Cost-Benefit Analysis of SysML Modelling

for the Atomic Clock Ensemble in Space (ACES) Simulator

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Outline of the presentation

1. Introduction
2. Cost/Benefits Analysis methodology
3. Results of the analysis
4. Improving the analysis
5. About SysML
6. Conclusions

1. Introduction

1.1 Sponsors

1. Introduction

1.2 Presentation of ACES

- Project on which modelling activities were performed
- ACES = Atomic Clocks Ensemble in Space

1. Introduction

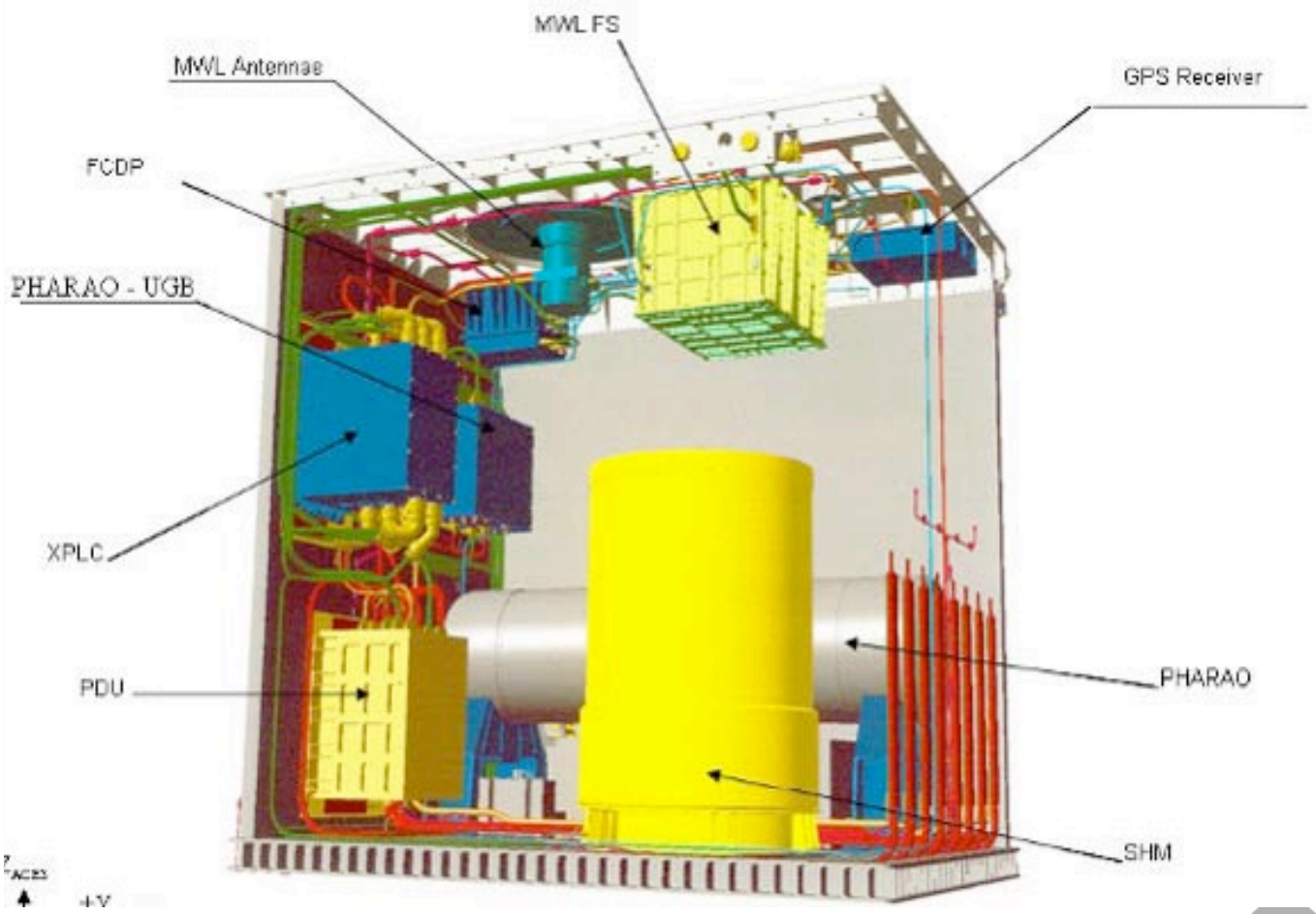
1.2 Presentation of ACES

- External Payload for the ISS
- 2 atomic clocks + supporting subsystems
- ACES has 3 main objectives:

1. Demonstrate the high performance of a new generation of atomic clocks (1 s accuracy in 300 million years)
2. Demonstrate capability to compare ground clocks at high accuracies
3. Perform fundamental physics experiments with *large improvements* in measurement's precision.

