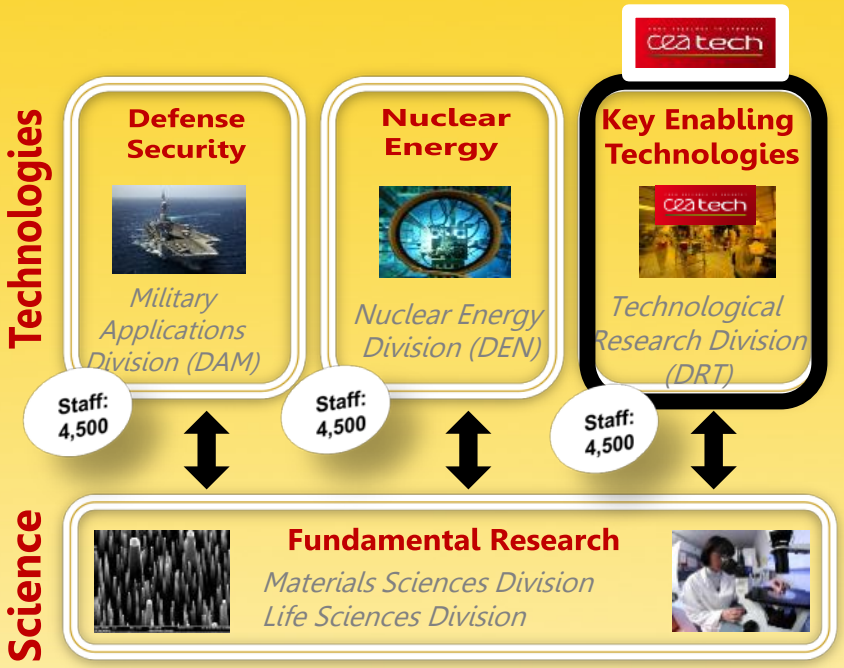
What's App at CEA for Batteries Taking the Corner of Space Industrial (and More Electric Aircraft) Revolution

Laurence Perino-Gallice, Olivier Masson, Michel Bel & Florence Fusalba

CEA-Grenoble, 17 rue des Martyrs, 38054 Grenoble Cedex 9 France

CEA = French Alternative Energies and Atomic Energy Commission

CEA GLOBAL ORGANIZATION



CEA global figures

Human ressources **16,000**

10 Research centers

Budget: **4,3 billion €**

Scientific publications: **4,735**

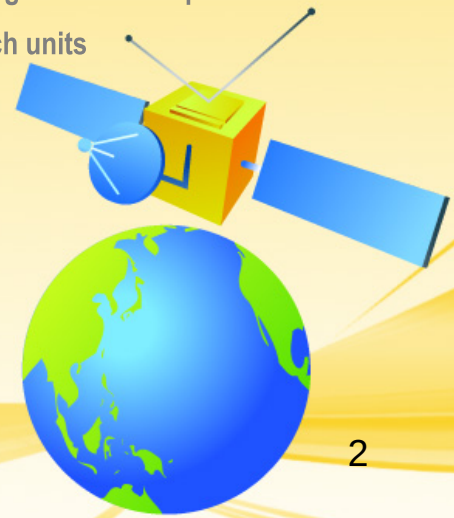
5,200 Patent families in portfolio (2012)

