

Cost Engineering in the ESA Academy Concurrent Engineering Workshop

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ESA Internal

- **ESA Internal University Cost Estimating Course** (2 days, every year)
- **Concurrent Design of Space Systems Course** – lecture on cost engineering
- **ESA Systems Engineering Academy** – lecture on cost engineering

Universities

- **TU Delft Space System Engineering** students yearly lecture on cost engineering
- **ISAE-SUPAERO** students yearly lecture on cost engineering

For students, with the ESA Academy

- **ESA/CNES Student Cost Estimating Challenge**
2 winning students the ESA Academy Concurrent Engineering Course
- Support to the **ESA Academy Concurrent Engineering workshop** in Redu.



STEM LEARNING & INSPIRATION

ESA ACADEMY



esa academy



For tertiary-level students & early-career professionals from ESA Member and Associate States



Connecting academia & industry by transferring space know-how and fostering interactions with professionals



Boosting careers in space through enriched academic education and increased employability



Driving innovation & entrepreneurship to tackle real community needs





- ❖ Conference Student Sponsorship
- ❖ Short Course Scholarships
- ❖ Academic Scholarships
- ❖ Book a Space Pro (pilot) & Alma Mater
- ❖ Careers For You
- ❖ Collaborations

<https://www.esa.int/Education/Engagement>

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Projects - Example

REXUS

Facility:

Sounding rocket, Esrange Space Center
(Sweden)

Microgravity: Up to 10⁻⁴ g, ~ 2 minutes

Goal:

Development of an experiment
and launch campaign

Call for proposals:

Once a year

Who can apply:

Team: bachelor, master, PhD students



BEXUS

Facility:

Stratospheric balloon, Esrange Space Center
(Sweden)

2-5h floating at 20-30 km altitude

Goal:

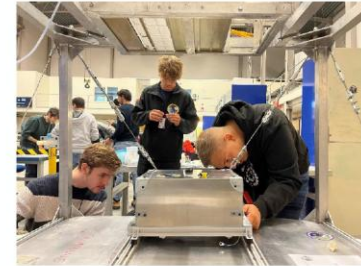
Development of an experiment
and launch campaign

Call for proposals:

Once a year

Who can apply:

Team: bachelor, master, PhD students



Rymdstyrelsen
Swedish National Space Agency





Facility: Training and Learning Facility
ESA/ESEC-Galaxia (BE) + ESOC, ESTEC +
online

What: 1–4 week intensive training
sessions

Learners: Bachelor/Master/PhD + early-
career (30 students per class)

When: Continuous, 1-2 sessions per month,
new calls for applications every few weeks

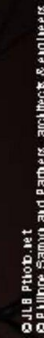
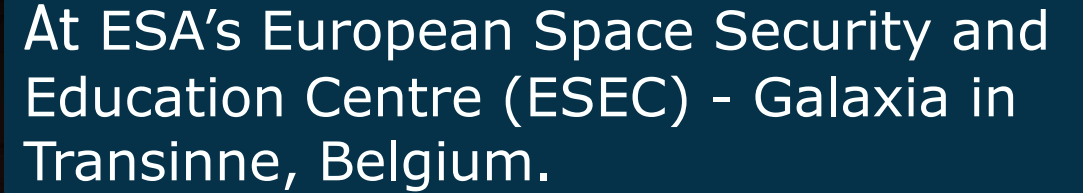