1. Introduction

1.2 Presentation of ACES



PHARAO = **P**rojet d'**H**orloge **A**tomique par **R**efroidissement d'**A**tome en **O**rbite

SHM = **S**pace **H**ydrogen **M**aser

PDU = **P**ower **D**istribution **U**nit

XPLC = e**X**ternal **P**ay**L**oad **C**omputer

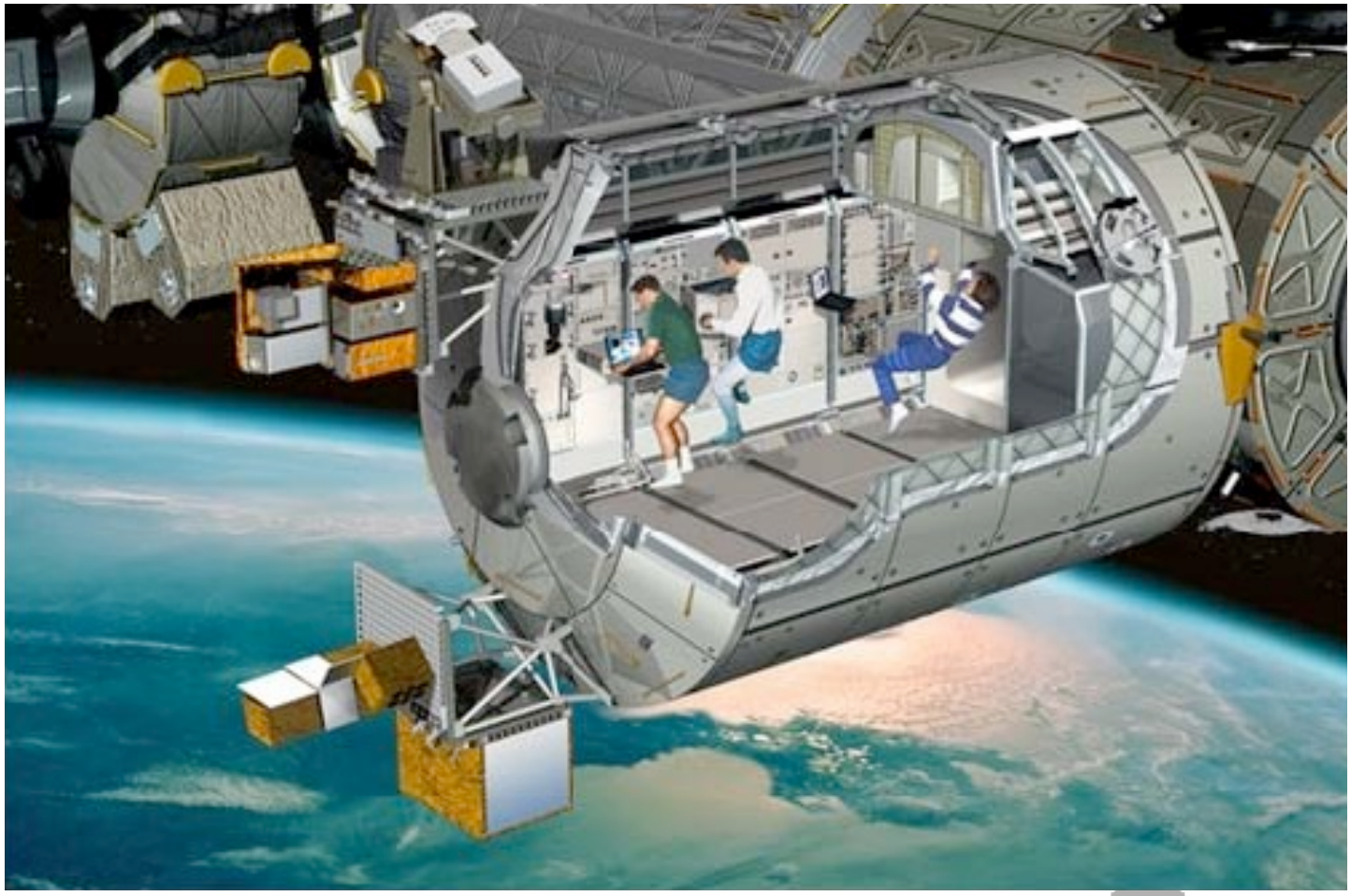
PHARAO UGB = PHARAO **U**nité de **G**estion de **B**ord

