



MINISTÉRIO DA CIÊNCIA, TECNOLOGIA, INOVAÇÕES E COMUNICAÇÕES
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS



Curso de Inverno 2018
Introdução às Tecnologias Espaciais



CPRIME: Centro de Projeto Integrado de Missões Espaciais.

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11Jul2018

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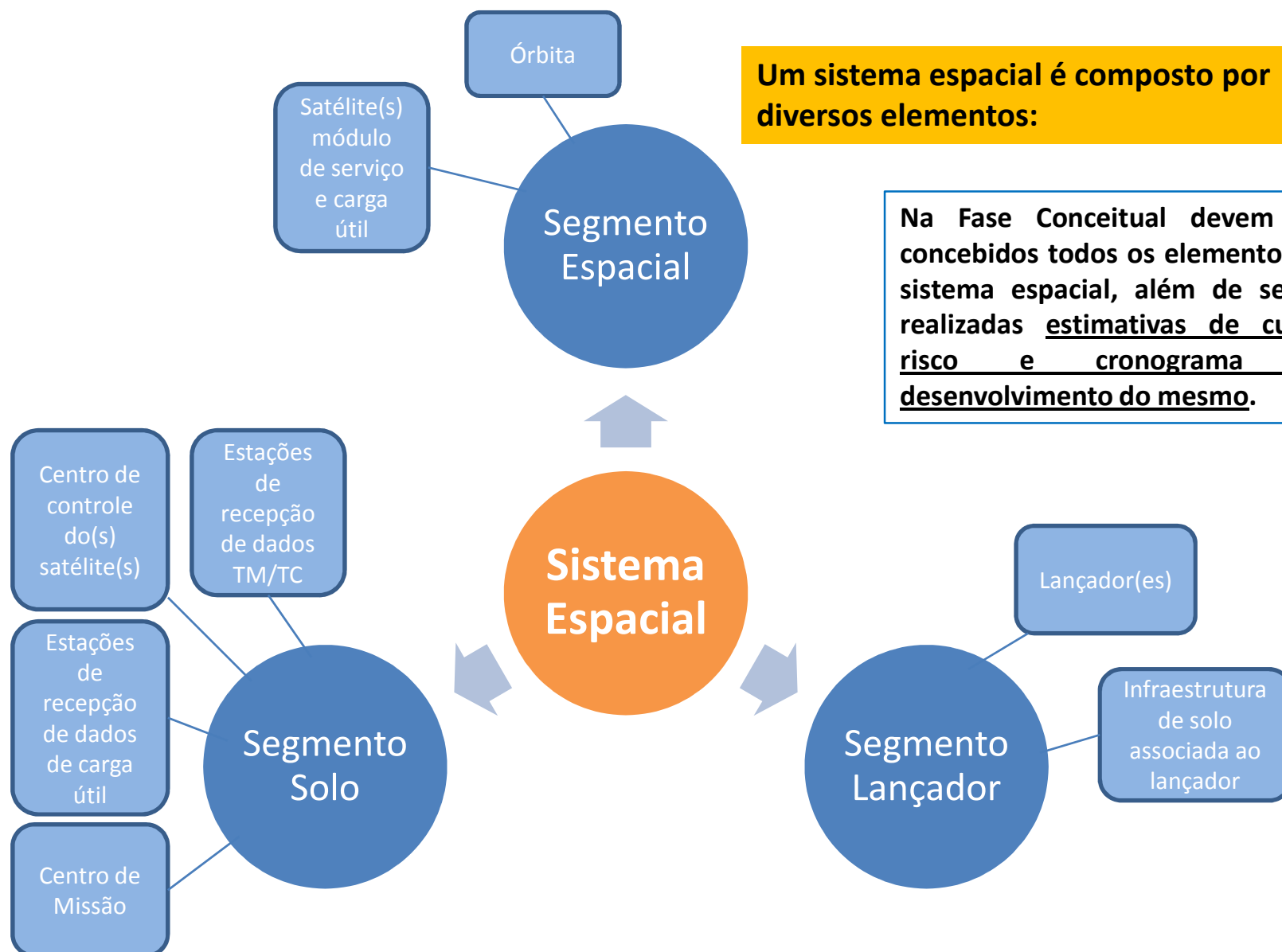


Criado no escopo de um projeto de P&D, que visava implantar na DIDSE/ETE um ambiente integrado de projeto para ser utilizado pela engenharia espacial do INPE para o projeto e análise conceitual (Foco na Fase 0 - Pré-Fase A) de sistemas espaciais, usando uma combinação de técnicas de engenharia simultânea e otimização de projeto multidisciplinar;

➔ Instalações de engenharia simultânea como o CDF (ESA), CEF (DLR) e TeamX (JPL/NASA) foram utilizadas como benchmark para a instalação construída na DSE/ETE, no que concerne a aplicação de engenharia simultânea na fase conceitual de desenvolvimento de uma missão espacial.

Sistemas espaciais são construídos para atender diversos tipos de demandas:

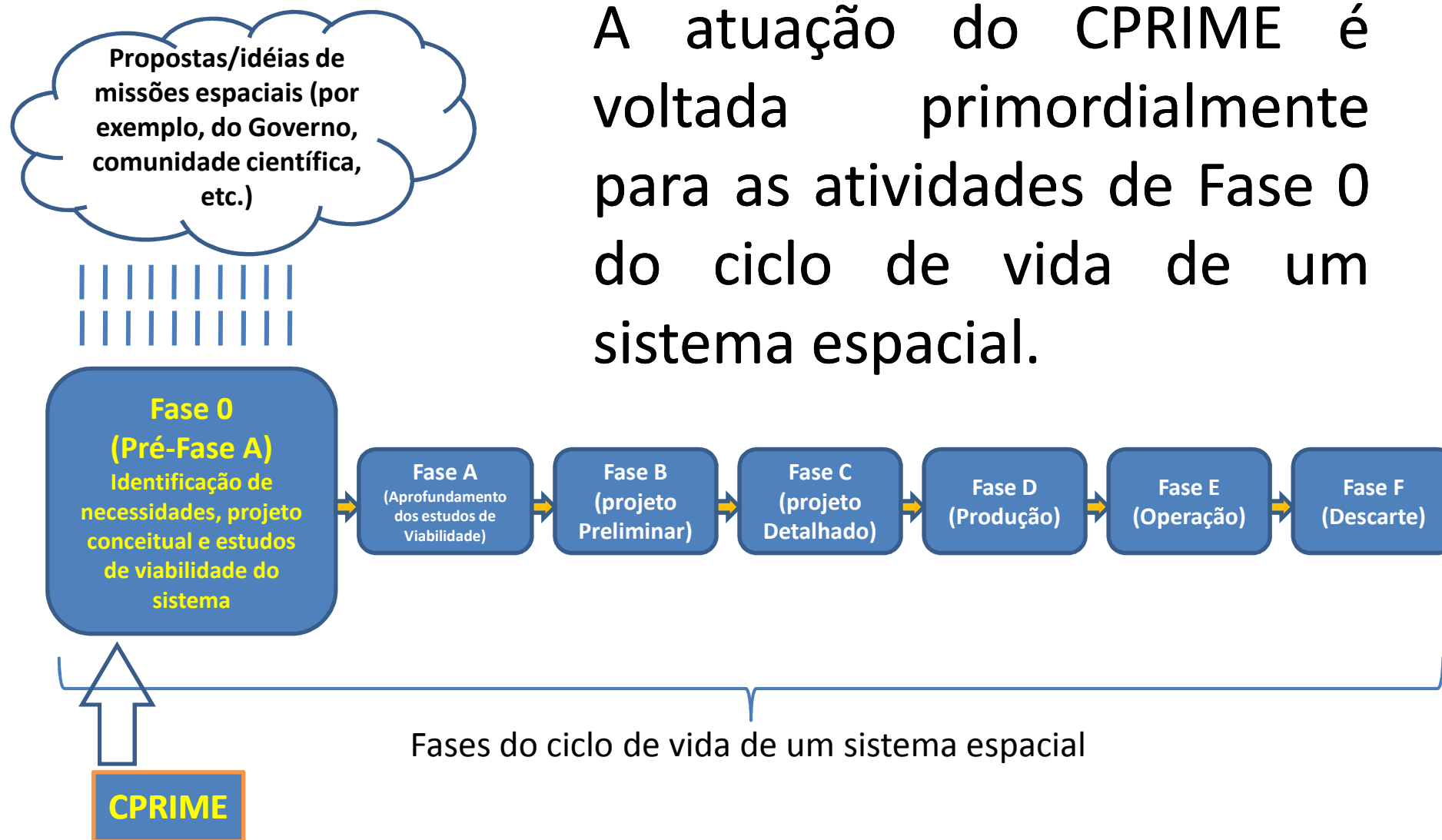


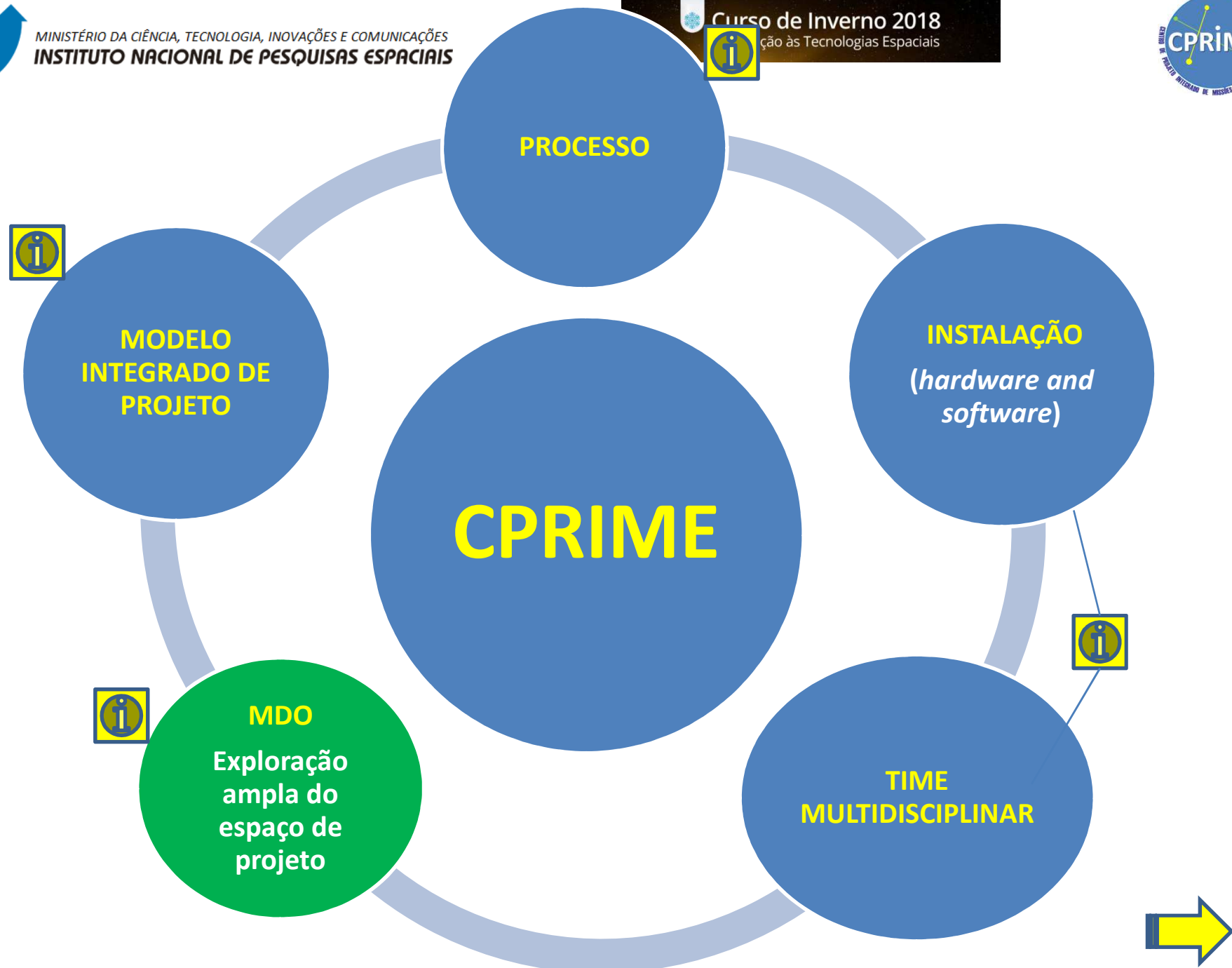




O objetivo primário do CPRIME é, através do uso de engenharia simultânea em um ambiente de projeto integrado, prover os meios para que haja uma redução significativa no tempo em que a engenharia de satélites do INPE concebe opções de sistema, no atendimento aos objetivos de uma dada missão espacial, ao mesmo tempo em que a qualidade daquelas é incrementada, em relação ao processo tradicional de projeto.

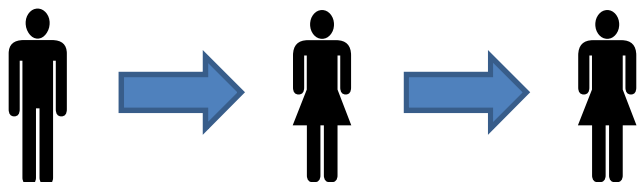
A atuação do CPRIME é voltada primordialmente para as atividades de Fase 0 do ciclo de vida de um sistema espacial.



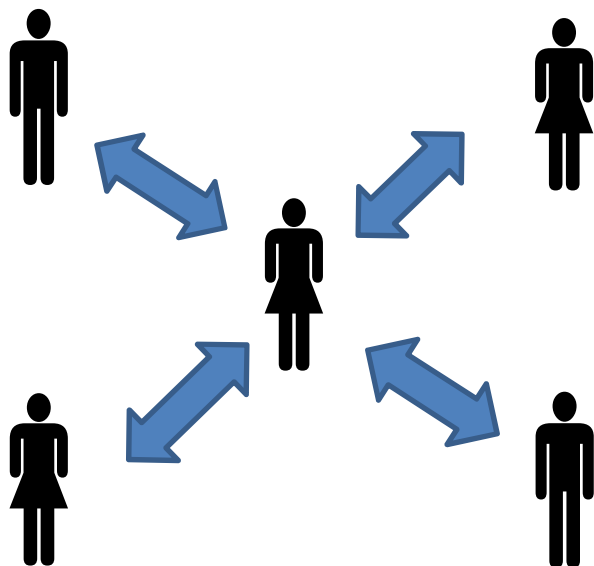


Processo

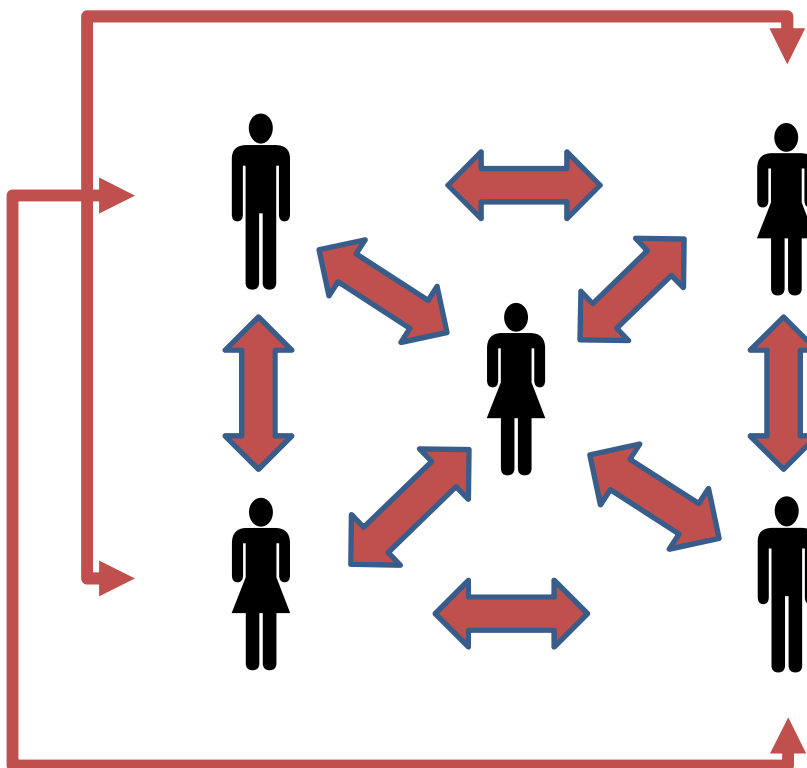
Fluxo da informação no projeto sequencial