Scan for more information
about the Training
Programme



Example: CubeSat Summer School



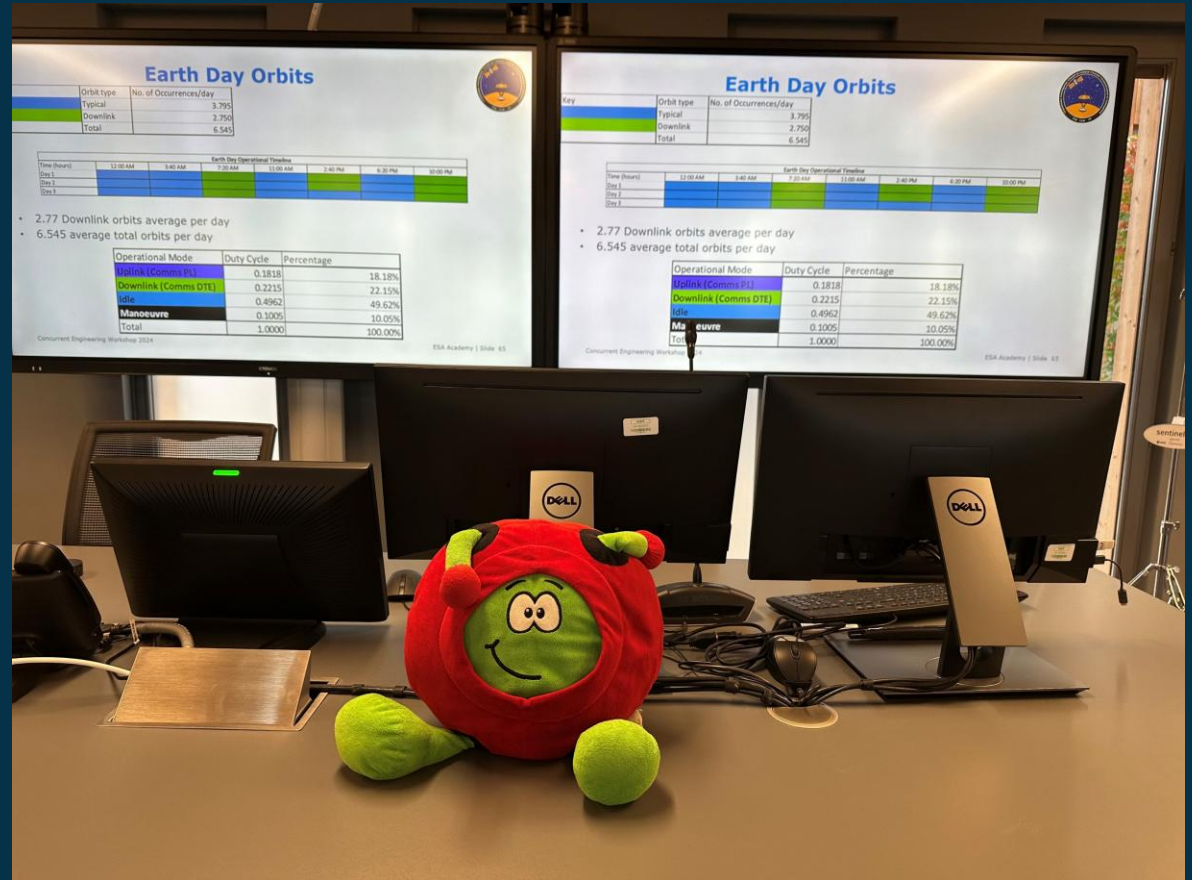


Concurrent Engineering Workshop

This intensive workshop introduces students to the concurrent engineering approach, a method used at ESA to efficiently design space missions.

traditional design methods:
subsystems are developed sequentially

concurrent engineering:
all subsystems are designed simultaneously in a collaborative, multidisciplinary environment.





esa academy
training and learning facility



Cost Engineering in the Workshop

In 2024 Cost Engineering has been added to the disciplines covered in the Workshop

One or two participants made responsible for cost estimates, cost trades and design-to-cost.

The ESA Cost Engineering section is supporting this with onsite guidance for some of the Workshop editions and online consultancy for others.

Cost Estimation Tool for the Workshop

ESA Cost Engineering has developed an educational cost estimation tool

- sufficient in scope and realism for use by the students
- yet does not contain confidential information.