754 Priority patents delivered

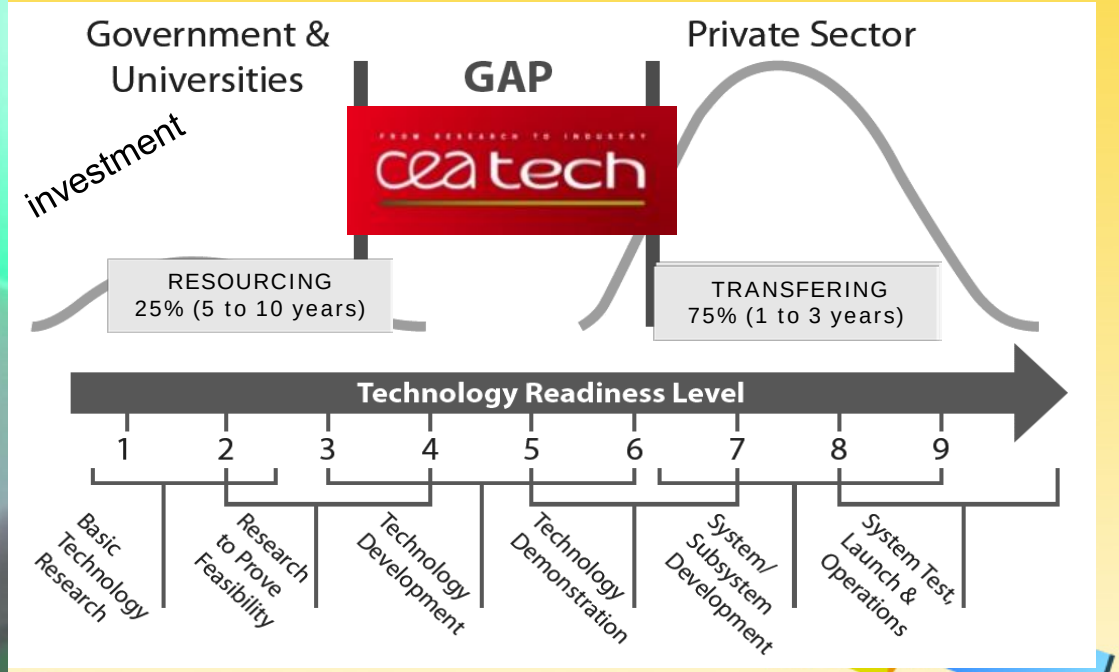
100 Innovative high-tech start-ups since 2000

54 Joint research units

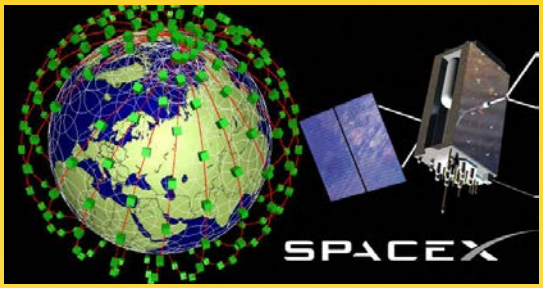
- *Mission DAM : France's national **security independence***
- *Mission DEN : France's **energy independence***
- *Mission DRT : French business' **economic competitiveness***



FROM RESEARCH TO INDUSTRY : MIND THE GAP !



THE NEW SPACE



- **Context :**

Satellites, Launchers, Exploration use batteries (accumulators & piles)

- **Economic Stakes:**

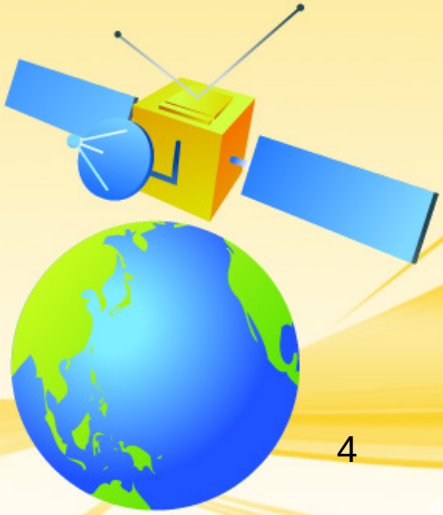
Launched costs 19000$/kg (Ariane5 GTO)

