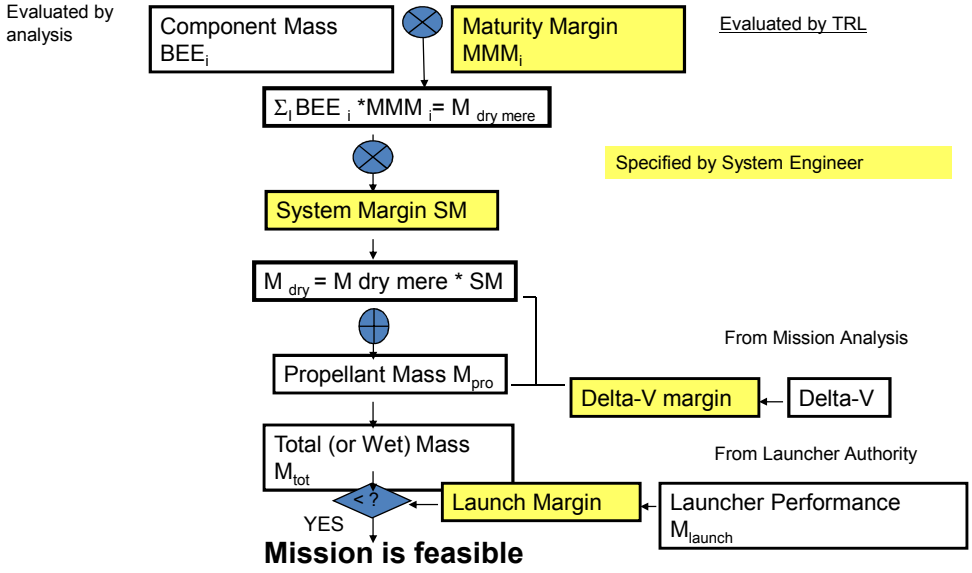
Mass Margin Definition (CDF rules)

- A cascade of margin from basic units upwards
- Design units/subsystems always for the relevant worst (load) cases
- Include design margin, safety factors, redundancies, at unit/subsystem level
- Add technology margin at unit level (based on TRL):
  - 5% mass margin at subsystem level must be considered if the related technology is well known and already space proven (TRL8 or 9)
  - 10% mass margin at subsystem level must be considered if the related technology is not well known and already space proven (6<TRL<7)
  - 20% mass margin at (sub)system level is strongly recommended in general and is compulsory if a new technology is necessary (TRL≤5).
- Uncertainties and possible changes in requirements: 20% margin at system level
- Propellant to be computed against the S/C dry mass, including system margin
- Always size tanks taking into account a min ullage (95% filling factor max)
- Launcher margin shall be considered. Final wet mass of the spacecraft must be smaller or equal to the launcher capabilities (5-10% margin is recommended)

Other Margins Definition (CDF Rules)

- ΔV margin, at least 5% (higher if gravity losses are not accounted for)
- Data processing margin
  - 50% for mass memory
  - 100% for computing power
- Communications, 3 dB in the link budget
- Temperatures, ±10 deg
- Power, 20% in the power budget
- Consumables (AOCS propellant, battery, to be sized for mission lifetime + extension)
- Propellant residuals (unusable): 3% of propellant mass

Mass margins & Mass budget



More on margins

- Margins are the property of the system engineer
- Always have robust margins but be careful to oversize your system.
- Lot of pressure to reduce margin to have more payload
- Margins evolve with mission phases a typical evolution is:
  - 20% at SRR
  - 15 % at PDR
  - 10% at CDR
  - 5% or less at FAR

Harness

- Harness mass calculation is difficult in phase 0
- Bottom-up approach virtually impossible
- A statistical model based on previous spacecraft data is used in CDF: Interpolation of harness mass versus S/C mass and dimensions
- Alternative: count number of boxes and connections from electrical architecture
- 5% of total mass a starting point