FCDP = Frequency Comparison and Distribution Package

MWL = MicroWave Link

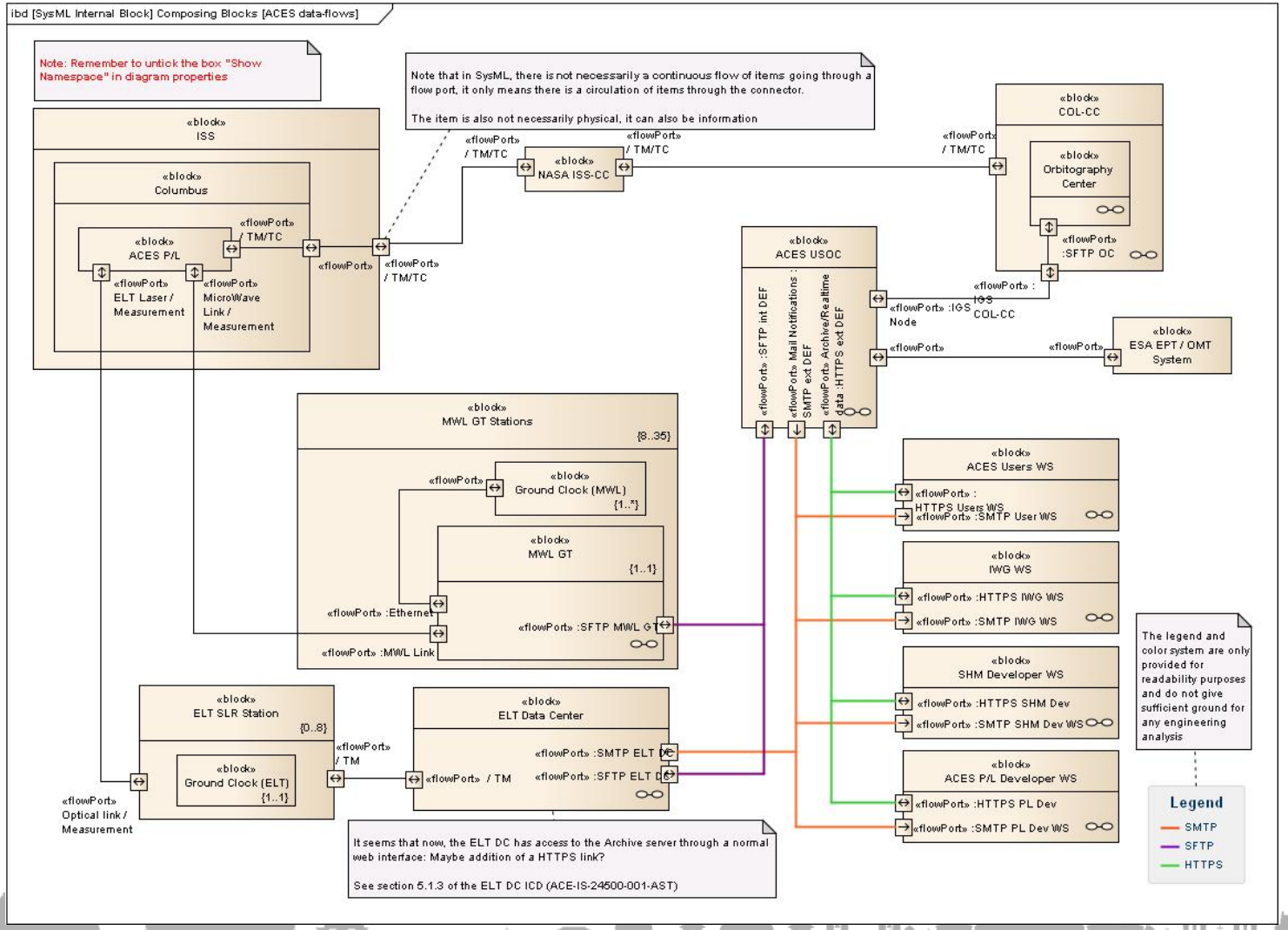
1. Introduction

1.2 Presentation of ACES



1. Introduction

1.3 Example of work performed



2. Analysis Methodology

2.1 Foreword

- Purpose is only to **suggest a way of making the Cost-Benefit analysis**, not giving final results
- Improvements have to be made to the methodology to remove potential bias