Extended missions, more energy needs

- **Industrial Space Revolution :**

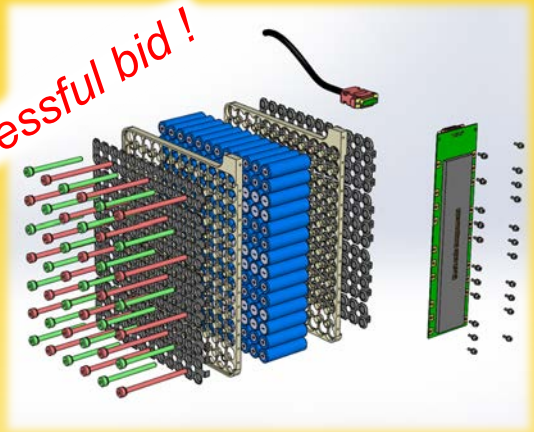
Worldwide affordable (lower costs) high-speed Internet

Satellites Constellations



COTS 18650 Li-ions for Space Missions ?

July 2014 : ESA looking for ExoMars Rover battery



July 2016 : Project Start
Feb. 2017 : CEA Iso 8 Battery Assy Line Inauguration
Dec. 2017 : QM
June 2018 : MRR
Dec. 2018 : PFM ready
Q1 2019 : Launch

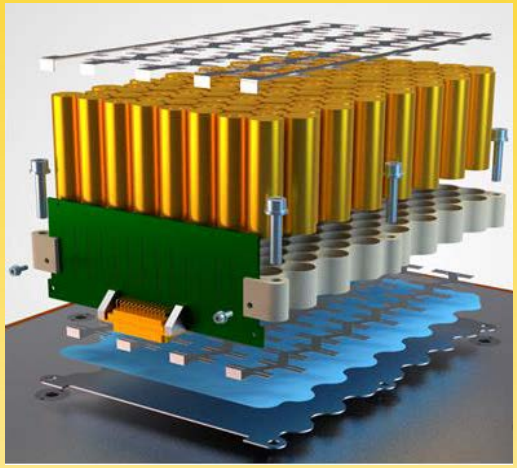
CEA proposed **a battery system built from terrestrial COTS 18650 cells** qualified to operate under space environment **wo cell manufacturer design modification and with no cells sorting/sparing**

2015 : CEA proposed **the use of its Semi automatic Battery Assembly Line built for Automotive terrestrial developments** (CEA-Renault Cooperation signed in 2010) **to develop competitive aerospace batteries made of commercial 18650 Li-ion cells (COTS) following a Lean 6σ manufacturing approach**

BATTERY ASSEMBLY FOR NEW SPACE

Goal:

KOM July 2016



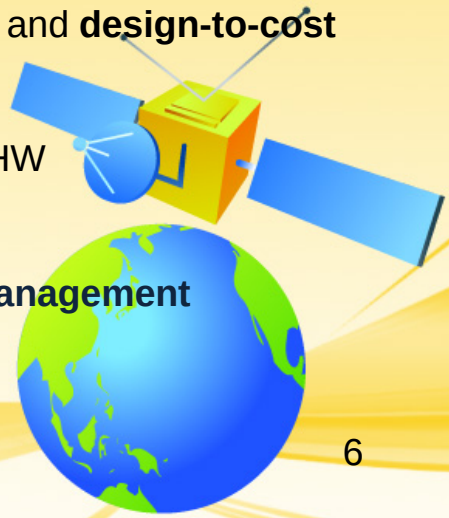
The objective is to develop a battery for **constellation satellites (LEO)**

-Customer is Design authority
-CEA is Design to industrialization authority
-Process developments and qualification
-Follows preventive approach using Lean 6σ manufacturing method
-Quality ISO10005-EN9100 management, problem solving, risk management
-Line installation, process flow definition, industrial plan, assembly operation
-PFM manufacturing
-Industrial transfer

Design very specific :

- Baseline is the fruit of **design-to-industrialization** and **design-to-cost engineering**
  - Use of automatized processes
  - Use of low-cost approaches for mechanical HW
  - Use of COTS cells

3/1000 defect level in Operation Guideline management



DESIGN TO COST ANALYSIS

Design to cost engineering using automatized processes and working to qualify COTS within a LEAN 6σ manufacturing method