Fluxo da informação no projeto centralizado

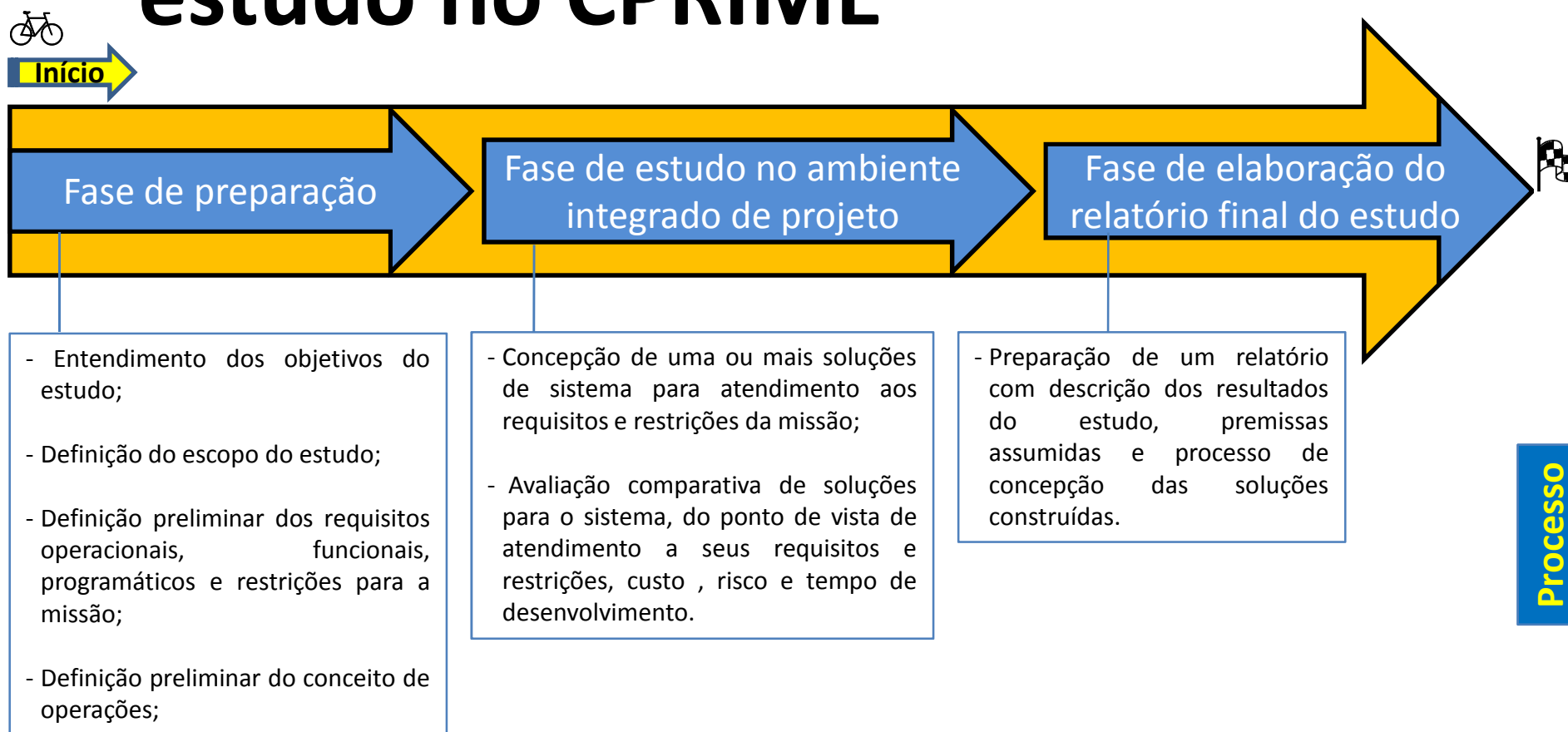


Fluxo da informação usando abordagem de engenharia simultânea



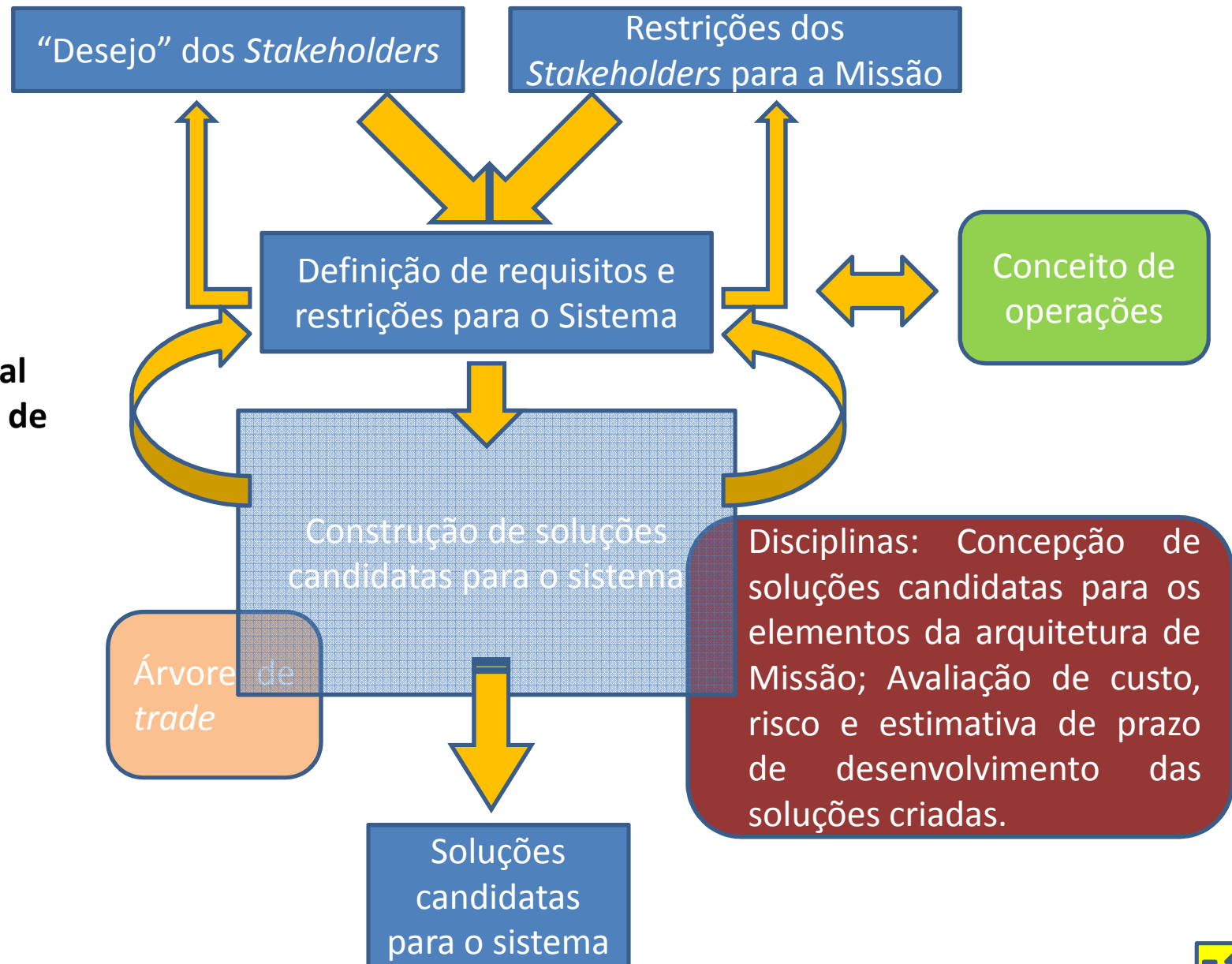
- Redução significativa na latência da informação: **Redução significativa no tempo de projeto.**
- Melhora na consciência sistêmica: **Projetos melhores.**

Fases e atividades típicas em um estudo no CPRIME



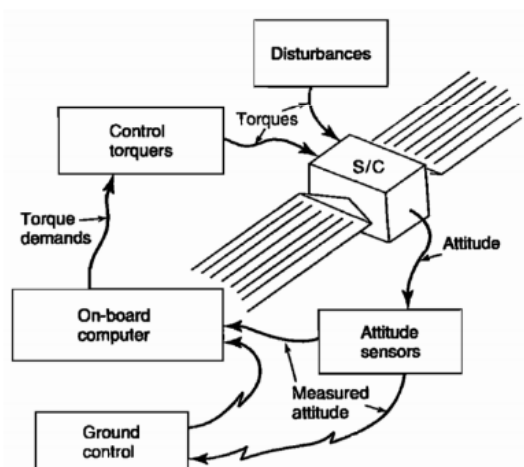
- Os *stakeholders* demandantes do estudo participam da sua realização, seja ativamente (tipicamente na fase de preparação) ou acompanhando seu andamento.

Processo
Estratégia Geral
de construção de
soluções
candidatas



Um modelo de uma disciplina pode usar relações paramétricas, subrotinas implementadas numericamente, banco de dados, etc, ou uma combinação destes elementos.

Exemplo: Projeto do AOCS.

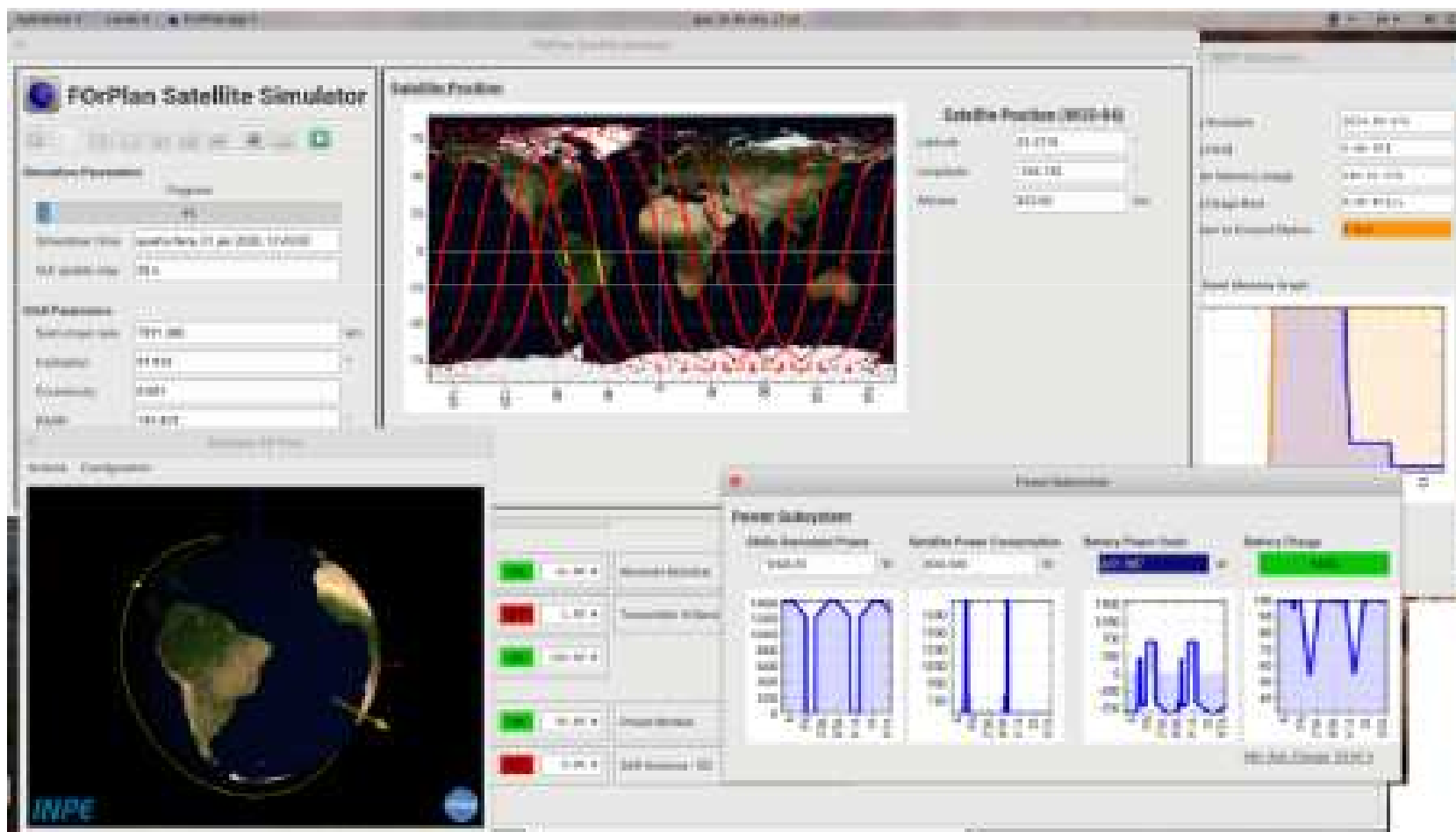


Modelo para projeto conceitual do AOCS construído utilizando Excel/VBA.



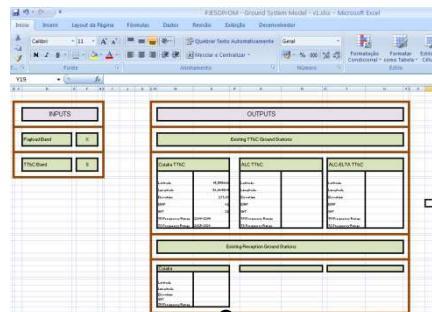
Banco de dados de sensores e atuadores.

Simulador do Conceito de Operações





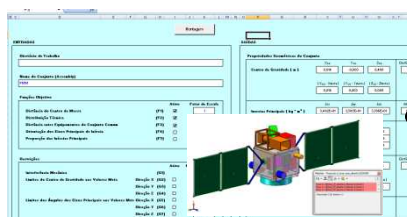
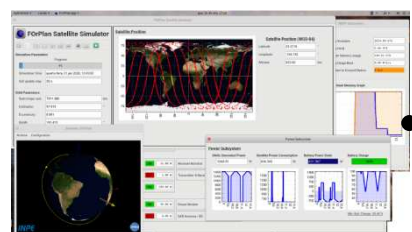
PARAMETRIC COST ESTIMATING MODEL - ETAPME									
INPUT DATA RULES									
PARAMETER	UNIT	VALUE	MIN	MAX	COEFFICIENT	WGT	MIN	MAX	WGT
MASS	kg	1000	100	10000	1.0	1.0	100	10000	1.0
POWER	W	1000	100	10000	1.0	1.0	100	10000	1.0
DURATION	min	1000	100	10000	1.0	1.0	100	10000	1.0



TIME	POWER	TEMP	... (other parameters)
0	1000	25	...
100	1000	25	...
200	1000	25	...