Subsystem		Phase B2		Phase C/D		Phase E1		Unit Mass excl. Margin [kg]			Design Status	
Power		0		20,010		0			Area [m2]	Type		
	Solar Arrays				13,060				15.0	Deployable	Newly Developed	
	PCDU	0		4,820				20.0			Modified	
Battery		0		2,130					Capacity [Wh]	Type		
	Radioisotope Thermoelectric Generator (RTG)			0				45.0	2,000		Newly Developed	

Hardware Matrix		Indicated values are cost multiplication factors w.r.t. 1 FM															
Total Equivalent Models	# of BB - BreadBoard	Rel. value w.r.t. FM	# of Mass Dummies	Rel. value w.r.t. FM	# of SM - Structural Model	Rel. value w.r.t. FM	Structural Thermal Model	Rel. value w.r.t. FM	# of EM - Engineering Model	Rel. value w.r.t. FM	Eng. Qualification Model	Rel. value w.r.t. FM	# of QM - Qualification Model	Rel. value w.r.t. FM	# of PFM - ProtoFlight Model	Rel. value w.r.t. FM	
1.3	0	0.1	0	0.1	0	0.1	0	0.3	0	0.5	0	1.0	0	1.1	1	1.3	1.0 in combination with (E)QM
2.3	0	0.1	0	0.1	0	0.1	0	0.3	0	0.5	0	0.8	0	1.1	1	1.3	1.0 in combination with (E)QM
0.0	0	0.1	0	0.1	0	0.1	0	0.3	0	0.5	0	1.0	0	1.1	0	1.3	1.0 in combination with (E)QM

Cost Estimation Tool for the Workshop



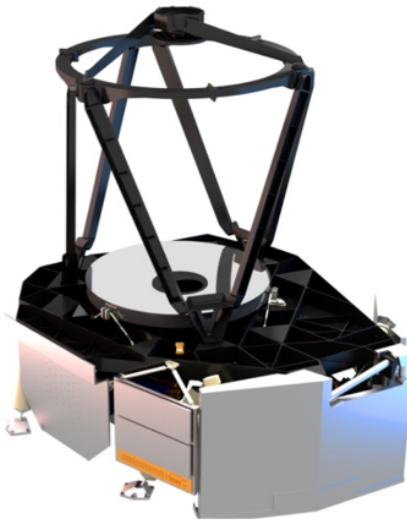
Reflector Telescope Assembly mainly applicable for large science space telescopes
Excluding payload instruments and their integration (except for Gaia-like assemblies, which are effectively PLMs).

Cost in k€ EC **Mid-2024**

General Model Philosophy: **Dummies + PFMs + some Spares** (uncoated blanks for Mirrors)
Refocussing Mechanism: STM + EQM + (P)FM + Spares if new development; PFM + Spares if modified.

Optics Inputs

Aperture Diameter	<div>Circular<div>1.00</div>m</div> or <div>Elliptical<div>m</div> x <div>m</div></div>	Retained <div>1.00</div> m	0.50 to 2.5 meter
If M1 AND Secondary Optics surface areas are known (else leave empty):			
Primary Reflector Mirror, M1	<div>Circular Diameter<div></div>m</div> or <div>Elliptical Dimensions<div>m</div> x <div>m</div></div>	Retained <div>0.00</div>	m² M1 surface area (0.5 to 10 m²)
Central Hole in Primary (if any)	<div></div> m		
Secondary Optics: M2, M3, etc.	sum of secondary reflectors surface areas		m² combined secondary optics surface area (0.05 to 0.7 m²)
Gaia-like Telescope Assembly (= PLM incl. instrument integration)	☐ Yes	For Gaia-type telescopes, aperture and mirror dimensions (use equivalent circular diameter) should be the sums for the combined two telescopes.	