SCOPE : IMPROVE BATTERY COST AS PER S/C NEEDS

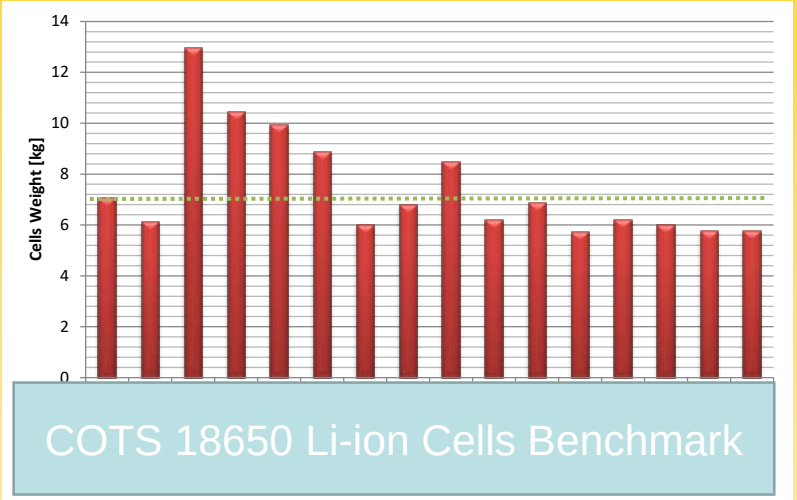
COST ELEMENTS	Cost ==>	Value ==>	PROVIDE ENERGY TO PAYLOAD		PROVIDE POWER		SUSTAIN CYCLE LIFE		SUSTAIN LIFE DURATION		SUSTAIN ENVIRONMENT		INTERFACE WITH S/C		ENSURE RELIABILITY		SAFETY USE		Total function value per cost
			500		500		500		500		200		200		200		50		
Cell (procurement parts cost, incoming activity if any, cell test, sorting,...)	200			400		400		250		250		80				20		10	1410
			40		40		40		40		10				10		20		
Mechanical parts including assembly parts (glue, tapes..)	100			25				50		150		80		100		20		10	435
											50		20		10		20		
Electrical parts (straps, EEE parts, connectors, wires, heaters ..)	150			25		80								50		20		10	185
					50						30		30		20		20		
Electronics card (PCB assembled), monitoring interface	250			50				200		100		40		50		40		10	510
							100		40				40		40		30		
Battery manufacturing (operators actions, intermediate inspection check, manufacturing paper work)	200															50			50
			20								50				80		50		
Battery test (intermediate test, final test)	100															50			50
			20		20						20		20				20		
Others expenses. Includes: Manufacturing line amortization Packing and transportation cost	20																	10	10
											10						10		
		Total cost per function	80		110		140		80		170		110		160		170		
EXCLUDED in perimeter: Paper work as the DRL general quality and management																			

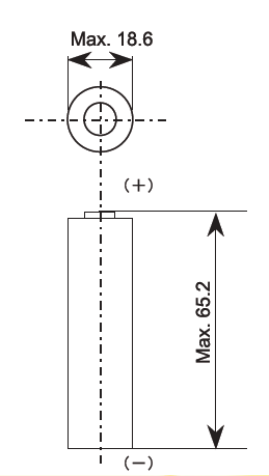
EXAMPLE

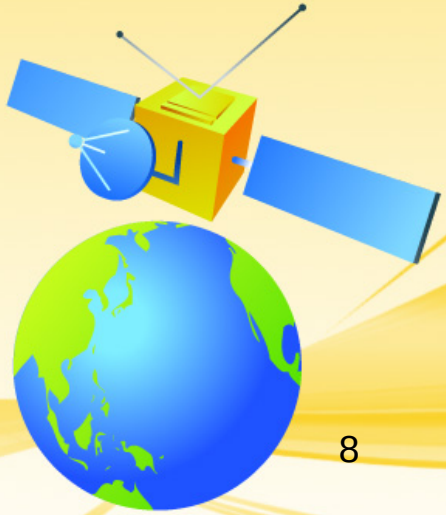
- Weight Battery Components Performance impact versus Cost
- i.e. COTS like 18650 commercial Li-ion cells Total Function Value per Cost is high