2. Analysis Methodology

2.2 Basis

- Two alternatives considered:
  - Document-Based Systems Engineering
  - Model-Based Systems Engineering with SysML
- Each alternative *i* is given a "final score F_i"
- F_i is the ratio of a "benefits score S_i" to a "cost ratio R_i":

$$F_i = \frac{S_i}{R_i}$$

2. Analysis Methodology

2.3 Evaluation of S_i

3 aspects to be covered:

1. What is measured?
   => Characteristics (ex: diameter)
2. On what is it measured?
   => Object of the measurement (ex: pipe)
3. How is it measured?
   => Measurement procedure (ex: using a calliper)

2. Analysis Methodology

2.3 Evaluation of S_i

What is measured ?

What do we write documents for?

Documents writing aims to **store information** on one hand, and **communicate it** on the other.

2. Analysis Methodology

2.3 Evaluation of S_i

- Information Storage
  - Completeness
  - Consistency
  - Extendibility
- Communication
  - Readability
  - Good layering

2. Analysis Methodology

2.3 Evaluation of S_i

On what is it measured?

- Ideally, a **set documents** should be compared to a **model** containing exactly the same information
- In practice, the information contained in each object of measurement tends to differ

2. Analysis Methodology

2.3 Evaluation of S_i

How is it measured ?

- **Analytical Hierarchy Process** (Thomas L. Saaty) allows extracting global scores out of **pair-wise comparisons**
- **Arguments** were held to **justify** the outcome of each pair-wise comparison

2. Analysis Methodology

2.4 Costs ratios & cost model

$$F_i = \frac{S_i}{R_i}$$

The sum of the total cost of each alternative is used to generate a unitless cost ratio

$$R_i = \frac{C_i}{\sum_j C_j}$$

2. Analysis Methodology

2.4 Costs ratios & cost model

$$C_{DBSE} = a_1 Q + b_1 \qquad C_{MBSE} = a_2 Q + b_2$$

$$C_{MBSE} = a_2 \frac{C_{DBSE} - b_1}{a_1} + b_2$$

$$C_{MBSE} = a' C_{DBSE} + b'$$

3. Results

- Benefit Scores:
  - $S_{MBSE} \approx 0.564$
  - $S_{DBSE} \approx 0.436$
- Cost ratios:
  - $R_{MBSE} \approx 0.489$
  - $R_{DBSE} \approx 0.511$

$$F_i = \frac{S_i}{R_i}$$

- Final Scores:
  - $F_{MBSE} \approx 1.15$
  - $F_{DBSE} \approx 0.85$

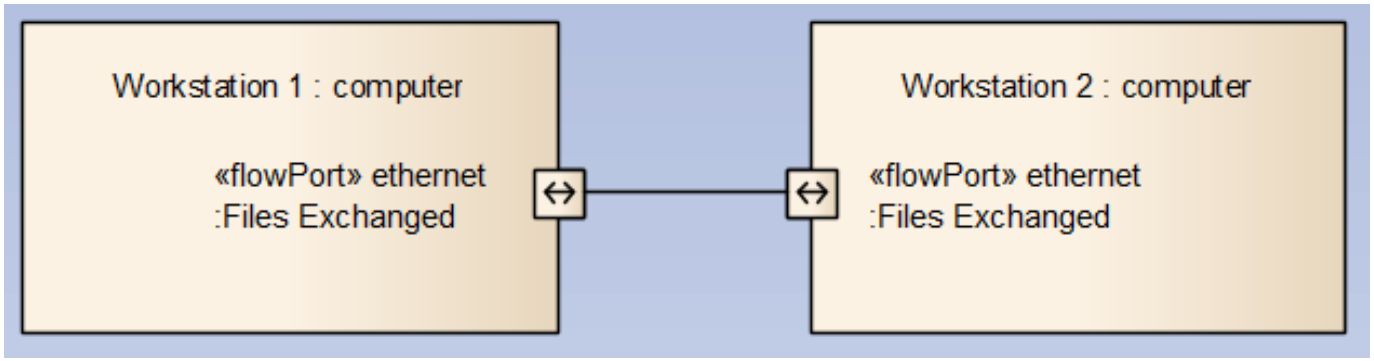
4. Improving the analysis

1. **Consider more than 2 alternatives** (MBSE with SysML, DBSE and ... ?)
2. **Investigate way to remove any bias in pair-wise comparison** (use more people)
3. **Improve of the cost evaluation** (use a more detailed analysis)