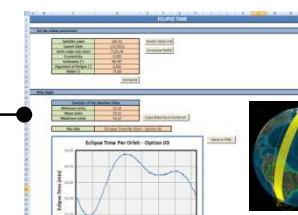
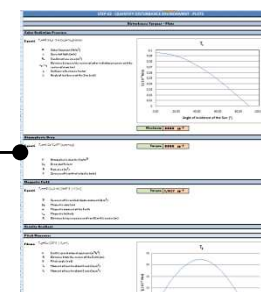
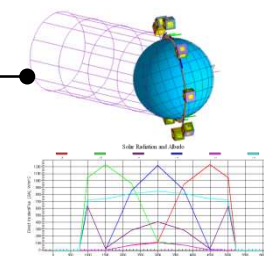
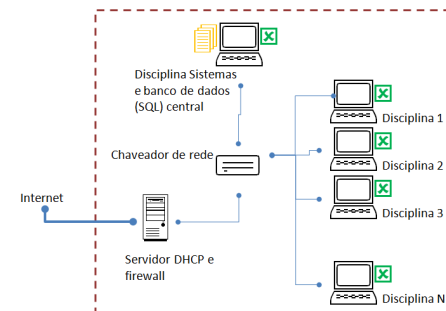
SAG AND BATTERY	
PARAMETER	VALUE
POWER	1000
CURRENT	1000
VOLTAGE	1000

TIME	ALTITUDE	... (other parameters)
0	0	...
100	100	...
200	200	...



- Modelagem específica para cada disciplina, utilizando ferramentas comerciais ou proprietária;
- Armazenamento de parâmetros de projeto em um banco de dados central;
- Troca de dados entre as disciplinas por meio de acesso ao banco de dados central;
- Excel® utilizado como interface para entrada, recuperação e troca de dados;
- Simulação dinâmica do conceito de operações.

Intranet dedicada na sala de projeto do CPRIME



Disciplina N



Sistemas

Operações

Análise de órbita

Carga útil

Controle de atitude e órbita

Propulsão

Supervisão de bordo

Telecomunicações

Potência

Configuração (Layout)

Mecanismos e pirotécnicos

Estruturas

Controle térmico

Sistemas de solo

Análise de possíveis lançadores

Simulação

Análise de abordagem de desenvolvimento

Análise de risco

Análise de custo

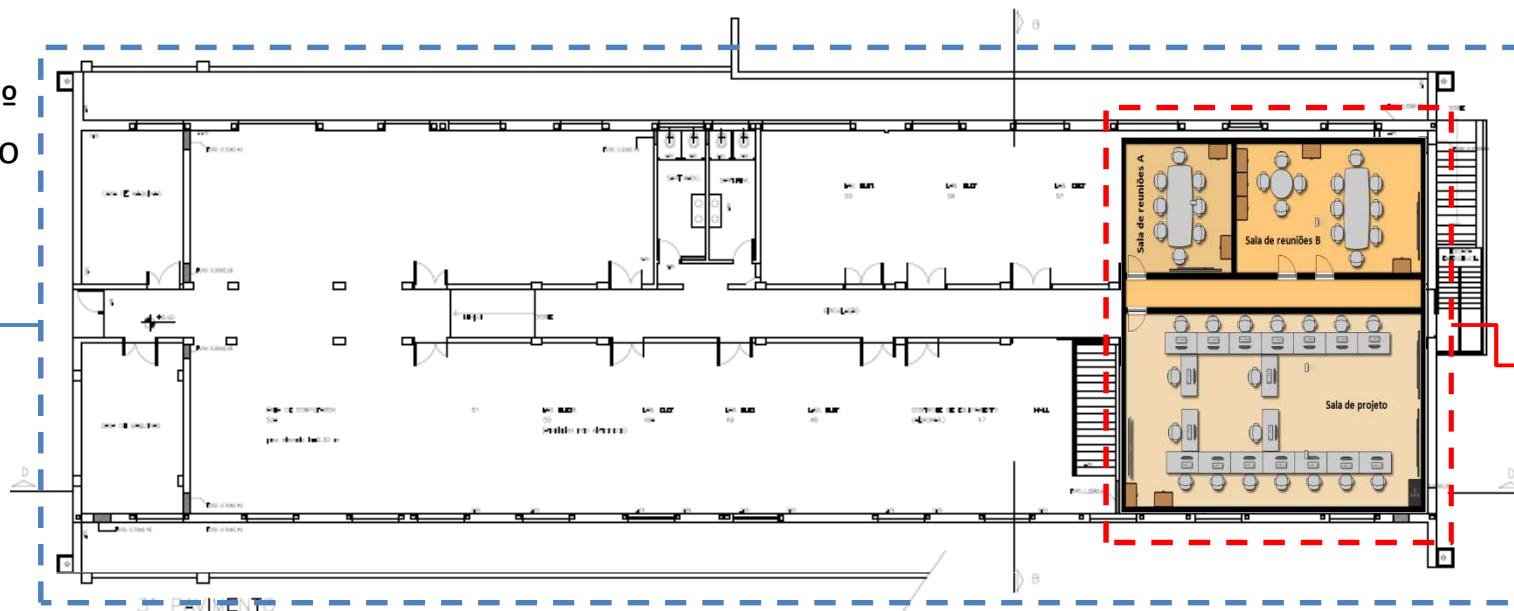
Disciplinas no ambiente integrado de projeto do CPRIME



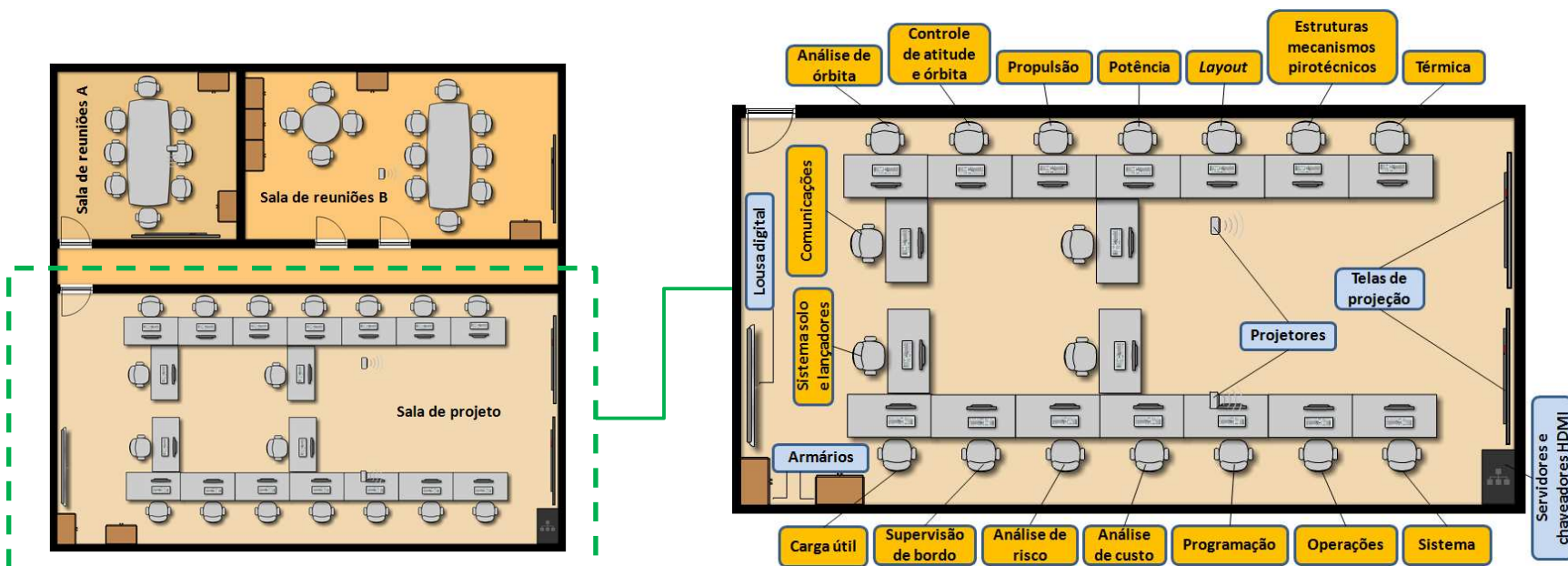
O time é montado em função do tipo de missão a ser estudada.