BENCHMARK GIGA MANUFACTURED COTS CELLS

- **<u>An extensive series of tests</u> :** characterization and cycling tests (representative of mission) of several cell models
- The baseline solution is to use **<u>18650 Li-ion cells</u>** (highest energy densities on the shelf with low dispersion)
- Allows switching the 18650 cell by a new qualified one with higher performance wo battery design major impact (within the design tolerance**) : risk mitigation if procurement shortage and warranty of bests performances wo major additional costs. Delta Qualification Strategy**
- Fully qualify the cell and establish LAT strategy







LONG LEAD ITEMS LIST - CLEAN ROOM FOR BATTERY ASSEMBLY

February 2017 Delivery
8 months from scratch

- ✓ ISO8 level clean room for Space Batteries Assembly
- ✓ EN9100 level quality standard for manufacturing
- ✓ Space qualified processes
- ✓ Industrial process control by
  - ✓ CEA **MES** = Manufacturing Execution System
  - ✓ Bar Codes scans
- ✓ Cost-effective
- ✓ For fast prototyping and industrial developments

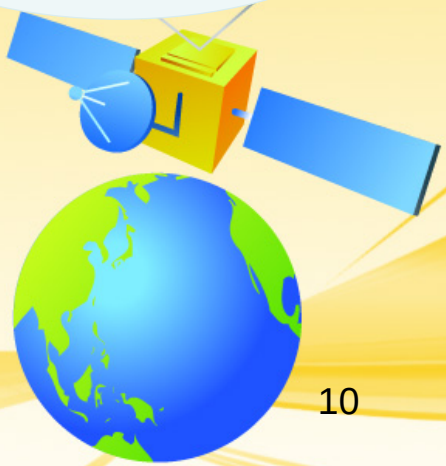
QUALITY MANAGEMENT

- 3/1000 defect level in Operation Guideline management

Preventive Approach
- Design & Process FMEA*
- Engineer expertise

Complete Process and Product Qualification
- Check Robustness

In-line Controls
- Primary parts
- Equipment
- Processes
- Products
- Operators



*Failure Mode & Effects Analysis

A Preventive Approach

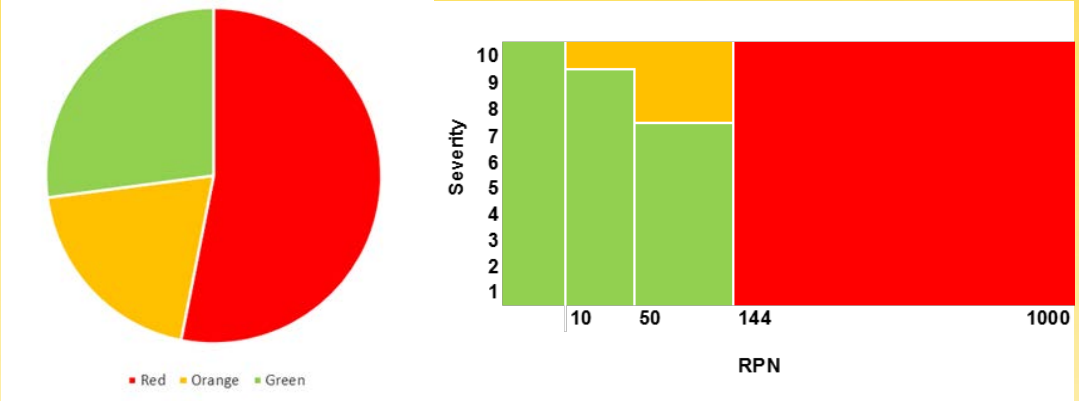
ISO 10005 - EN 9100 Quality Management followed