Cost Estimation Tool for the Workshop

Cost in k€		Economic Conditions:		Mid-2024			Legend:	INPUT	RESULT	FIXED	N/A	Cost Estimate Input Parameters		
		Phase B1		Phase B2		Phase C/D		Phase E1				Complexity (scale 1 to 5)		
Spacecraft System Level Activities														
Project Office		3,300		19,120		57,400		8,060						
Management			900		4,900		12,000		600			3.0		
Product Assurance			500		2,600		6,300		320			3.0		
Engineering			1,900		11,000		26,700		1,340			3.0		
Assembly, Integration and Verification/Test (AIV/T)					620		12,400		5,800			3.0		
Facilities		0		0		4,400		2,000						
Cleanrooms and Test Facilities use for AIV/T							4,400							
Spacecraft Storage incl. regular checks									2,000				5.0	Months storage
Ground Support Equipment		0		0		2,300		0						
Mechanical + Electrical Ground Support Equipment (MGSE + EGSE)							2,300					0.5	Lower limit is 1	
Spacecraft System Complexity ranges from 1.0 to 5.0, with 1 for the most simple spacecraft, 3 for "typical" spacecraft, 5 for the most complex. Examples:														
Based on existing satellite Platform, simple Payload interfaces, few payload instruments													~1.0	
Based on existing Platform but with significant modifications (e.g. Proba 1, Proba 2, Cryosat-1, Sentinel 5P)													~2.0	
"Typical" spacecraft, specifically developed platform mostly based on existing equipment, medium size, medium complexity payload interfaces (e.g. Mars Express, SOHO, Seosat, Sentinel 3A).													~3.0	
Complex spacecraft, specifically developed platform with much new/modified equipment, large, complex payload requirements and interfaces, many payload instruments (e.g. BepiColombo MPO, Integral, ISO, Rosetta, EarthCare).													~4.0	
Complexities can be different between Management, Engineering etc. For instance, a spacecraft with AIV/T complexity 3 may have a Management complexity of 4 due to a complex industrial organisation with many companies and/or inter-Agency cooperation.														

Selection of the students who will act as Cost Engineers is done by ESA and CNES Cost Engineering.

This is done through the **ESA/CNES Cost Estimating Challenge**

1. We define a Space Mission, with high-level requirements, definition and mass budget.
2. We ask a number of questions for the students to solve, for example:
 - Estimate the cost of the development and production of the first, Proto-Flight Model (PFM);
 - Estimate the cost of the entire constellation of 1 PFM, 23 Recurring Flight Models (RFM) and 1 (not launched) Spare Flight Model;
 - Estimate the cost of operating the satellites for 5 years;
 - Estimate the cost of an enhanced constellation consisting of 5 instead of 4 satellites per orbital plane;
 - On the basis of the above estimates, make a viable proposal to reduce the total cost by at least 10%.

ESA/CNES Cost Estimating Challenge

Estimate the total Life Cycle Cost for a Small Mars Communication and Navigation Constellation

The goal of this challenge is to estimate the cost for a small constellation of Mars Telecommunications and Navigation satellites, to be developed, launched and operated by a commercial space company. These satellites will support landers and rovers on Mars with communication services as well as positioning services.

The definition of this constellation is in a very early stage, hence only high-level information is currently available. Nevertheless, a Rough Order of Magnitude (ROM) cost estimate, with some breakdown to the level of major cost elements, is needed to assess the commercial viability/affordability of the constellation and to be able to compare it with competing projects and options.

System

- 24 identical satellites in 6 orbital planes (4 per plane), plus 1 on-ground spare;
- Mars orbits, circular altitude of 9100 km, each plane 20 degrees inclination.
- Satellites are 3-axis stabilised.

Technical Data

- Satellite Mass Budget:

Subsystem	Mass [kg]
AOCS	30
Power	120
Harness	35
Data Handling	40
Communications	60
Chemical Propulsion	45
Equipment	20
Propellant	25
Structure	180
Thermal	20
Mechanisms (antenna pointing mechanisms, solar array drive mechanisms)	100
Platform Wet Mass	630
Communications & Navigation Payload	230
Total Launch Mass per Sat	860

Programmatics

- Use of existing, off-the-shelf equipment for the platform, but with specifically designed Structure, Thermal and Harness.
- The Payload Instrument is however newly developed (developed already up to Technology Readiness Level 5, i.e. TRL-5, before the start of this satellite project).
- The estimated development duration (Phase B/C/D) for the first satellite is 4 years.
- Multiple launchers and Propulsion Modules will be required to launch the satellites to Mars and place them in the various orbits. **The cost of the launchers and the Propulsion Modules are beyond the scope of this challenge and can be excluded.**
- 5 years of in-orbit operational life using a ground segment with a new control centre and existing ground antenna network.