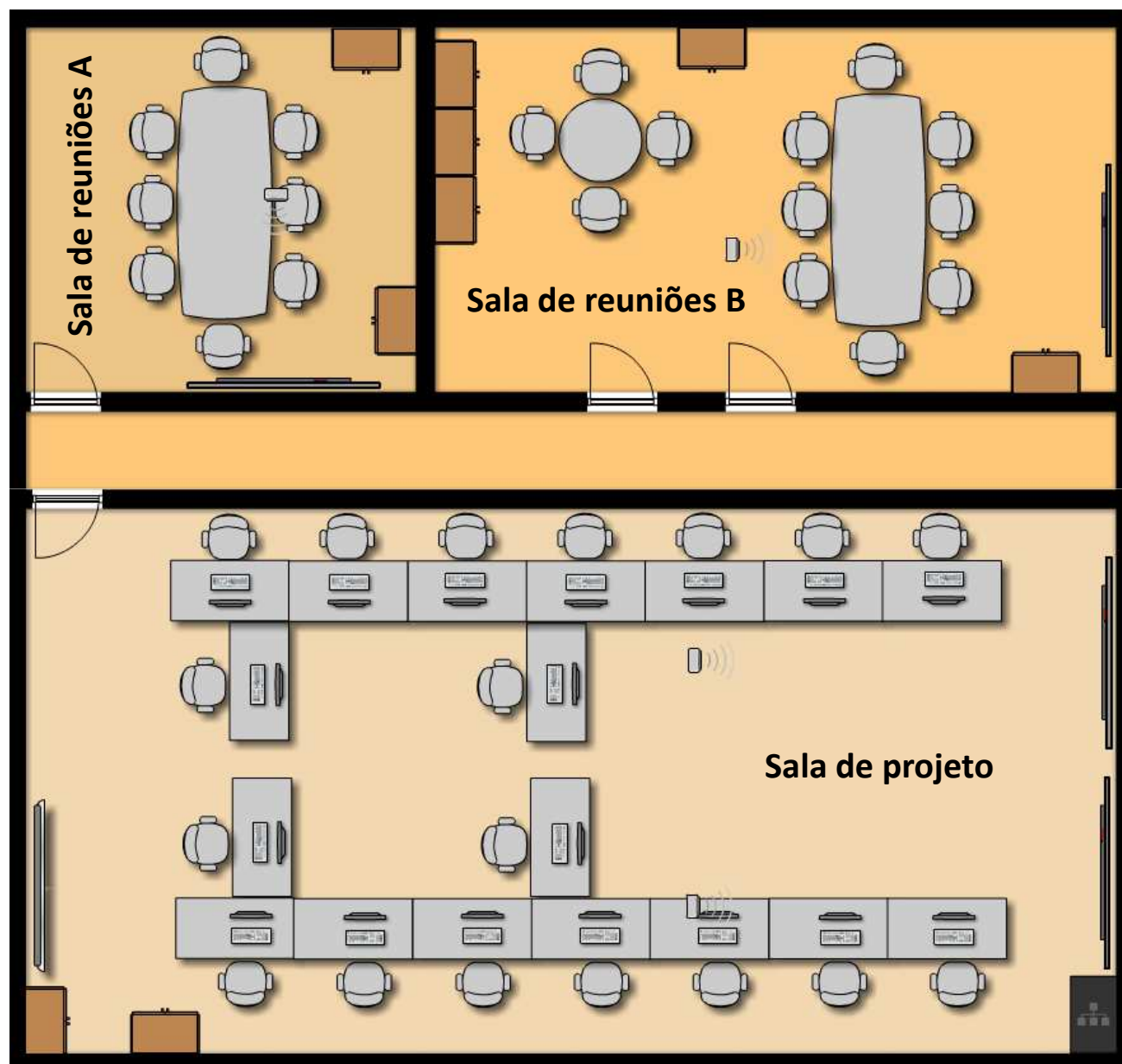
Instalação e time

DIDSE – 3º
pavimento
do prédio
Beta.

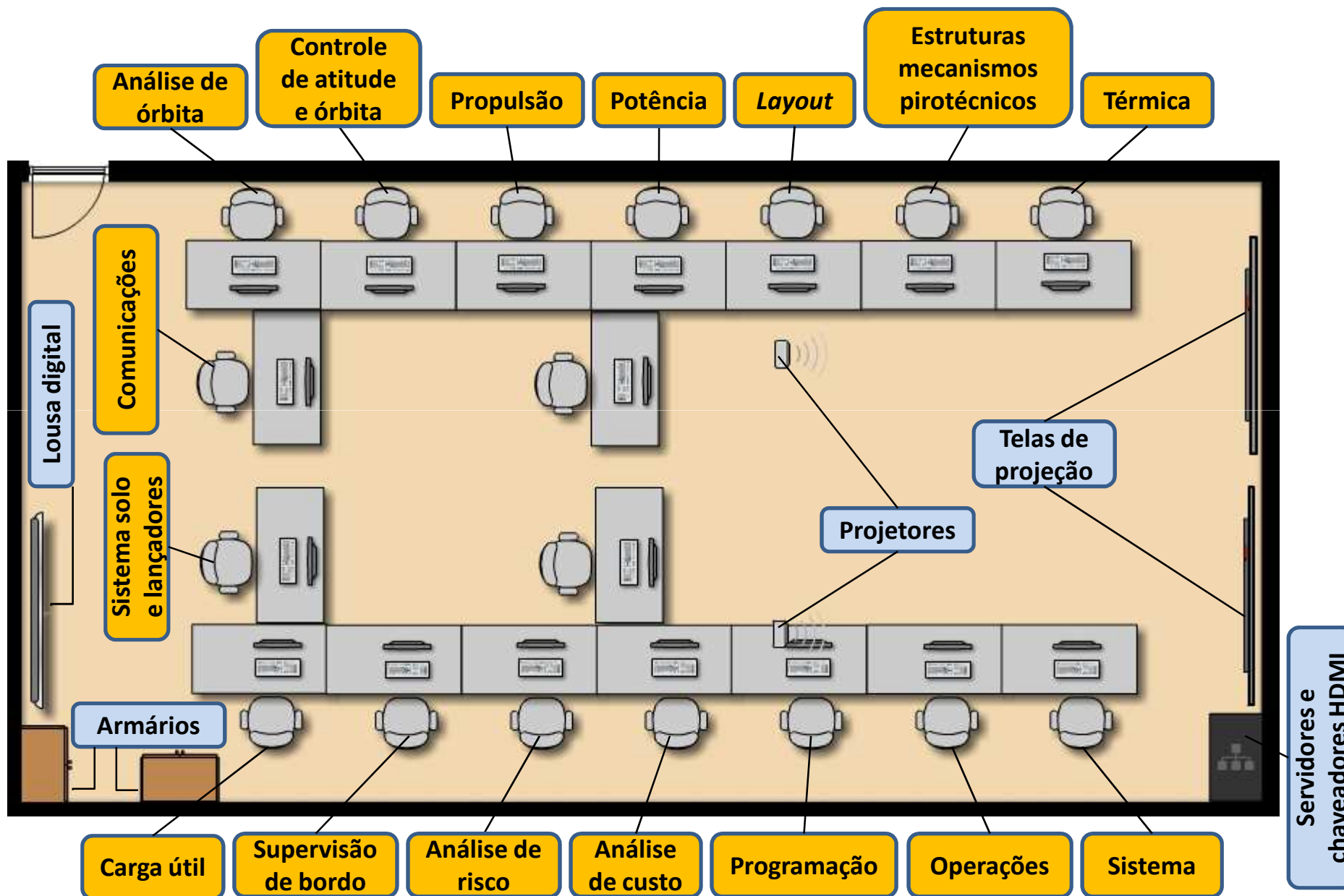


CPRIME:
Sala de
Projeto e
salas de
reuniões





Layout das Instalações do CPRIME (as salas de reunião são compartilhadas com outras atividades da DIDSE).

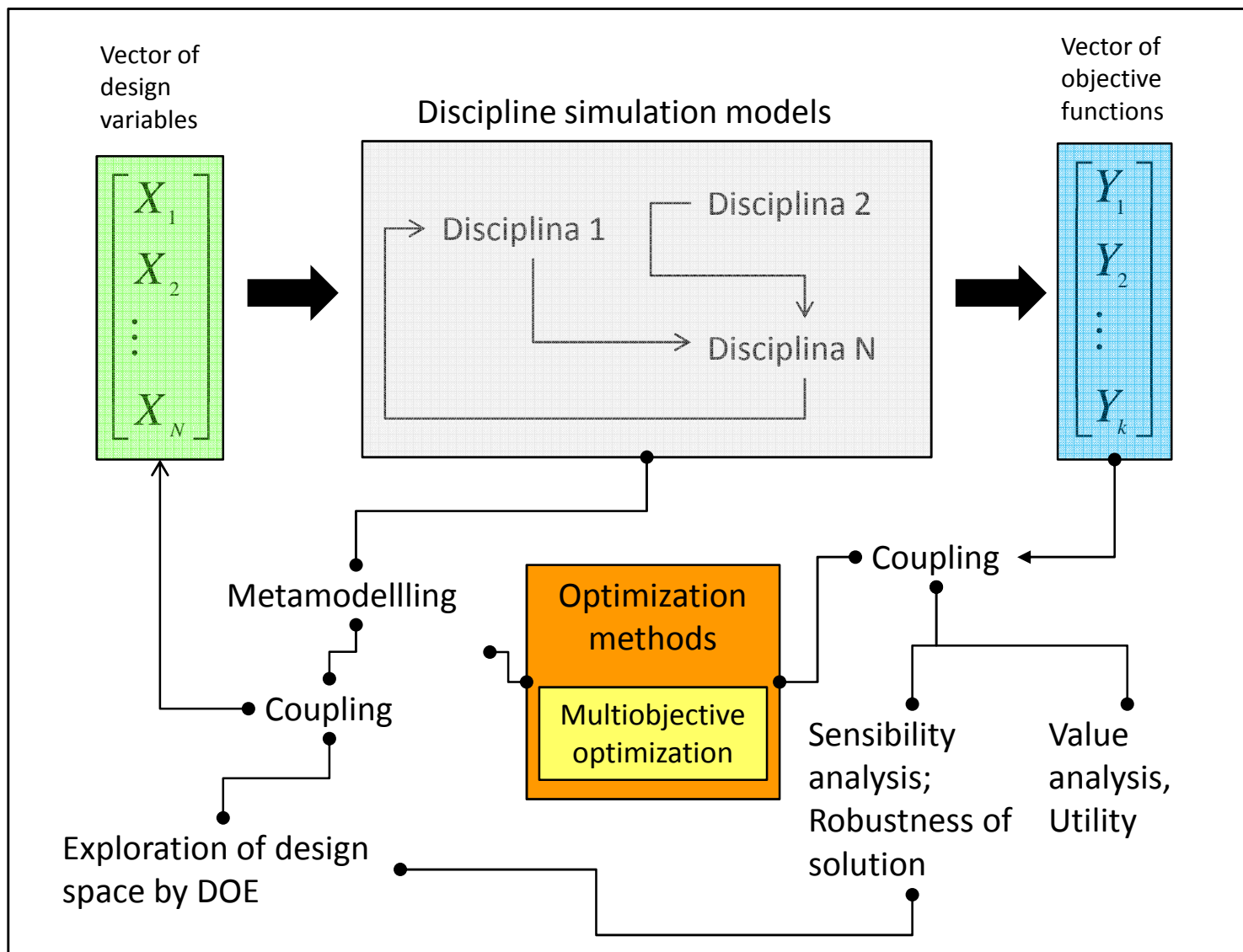




**Momentos de
um estudo no
CPRIME, 2016.**



A pictorial view of the main elements of a MDO architecture



Multidisciplinary Optimisation in Mission Analysis and Design Process

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GSP programme ref: GSP/03/N16
Contract Number: 1782/03/NL/MV

Available on the ACT net (www.esa.int/act)



GENETIC ALGORITHM APPROACHES FOR CONCEPTUAL DESIGN OF SPACECRAFT SYSTEMS INCLUDING MULTI-OBJECTIVE OPTIMIZATION AND DESIGN UNDER UNCERTAINTY

A Thesis

Submitted to the faculty

of

Purdue University

by

Rania A. Hassan

In Partial Fulfillment of the Requirements for the Degree

of

Doctor of Philosophy

May 2004

YACQUES COMPTON

Large-Scale MDO of a Small Satellite using a Novel Framework for the Solution of Coupled Systems and their Derivatives

John T. Hwang¹, Dae Young Lee¹, James W. Cutler¹, and Joaquim R. R. A. Martins¹
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Gradient-based multidisciplinary optimization is applied to a small satellite design problem. A novel MDO framework is developed by extending a non-commercial definition of components which yields two key benefits for solving multidisciplinary analysis and optimization problems. The first is a unified solver which generalizes many existing methods for solving nonlinear and linear systems, and the second is an automated and efficient method for computing coupled derivatives. This framework is used to solve a small satellite optimization problem involving several disciplines including orbit dynamics, attitude dynamics, attitude control, temperature, solar power, battery, and communication. Multi-point optimizations involving over 35,000 design variables and 1.2 million unknowns require on the order of 5 hours to converge to significantly improved designs, and this efficient design optimization capability is used to compare potential launch options.