**French = Equipements de Contrôle, de Mesure et d'Essai; Control, Measurement and Testing Equipment*

PROCESS FAILURE MODE & EFFECTS ANALYSIS

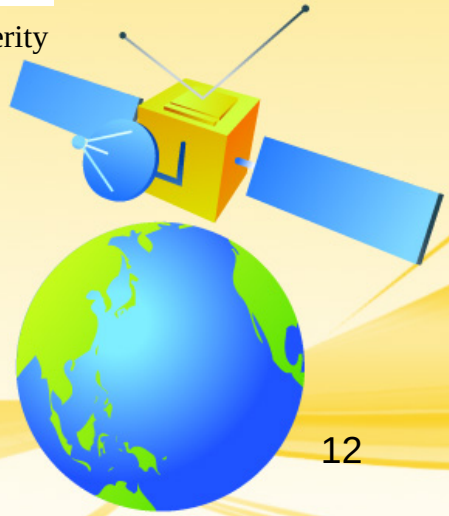
Risk Priority Number (RPN)

- Actions are already taken into account during Equipment Installation and Process Qualifications to reduce them



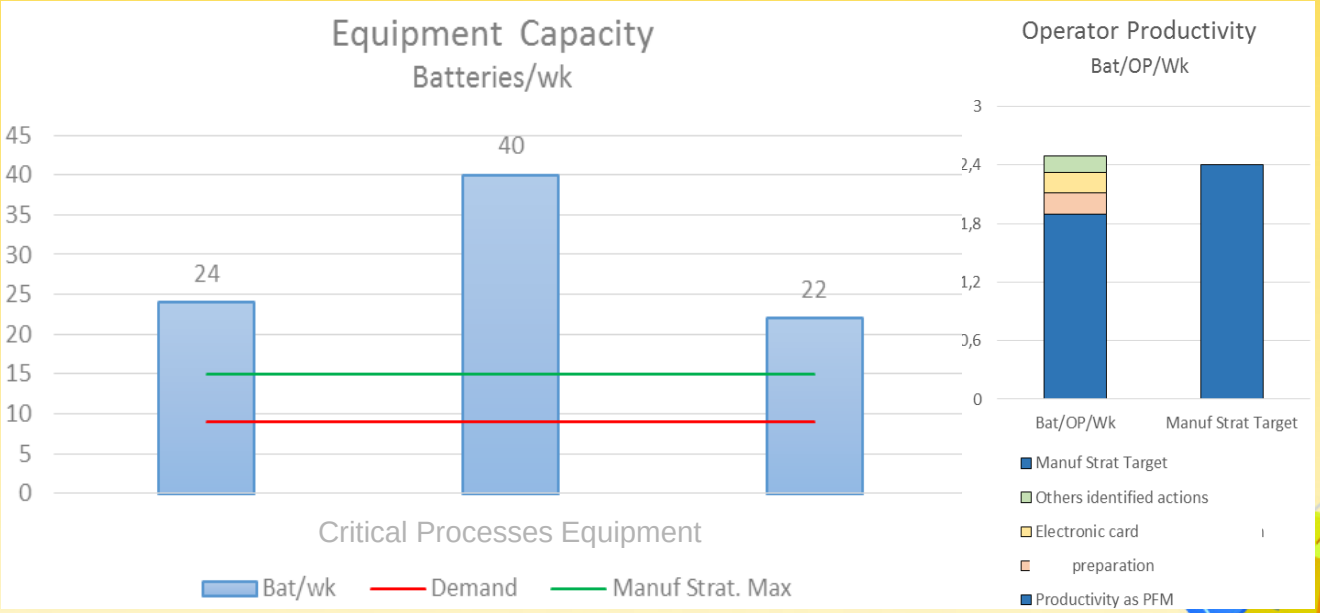
Example of PFMEA status review with RPN classification repartition and severity

- PFMEA completed for MRR
- All risks mitigated at that time



ON TIME DELIVERY (OTD) STRATEGY

- Equipment Capacity, more equipment capacity than needed
- Make batteries prior to demand, at maximum of operator capacity