Payload Cost

From the pre-selected payload provider it is already known that:

- The development and production of the first payload units for the first satellite will cost **25 M€[2025]** (25 million euro in prices of 2025);
- The production of the additional 24 recurring payload units (23 operational plus 1 flight spare) will cost in total **140 M€[2025]**.

The Challenge:

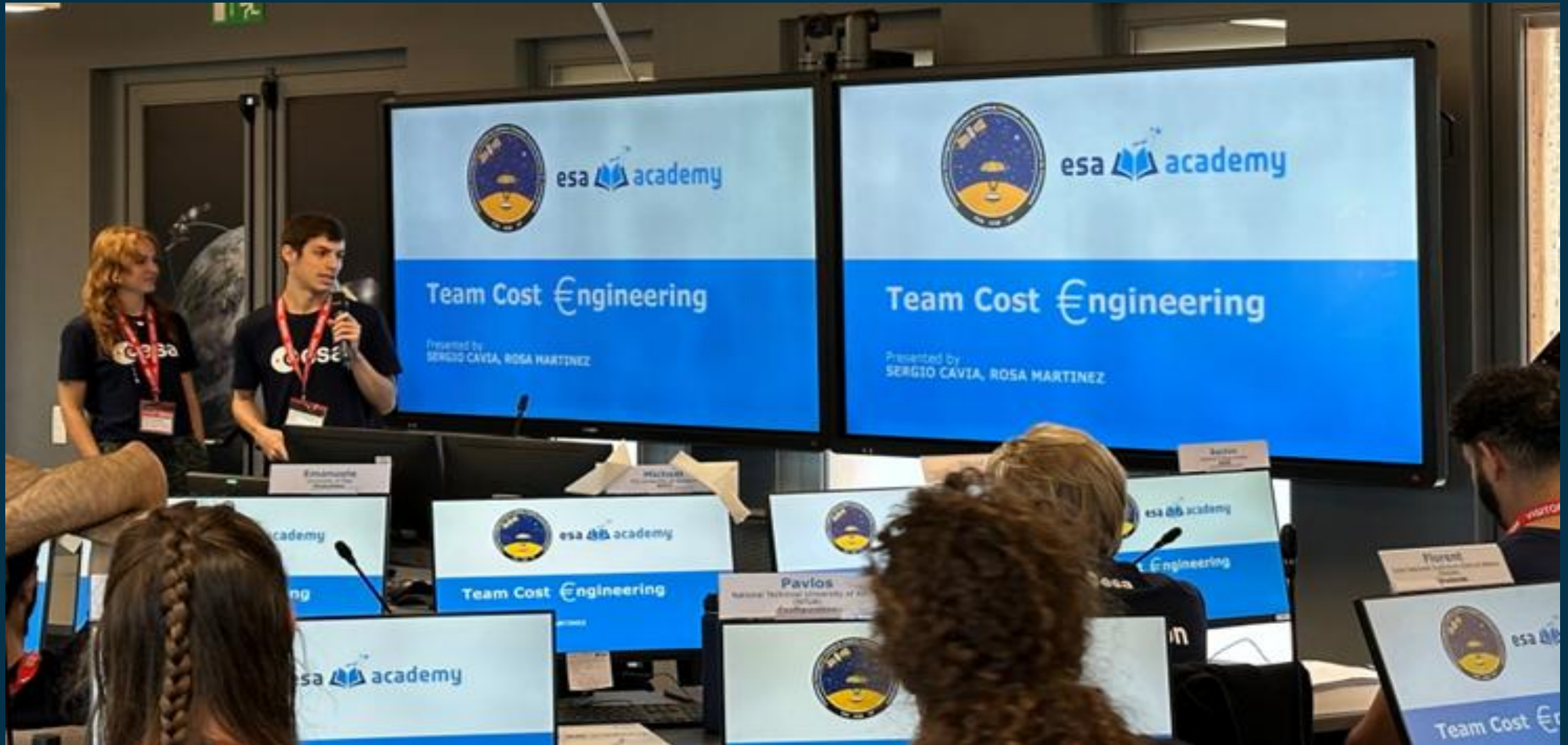
1. Estimate the cost of the development and production of the first, Proto-Flight Model (PFM), satellite;
2. Estimate the cost of the entire constellation of 1 PFM, 23 Recurring Flight Models (RFM) and 1 (not launched) Spare Flight Model;
3. Estimate the cost of operating the satellites for 5 years.
4. Estimate the cost of an enhanced constellation consisting of 5 instead of 4 satellites per orbital plane.
5. On the basis of the above estimates, make a viable proposal to reduce the total cost by at least 10%.