1. Introduction

Satellites serve a multitude of purposes ranging from navigation and scientific research to military applications. Over the past decade, small satellites have gained increasing interest as alternatives to larger satellites because of the low time and cost required to manufacture and launch them. The CubeSat class of small satellites conforms to a set of specifications that facilitates relatively frequent launches as secondary payloads, and as a result, they are becoming a common platform for education and research.

The CubeSat investigating Atmospheric Density Response to Extreme driving (CADRE) mission is an effort funded by the NSF to study the response of the Earth's upper atmosphere to auroral energy inputs [1]. This project addresses the need for more accurate modeling of space weather effects, motivated in part by the growth of the global space-based infrastructure. To help answer some of the important scientific questions in this area, CADRE will provide critical in-situ measurements in the ionospheric and thermospheric regions.

The CADRE CubeSat is to inherit much of the design of the University of Michigan's Radio Aurora Explorer (RAE) CubeSat; however, the unique scientific goals of the mission necessitate a detailed design study. One is a driving factor is the scientific instruments are to run continuously for large parts of the mission. To ensure sufficient power can be generated and stored, variables such as battery sizing, solar panel sizing, and attitude must be considered. The tradeoffs involved with these variables drive in a large number of disciplines, resulting in a highly coupled and complex problem not well-suited to design using experience and human intuition.

There are many studies in the literature that propose systematic methodologies for solving such a complex multidisciplinary problem. For instance, Etkin and George [2] presented a system-based methodology for designing highly adaptive small satellites, while Cutler and Robinson [3] presented designing small satellites for remote sensing by adopting an existing small satellite design and decomposing the problem into subsystems. Other authors also proposed separating by subsystem, but added the idea of simulation-based design within an integrated framework [4] that also supports hardware-in-the-loop simulations [5] and knowledge-based design and optimization [6]. Spangola and Cutler [7] performed optimization of both the design of the vehicle and operations, using a Monte Carlo algorithm to search the design space.

The current works seek to consider the multidisciplinary problem with a greater level of detail and coupling than existing studies. The approach is to focus on the scientific computing side of the problem and use efficient numerical algorithms in an effort to incorporate as much fidelity as possible within a monolithic computational design framework. The motivation comes from the fact that there are many variables over which the designer has control, and it would be desirable to simultaneously optimize the design and operation of CADRE.

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1 of 23

Proceedings of the 2012 IEEE 16th International Conference on Computer-Supported Cooperative Work in Design

Satellite Multidisciplinary Collaborative Optimization with Distributed Computing

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Abstract—Using the high fidelity model in the multidisciplinary design optimization (MDO) application is becoming more and more popular, but it brings complex coupling relationship and large amount of memory which makes it difficult to be well organized to reduce the computation time. In this paper, a parallel computing environment distributed in local area network (LAN) was established based on the collaborative optimization (CO) method. The distributed computing system constructed with Transputer Control Protocol (TCP) and XML database to store and manage the data. The proposed system can realize remote sensing satellite system parameters design consisting four subsystems, which include structure, attitude control (AC), power, and thermal control (TC). The result shows that the efficiency can be improved by about 60% relative to the sequential running phase.

Keywords—collaborative optimization, distributed computing, parallel computing, multidisciplinary design optimization

1. INTRODUCTION

Small satellite system design is a multidisciplinary process, which needs collaborative design from multiple fields and departments. It has traditionally been a highly, non-structural process, unique to specific missions and institutions, and shows more and more difficulty with increased requirements of performance, time and cost. MDO technology provides an effective approach for the complex system, and seems especially suitable for each kind of design purpose. By applying MDO in the satellite system design, the efficiency of design can be improved to improve and powerful technical supports can be obtained, which means better performance, faster design process and lower cost.

Researchers have applied MDO technology to satellite design mostly using empirical formulas [1-3]. Using empirical formulas to represent subsystems are especially less intuitive, but it is sometimes not adequate for describing necessary properties of the problem. Use of the high fidelity model in MDO problems is becoming more and more popular [4]. With the high fidelity model, more complex coupling relationship can be considered in high fidelity model, but execution of analyzing high fidelity model often takes very long CPU time. Therefore, efficiency improvement is strongly needed in MDO application. Distributed analysis system could utilize multiple computers, increasing the practical scale of

MDO problems. Database management and modular analysis condition can improve efficiency and maintainability. In the last decades, significant progress has been made in super-computing using cluster or parallel computing [5-6]. LAN distributed computing and parallelized computing technologies have been widely researched. It is an appropriate technology worthy to be developed to improve the efficiency of the complex MDO application. In the present paper, we have designed a distributed computing environment based on CO method. The system is applied to a remote sensing satellite system parameters MDO problem.

II. COLLABORATIVE OPTIMIZATION METHOD
The simple coupled problems like two blocks interacting inputs and outputs are often solved by the fixed-point iteration (FPI) method. If the coupling relationship is more complex, FPI is no longer suitable to solve the problem, and the optimization-based decomposition (OBD) [8] was proposed to provide a solution that can uniformly solve this kind of complex coupled problems. In an integrated design problem, the feedback is removed by introducing auxiliary design variables and compatibility functions. The auxiliary variables are new design variables that are "copies" of the computed values from block i , i.e. the compatibility function added at the output of block i but two values is equal. The feedback is eliminated in the same way. Although this type of decomposition generally increases the computational intensity, it may be still advantageous since the analysis may be run in parallel. The decomposition method is illustrated as in Fig. 1.

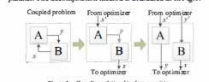


Figure 1. Decomposition method diagram showing a system with inputs A and B, and outputs C and D, with compatibility functions and auxiliary variables.

Collaborative Optimization (CO) method was proposed by Braun, et al. [9, 10] based on the decomposition method described above. The compatibility functions of each module are dealt with individually. The key idea of CO method is to

Curso de Inverno 2018 Automating the Process of Optimization in Spacecraft Design

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Abstract—Spacecraft design optimization is a difficult problem, due to the complexity of optimization cost surfaces and the human expertise in optimization that is necessary in order to achieve good results. In this paper, we propose the use of a set of generic, meta-heuristic optimization algorithms (e.g. genetic algorithms, simulated annealing), which is configured for a particular optimization problem by an adaptive problem solver based on artificial intelligence and machine learning techniques. We describe work in progress on OASIS, a system for adaptive problem solving based on these principles.

TABLE OF CONTENTS

1. INTRODUCTION
2. OPTIMIZATION USING METAHEURISTICS
3. ADAPTIVE PROBLEM SOLVING
4. OASIS ARCHITECTURE
5. EXAMPLES OF OPTIMIZATION PROBLEMS
6. SUMMARY AND CONCLUSIONS

1. INTRODUCTION

Many aspects of spacecraft design can be viewed as instances of *constrained optimization problems*. Given a set of decision variables X and a set of constraints C on X , the constrained optimization problem is of the form as

0-7803-3741-7/97/\$5.00 © 1997 IEEE

Evaluation of Multidisciplinary Design Optimization Techniques as Applied to Spacecraft Design

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Abstract—The application of optimization to spacecraft design has the potential to significantly improve design capabilities early in the design process. Successful system optimization and system-level spacecraft analysis are the concept architecture, technology choices, and performance requirements to be adjusted to meet an overall mission cost goal. Theoretically enabling spacecraft design to be optimized in a reliable, economical and timely manner.

Increasingly sophisticated synthesis tools provide more realistic models of the spacecraft system, it is useful to evaluate the ability of existing optimization techniques to rate on these mathematical models. This paper provides evaluation of optimization techniques as they are applied increasingly complex spacecraft design problems, including the advantages and disadvantages of traditional, closed-form optimization techniques and non-traditional heuristic methods. Domain comparison includes the ability of these tools to efficiently find optimal and near optimal solutions in situations where exhaustive enumeration is computationally infeasible.

TABLE OF CONTENTS

1. INTRODUCTION
2. SELECTION OF OPTIMIZATION TECHNIQUE
3. SPACECRAFT DESIGN OPTIMIZATION PROBLEM
4. EXAMPLE PROBLEM
5. CONCLUSIONS

1. INTRODUCTION

Optimization techniques are used in the design process to quickly find the system level effect of conflicting objectives. In spacecraft design, understanding these effects has increasingly become a lengthy process of disciplinary analysis, "what-if" analyses, and detailed trade studies. Consequently, existing spacecraft optimization techniques are mainly in disciplinary analysis, supporting design and optimization in related subsystems but rarely within the entire system. With these tools, some configuration decisions are usually made subsequent initial subsystem technology decisions, after a large

percentage of total system cost has been committed. A promising approach to improve early decision-making capabilities is the synthesis of optimization algorithms with system-level spacecraft analysis tools. The synthesis use of formal optimization to complex system design has led to the rapid expansion of an optimization field termed Multidisciplinary Design Optimization (MDO). MDO extends the Concurrent Engineering concept to the conceptual design phase by integrating disciplinary analysis with system level optimization [2].

Application of Multidisciplinary Design Optimization
By facilitating the consideration of both system performance and life cycle cost, MDO is potentially a powerful decision-making tool for spacecraft design. In general, MDO methods bridge the gap between disciplinary analysis and optimal system design by providing a domain optimization framework for design teams. The framework supports design improvement by systematically evaluating the potential consequences of different disciplinary components and configuration options. The full spectrum of options is intelligently evaluated, promising a faster and more extensive investigation of the design space than allowed by traditional design practices [3].