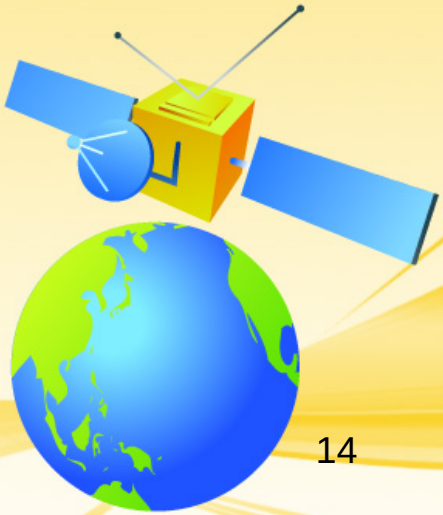


- Ensures maximum OTD level during all the production period
- Key demand from the satellite manufacturer in order to respect launch schedule

DELIVERY STRATEGY

- Sample batteries to be delivered within various manufacturing batches
- To preliminary detect any failure of batches (Battery SOC check before transport)
- Variation of the FIFO (First In First Out) method : **Example**

Fab		Year	2017			2018											2019											
		Month	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Delivery		Manuf Plan	0	16	32	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	48	36						
Year	Mon	Demand	Simulation																									
2017	10	0																										
	11	0																										
	12	8		8																								
2018	1	16		8	8																							
	2	24			20	4																						
	3	32			4	24	4																					
	4	32				20	8	4																				
	5	32					28		4																			
	6	32					8	20		4																		
	7	32						24	4		4																	
	8	32							28			4																
	9	32							12	16			4															
	10	32								28				4														
	11	32									28				4													
	12	32									16	12				4												
2019	1	32										28					4											
	2	32										4	24					4										
	3	32											20	8					4									
	4	32												28						4								
	5	32												8	20						4							
	6	32													24	4						4						
	7	32														24	4						4					
	8	32														16	12	4										
	9	32															28		4									
	10	20																16		4								
	11	20																16			4							
	12	20																8	8			4						
2020	1	20																	16				4					
	2	20																	16	4								
	3	20																		20								
	4	20																		16	4							
	5	20																			20							
	6	20																			16	4						
	7	20																				16	4					
	8	20																				20						
	9	20																					20					
	10	4																					4					
	11																											
	12																											



PROJECT RISKS MANAGEMENT PROCESS

CAUSE: 7M section	Risk description	Impact		Probability of appearance		Total risk	Action	Person in charge*	Status
		High	Low	High	Low	1 to 4			
Management	Industrial Project Organization	Y			Y	3	CEA ISO 9001 management + Priority 1 CEA labeled project + Department SteerCo weekly + Liten Unit SteerCo monthly	HoP	
METHOD	Quality Plan building and operating	Y			Y	3	ISO 9100 assessment, PQP (PA) writing and operation. Full Time Project Quality Manager Customer audit closure Q1 17 CEA space qualified with deviation for procurement	QM	
MATERIAL	Class 100 000 room	Y		Y		4	Ready for end of 2016 Delivered January 2 2017 Inauguration February 28 2017 MES 2017	IM	
MACHINES	XXX	Y		Y		3	Operating in November 2016 Full acceptance in February-March 2018	PM	
MANPOWER	Project resources	Y			Y	2	CEA internal meetings with HR	HoP / HR	
MATERIAL	New Components Providers using terrestrial mass prod. to Space Qualify for lower battery costs : Critical path	Y			Y	4	Strong Procurement Support	TM	
...									