This to be detailed in a Working file with the estimates (Excel or other), plus a short set of Powerpoint slides with the results, logic, assumptions etc (imagine you have to present your estimate to the “customer”).

The cost estimating methods, assumptions, references etc. need to be explained. Where information needed for cost estimation relationships is missing, please make your own assumptions based on the information that is available here, as well as publicly available references you may find for similar platforms and payloads. Furthermore you may point out options and alternatives that may influence the total cost.

Note that the main point of this Challenge is not the estimate itself but rather the structure and logic with which your estimates are made.

Cost Engineering in the Workshop



Cost Engineering in the Workshop



Cost Summary

- Total Cost without margin: 387.2 M€
- Feasible mission

Figure 9. Comparison between cost estimation models and actual estimation.

Estimation Models Comparison

Cost (M€)

USQMB Quick-Cost Actual Estimation

Cost Estimation Model

Summary

Total: 465.3 M€

System Level Cost Budget

- Platform H&S
- System Level Activ.
- Launcher
- Operations
- Risk Margin (~70% CL)

Figure 10. Final cost summary including margins and launch costs.

ESA Academy | Slide 166

Michael

The University of Glasgow

APCS

Summary

Cost Summary

Risk Margin

Risk Margin Analysis & Philosophy

- ~70% Confidence Level (CL)
- ~20% Risk Margin over total mission costs (Phase 0-A)

Figure 6. Platform subsystems risk margin.

Platform Cost Risk Margin

Cost (M€)

AC&C/CMC Propulsion Power Data Handling Onboard Software Structure Thermal Mechanisms

Risk Margin

Risk Margin and Confidence Level

Figure 7. Risk Margin and Confidence Level comparison.

Confidence Level

30.0% 68.8% 95.0% 99.7%

Figure 8. Platform subsystems risk margin.

Platform Cost Risk Margin

Cost (M€)

AC&C/CMC Propulsion Power Data Handling Onboard Software Structure Thermal Mechanisms

Florent

Ecole Nationale Supérieure d'Arts et Métiers (ENSAH)

Structures

Risk Margin

Risk Margin Analysis

Risk Margin and Confidence Level

Risk Margin and Confidence Level comparison.

- Involving students in educational Concurrent Engineering studies/workshops in a cost engineering role is a great way to get them interested in our domain.
- Cost models can be developed/adapted for student use, but:
 - Must not contain sensitive information and hence not be overly accurate (use public domain cost information, do not show the used data, simplify and distort parametric relationships)
 - But still maintain logical trends, relative magnitudes and realistic overall ROM outcomes as to remain educational.
- Guidance and support by professional cost engineers is usually required.
- Apart from the immediate educational aspects, it has also proven to raise interest among students to pursue a career in cost engineering after graduation.