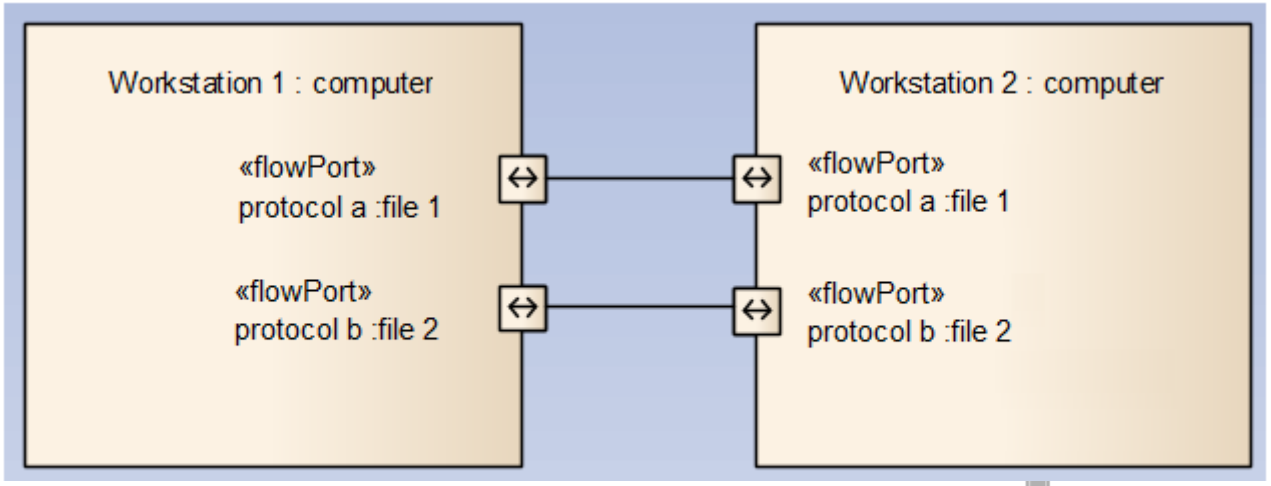
5. About SysML

5.1 Sample problem: Data flows

1



2



5. About SysML

5.2 Lessons learned

1. Always have clear modelling objectives, to avoid making someone else's work
2. Do not undertake modelling activities without a proper training
3. Take extreme care when showing diagrams to "non-initiateds": they will misunderstand it

5. About SysML

5.2 Lessons learned

4. Do not use MBSE with SysML for requirements handling only

5. Though it provides, in a way, some guidance, SysML does not substitute to experience in Systems Engineering

5. About SysML

5.3 Ideas for improvement

1. Replacing the conjugation of flow ports by something more intuitive
2. Allowing to organise ports into a hierarchy
3. Separating the SysML definition from UML
4. Providing the SysML Specifications with an MBSE dictionary

6. Conclusion

6.1 MBSE with SysML: Pros and Cons

- Advantages:
  - Design information is nearly perfectly consistent
  - Relevant information is easily found
  - Model and diagrams point out missing design information
  - Opens the way to automated Systems Engineering
- Drawbacks
  - Steep learning curve
  - Requires a significant knowledge before advantages show
  - Diagrams easily misunderstood if SysML not learned beforehand
  - Tools are not completely ready yet

6. Conclusion

6.2 Final word

Yes:

- Analysis seems to show **MBSE with SysML is worth being used**
- MBSE with SysML **does successfully tackle crucial problems** of modern Systems Engineering, and gives them an answer

But:

- **Radically changes** from the DBSE approach
- In practice, it **still needs significant improvements** before becoming a standard in the industry

Thank you for attention!

Any question?

1. Introduction

Problems of DBSE

- **Hard to find information**: often need to read a lot before information is found
- **Inconsistency**: updates of one piece of information has to done everywhere it appears
- **Difficult communication**: the more complex the system is, the more difficult it is to explain how it works with words

5. About SysML

5.3 Ideas for improvement

4. New: All integrated MBSE