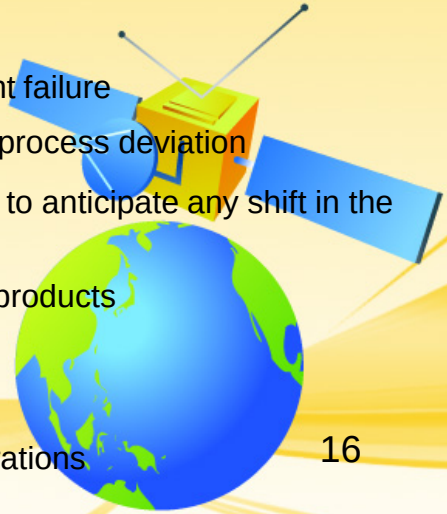
**HoP = Head of Project; QM = Quality Manager; IM = Industrialization Manager; PM = Process Manager; TM = Technical Manager, HR = Human Resources*

Process Qualification, Control Plan, SPC, 8D problem solving … Industrial Plan Summary !

- **3/1000 defect level Guideline management :**

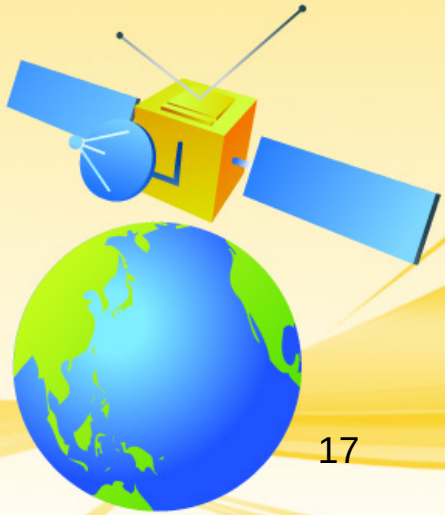
  - **Detailed PFMEA lead to preventive action plan in order to reduce number of non-conformance products**
  - **Qualification of processes and products**
    - **Qualification plan**, fed by DFMEA & PFMEA and engineer's expertise, warranty the robustness of the product and process
    - **Product Qualification qualify the Manufacturing Equipment / Process line**
  - **Primary parts management**
    - **Design and supply of parts under Customer responsibility**

    with their standard quality process ensuring a very low level of defects
  - **Equipment, Process and Products control**
    - **Problem solving based on 8D method**
    - **Control plan** is an output of the PFMEA to detect defects during manufacturing
    - **Maintenance plan** is an output of the PFMEA. The controls ensure no equipment failure
    - **Equipment operating mode** with control before new batch manufacturing to avoid process deviation
    - **Statistical Process Control (SPC)** approach on Critical Parameters, in order to anticipate any shift in the process
    - **A final inspection point**, done by quality engineer ensures good conformity of the products
  - **Operator control**
    - Training of operators reinforced during the Ramp-up phase
    - Regular line audits are included in quality plan, and ensure the conformance of operations



Battery Price Breakdown For Competitive Product Industrialization Is Demonstrated

Space Applications	Challenges	Achievements	Cooperation Benefits
Satellite Constellations	• Low-cost battery • Several hundreds of satellites • Use of COTS cells	• Co-development with our customer of the 1st generation battery and assembly line in CEA LITEN Grenoble (France) • Launch of PFM • Industrial Transfer	• **Batteries supply contract won by our customer** • Risk reduction • Battery cell usage expertise • Ability to deliver on time



AIRBUS/CEA COOPERATION
AEROSPACE BATTERIES TRACK RECORD

2019

Satellites Constellations…

Aircrafts Hybridization

120kWh

VTOL Full Electric (fourSeats) 1st Flight

Expected

163Wh/kg system (HV+LV)

Lift May 5 2018

ROTOR TRANSITION from Lift Off to Cruise

Cruise Feb. 2 2019

40kWh

VAHANA VTOL Full Electric (monoSeat) @ Pendleton, Oregon USA

>50 flights

Demonstration
Feb. 8 2018

1kWh

SKYWAYS Drones for Parcel Delivery @ Singapour

URBAN PERMIT TO FLY

Feb. 2018 May 2018 Feb. 2019

- ✓ Aero Demonstrators / Fast Protoyping
- ✓ Space Industrial Developments


CAFÉ DES FÉDÉRATIONS
THANK YOU !
8
LICENCE
MORGON
Selection
SélectionnéS
CÔTES du RHÔNE
CASSE-CROUTE