MDO for Spacecraft Design
MDO uses formal optimization techniques to mathematically trace a path in the design space from an initial point towards improved designs. In applying MDO, spacecraft designers are faced with the dilemma that once a spacecraft model has been sufficiently abstracted, it cannot be analyzed using traditional "closed-form" optimization methods. Because any realistic abstraction of the spacecraft design space has a complicated non-convex topography, there is no path of continuous improvement and many optimization algorithms become trapped in local optima. To obtain a global optimum, the lack of gradients requires combinatorial analysis of discrete information. Evaluation of combinatorial problems increases exponentially with the number of discrete variables. Exhaustive enumeration of a typical spacecraft design trade space (consisting 10 to 20 trade-offs with 3 to 4 trade options available for each area) can yield as many as 10^6 combinations to be evaluated. In

411

371

MDO in conceptual design of space systems

Multidisciplinary Design Optimization for Concurrent Engineering of Space Systems

Jian Guo, Luca Guadagni

Chair of Space Systems Engineering (SSE), Faculty of Aerospace Engineering



SECSA-2012, Lisbon, 17-19 Oct 2012

MDO tool for spacecraft equipment conceptual layout design

COMUNICAÇÕES
ESPACIAIS

Curso de Inverno 2018
Introdução às Tecnologias Espaciais



Recentemente foi desenvolvida no INPE uma ferramenta para otimização do layout de equipamentos em espaçonaves, utilizando Excel® e SolidWorks® (No escopo do PIOTLayout, encerrado em 2014).

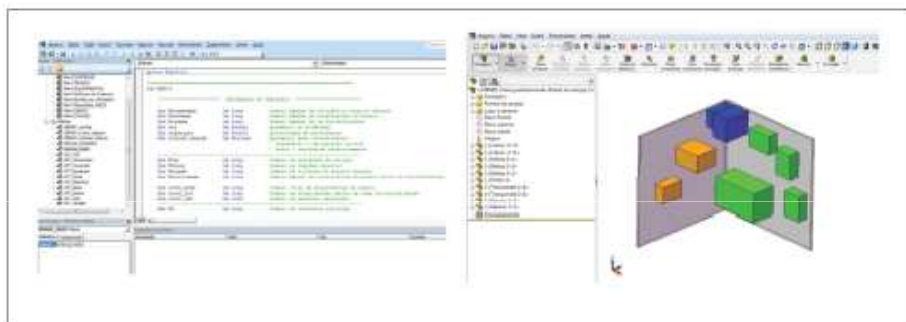
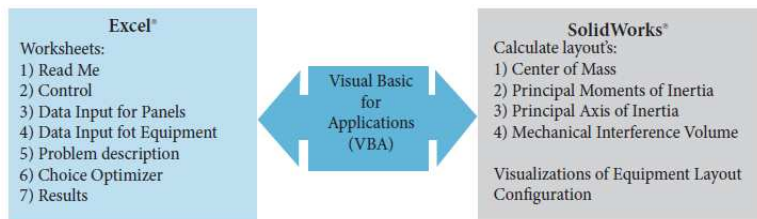


Figure 7. Screenshots of the VBA editor showing the M-GEO macro (left view) and SolidWorks® environment (right view).

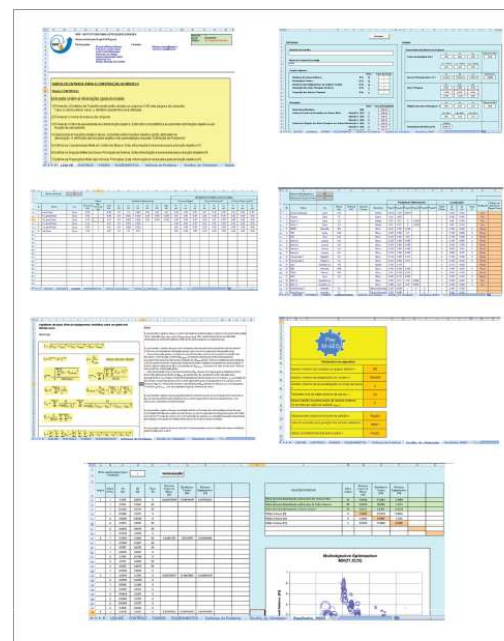


Figure 6. Screenshots of the layout tool Excel® worksheets.

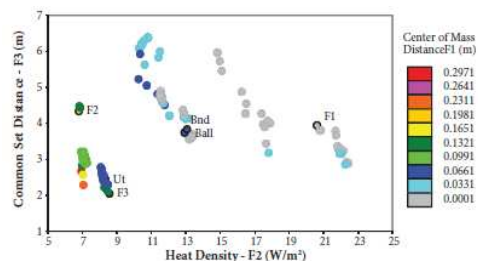
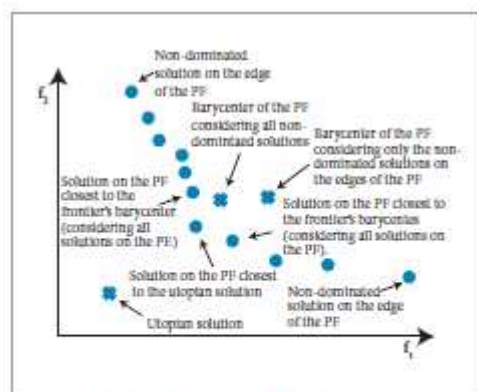
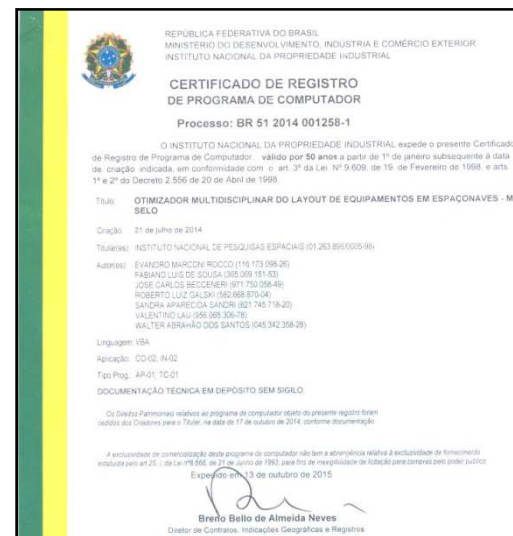


Figure 9. Some criteria to select solutions on the approximate Pareto Frontier (PF) for further analysis. A hypothetical example with two objective functions is presented here. Circles are non-dominated solutions. Crosses are reference marks based on the criteria [see text].



Certificado
de Registro
de
Software
no INPI
(out/2015).

Fonte: Lau, V., De Sousa, F.L., Galski, R.L., Rocco, E.M., Becceneri, J.C., Santos, W.A. Sandri, S.A. A Multidisciplinary Optimization Tool for Spacecraft Equipment Layout Conception. Journal of Aerospace Technology and Management, Vol. 6, No. 4, pp. 431-446, Oct-Dez, 2014.



TOWARDS THE AUTOMATION OF CONCURRENT SPACE SYSTEMS
CONCEPTUAL DESIGN THROUGH MULTIDISCIPLINARY DESIGN
OPTIMIZATION

Ronan Arraes Jardim Chagas
Bráulio Fonseca Carneiro de Albuquerque
Rafael Anderson Martins Lopes
Fabiano Luis de Sousa



- Given an analysis interval, and a region of interest, search the satellite constellations that **minimizes** the number and the total mass of spacecraft and **maximizes** the accessible area (or **minimizes** the not accessible area).

Table 2. Selected solutions for the hypothetical study case.

Altitude (km)	Inclination (°)	RAAN (°)	True anomaly (°)	Lifetime	Area Not Accessible	Satellite Mass (kg)
Ground Spatial Resolution = 20 m						
591.942	14.2857	11.4286	216.0	2 years	11.5932 %	194.388
686.430	14.2857	11.4286	264.0	4 years	9.8955 %	211.783
686.430	14.2857	11.4286	264.0	6 years	9.8955 %	217.269
Ground Spatial Resolution = 30 m						
680.131	14.2857	308.571	96.0	2 years	2.5447 %	164.243
717.926	14.2857	320.000	72.0	4 years	2.3550 %	169.063
717.926	14.2857	320.000	72.0	6 years	2.3550 %	172.186

Table 1. Input parameters for each simulated scenario.

Parameter	Value
Maximum number of generations in MGEO	100,000
Number of independent runs in MGEO	50
Interval of analysis	3 days
Latitude interval of the region of interest	$[-34^\circ, 6^\circ]$
Longitude interval of the region of interest	$[-74^\circ, -33^\circ]$
Launcher error in the semi-major axis	20 km
Launcher error in the inclination	0.01°
Perigee of the disposal orbit	500 km*
Camera resolution	[20 m, 30 m]
Expected mission lifetime	[2, 4, 6] years
Atmospheric density	Solar maximum**

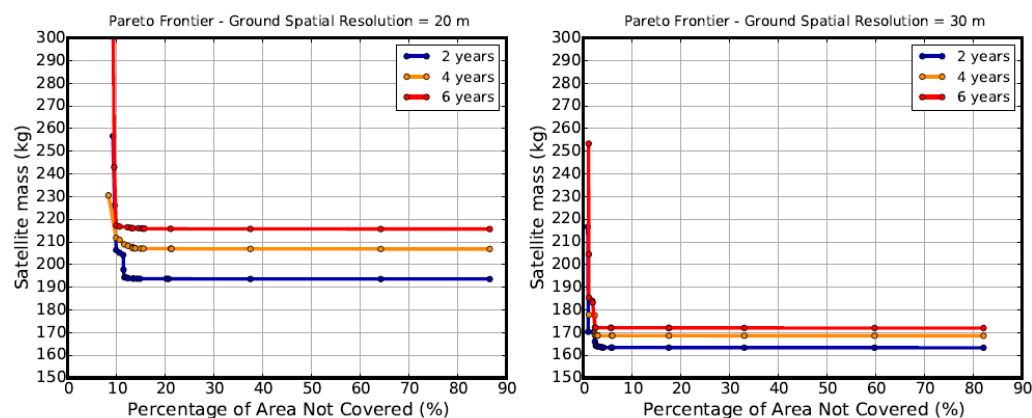


Figure 2. Pareto frontier for a payload with ground spatial resolution of 20m (left) and 30m (right).





O CPRIME em resumo

- ⇒ Ambiente integrado, multidisciplinar, criado para a realização do projeto e análise conceitual de missões espaciais em ambiente de engenharia simultânea;
- ⇒ Iniciado em Abril/2013, no escopo de um projeto de P&D da DIDSE/CGETE;
- ⇒ Realizados até o momento 8 estudos, cobrindo:
 - Missões de observação da Terra em órbita LEO, óptica e SAR;
 - Missões científicas em órbita LEO e GEO;
 - Satélites com massa na “categoria cubesat” à de várias toneladas.
- ⇒ Dois estudos previstos para realização em 2018 (1 em andamento).
- ⇒ O Centro mostrou ser capaz de atender eficientemente (em tempo e qualidade técnica) demandas institucionais para o projeto e análise conceitual de missões espaciais, cumprindo sua missão precípua.
- ⇒ Proveu a CGETE/INPE com a capacidade de “resposta rápida” à demandas para análise de viabilidade e projeto conceitual de missões espaciais, com uma ferramenta moderna, utilizada com comprovado sucesso por diversas agências espaciais, de fundamental importância no apoio técnico a tomada de decisão.
- ⇒ Atividades de P,D&I no CPRIME inclui a possibilidade de serem realizadas no contexto de programa de pós-graduação.





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INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS



Curso de Inverno 2018
Introdução às Tecnologias Espaciais



Obrigado!



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Slides de Apôio



MINISTÉRIO DA CIÊNCIA, TECNOLOGIA, INOVAÇÕES E COM
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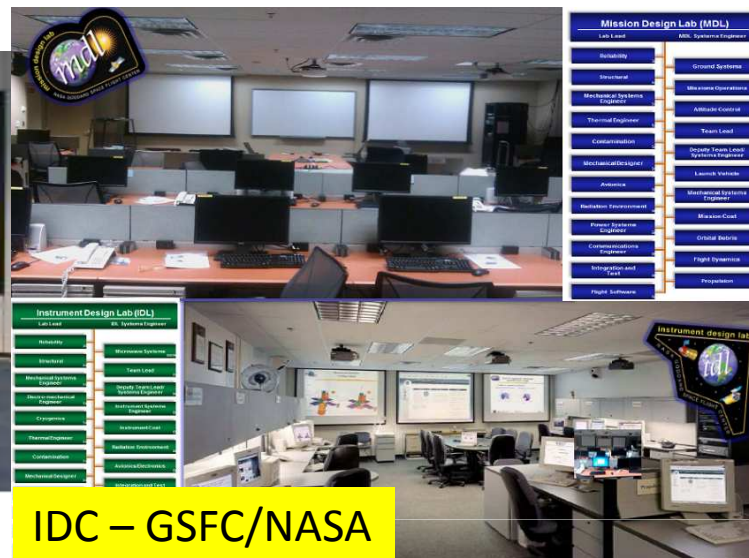
Exemplos de instalações existentes de engenharia simultânea para fase conceitual do desenvolvimento de missões espaciais.



CDF-ESA



Benefícios providos pelo CDF para a ESA



CEF-DLR



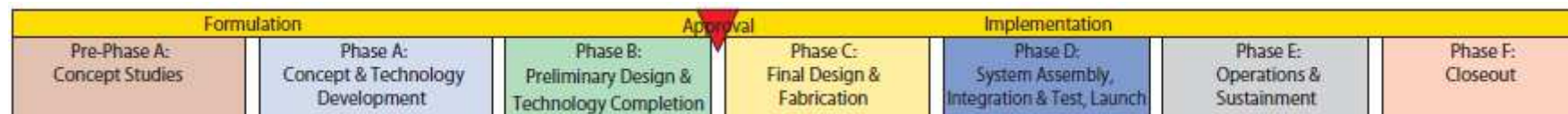
JPL/NASA-TeamX



Benefits



- **Performances** (typical pre-Phase A study):
 - **Study duration** (Design phase): 3-6 weeks (cp. 6-9 months!)
 - Factor 4 **reduction in time**
 - Factor 2 **reduction in cost** (for the Customer)
 - **Increased nr of studies** per year, compatibly with max 2 parallel studies
 - **Quality improvement**, providing quick, consistent and complete mission design, incl. technical feasibility, programmatics, risk, cost
 - Technical **report becomes part of the specs** for industrial activity,
(Cost report remains the ESA independent reference)
 - Capitalisation of corporate **knowledge for further reusability**
-
- **CDF: an essential tool for the ESA Decision Making & Risk Management processes**

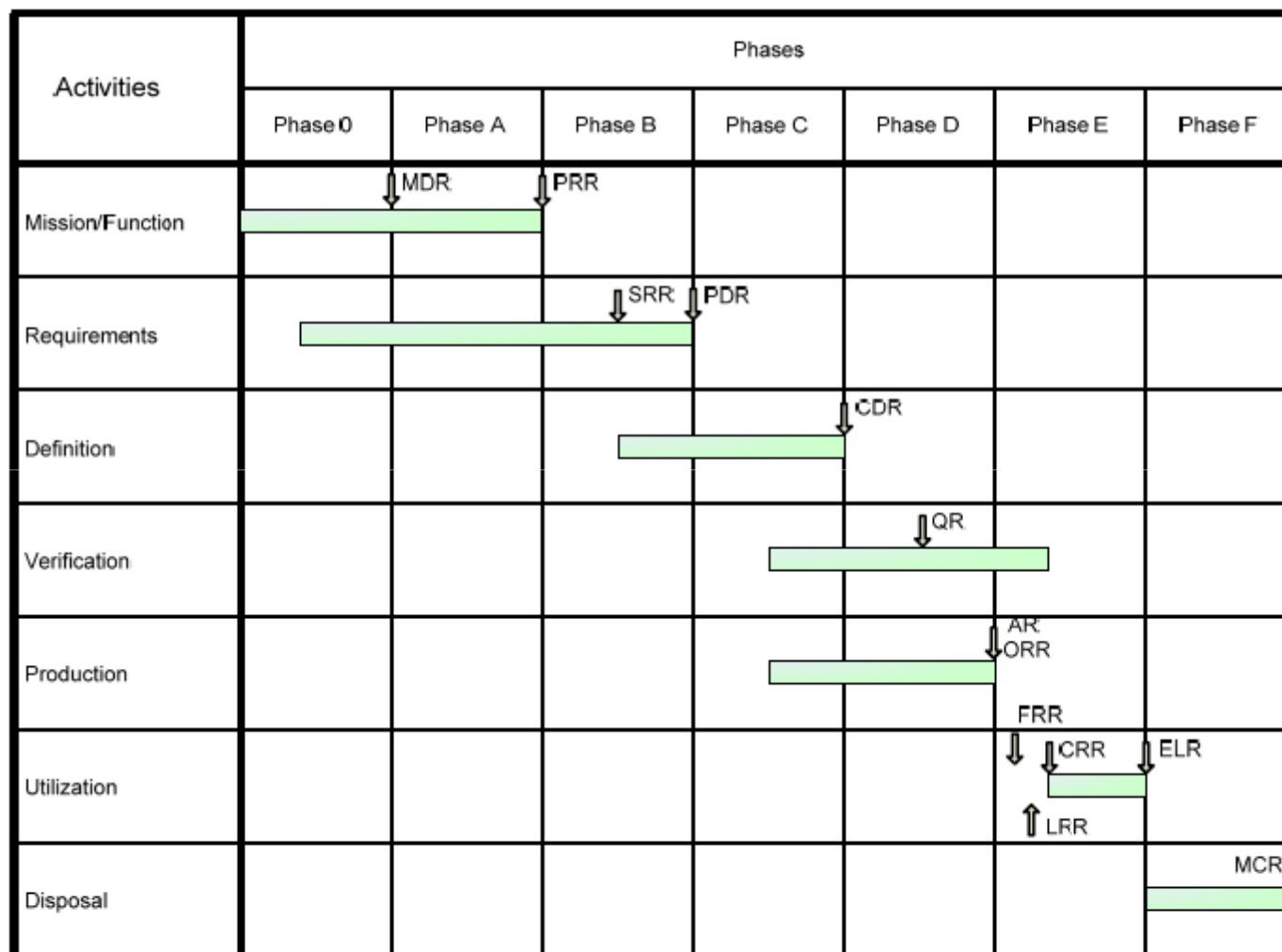


Project Life-Cycle Phases

Phase		Purpose	Typical Output
Formulation	Pre-Phase A Concept Studies	To produce a broad spectrum of ideas and alternatives for missions from which new programs/projects can be selected. Determine feasibility of desired system, develop mission concepts, draft system-level requirements, identify potential technology needs.	Feasible system concepts in the form of simulations, analysis, study reports, models, and mockups
	Phase A Concept and Technology Development	To determine the feasibility and desirability of a suggested new major system and establish an initial baseline compatibility with NASA's strategic plans. Develop final mission concept, system-level requirements, and needed system structure technology developments.	System concept definition in the form of simulations, analysis, engineering models, and mockups and trade study definition
	Phase B Preliminary Design and Technology Completion	To define the project in enough detail to establish an initial baseline capable of meeting mission needs. Develop system structure end product (and enabling product) requirements and generate a preliminary design for each system structure end product.	End products in the form of mockups, trade study results, specification and interface documents, and prototypes
Implementation	Phase C Final Design and Fabrication	To complete the detailed design of the system (and its associated subsystems, including its operations systems), fabricate hardware, and code software. Generate final designs for each system structure end product.	End product detailed designs, end product component fabrication, and software development
	Phase D System Assembly, Integration and Test, Launch	To assemble and integrate the products to create the system, meanwhile developing confidence that it will be able to meet the system requirements. Launch and prepare for operations. Perform system end product implementation, assembly, integration and test, and transition to use.	Operations-ready system end product with supporting related enabling products
	Phase E Operations and Sustainment	To conduct the mission and meet the initially identified need and maintain support for that need. Implement the mission operations plan.	Desired system
	Phase F Closeout	To implement the systems decommissioning/disposal plan developed in Phase E and perform analyses of the returned data and any returned samples.	Product closeout



Abbreviation	Meaning
AR	acceptance review
B/L	baseline
CBCP	current baseline cost plan
CDR	critical design review
CRR	commissioning result review
DRL	document requirements list
EAC	estimate at completion
EGSE	electrical ground support equipment
ELR	end-of-life review
ETC	estimate to completion
FRR	flight readiness review
GSE	ground support equipment
ILS	integrated logistic support
ITT	invitation to tender
LRR	launch readiness review
MCR	mission close-out review
MDR	mission definition review
MGSE	mechanical ground support equipment
N/A	not applicable
OBCP	original baseline cost plan
OBS	organizational breakdown structure
ORR	operational readiness review
PDR	preliminary design review
PMP	project management plan
PRD	project requirements documents
PRR	preliminary requirements review
QR	qualification review
RFP	request for proposal
RFQ	request for quote
SRR	system requirements review
WBS	work breakdown structure
WP	work package



Typical project life cycle

