Staircase to Utopia: Advances in Technology Roadmapping

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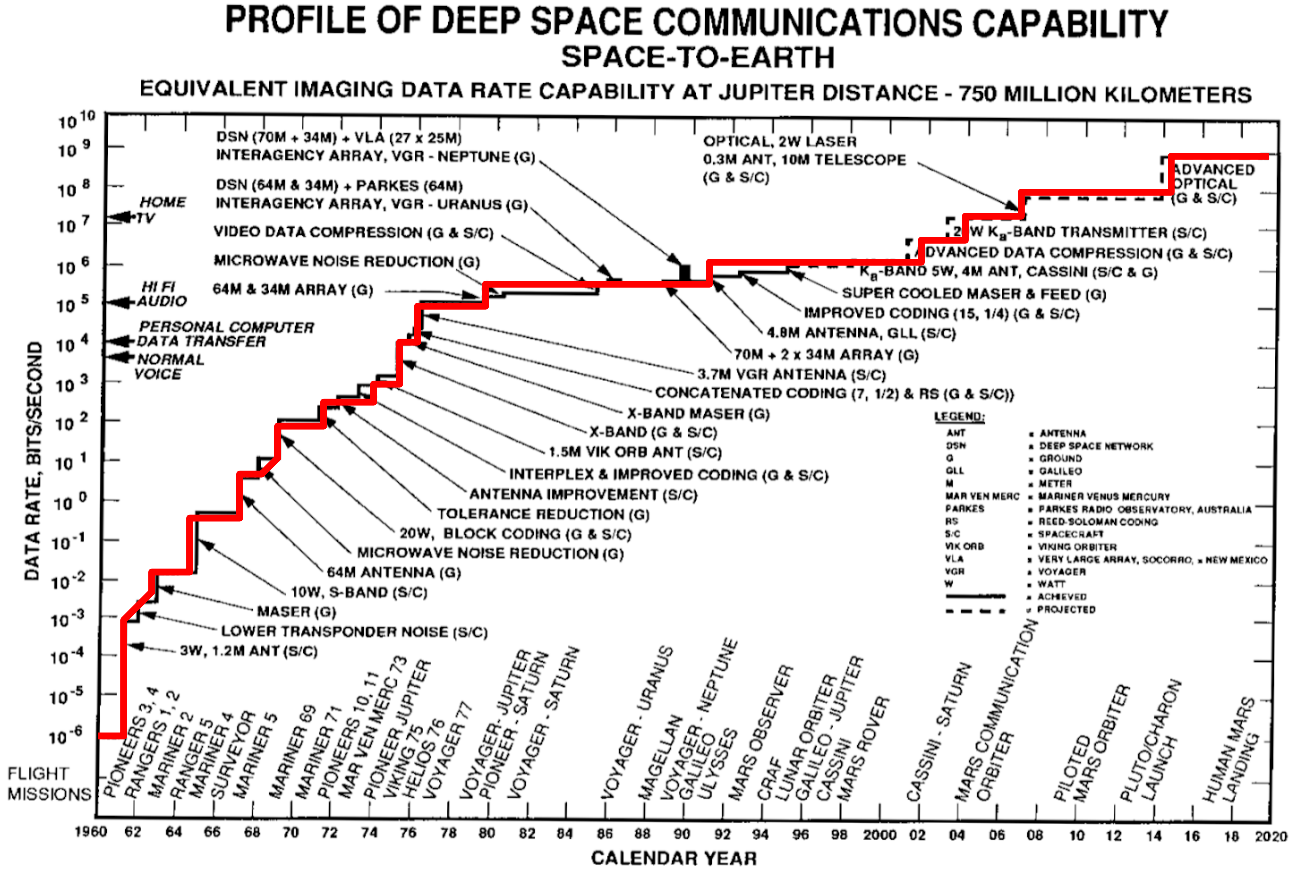


This chart documents the twelve orders of magnitude improvement of deep space communications capability since the beginnings of deep space exploration to the present. Another 3 orders of magnitude improvement are forecast by 2020. The increase of performance is due to a series of innovative cooperative improvements in both the spacecraft and ground. Key factors include higher operating frequency and improved coding techniques, spacecraft higher power and antenna size, and ground system lower noise amplifiers and increased antenna size.

DSN Capability over time

Data Rate [bps]: 10^{-6} to 10^{9} for S=750 Mkm

Timeline: 1960-2020

Flight Missions shown at the bottom

S/C = spacecraft
G = ground
G & S/C = ground + spacecraft change

_____ Achieved
- - - - - Projected

Source: JPL

Outline

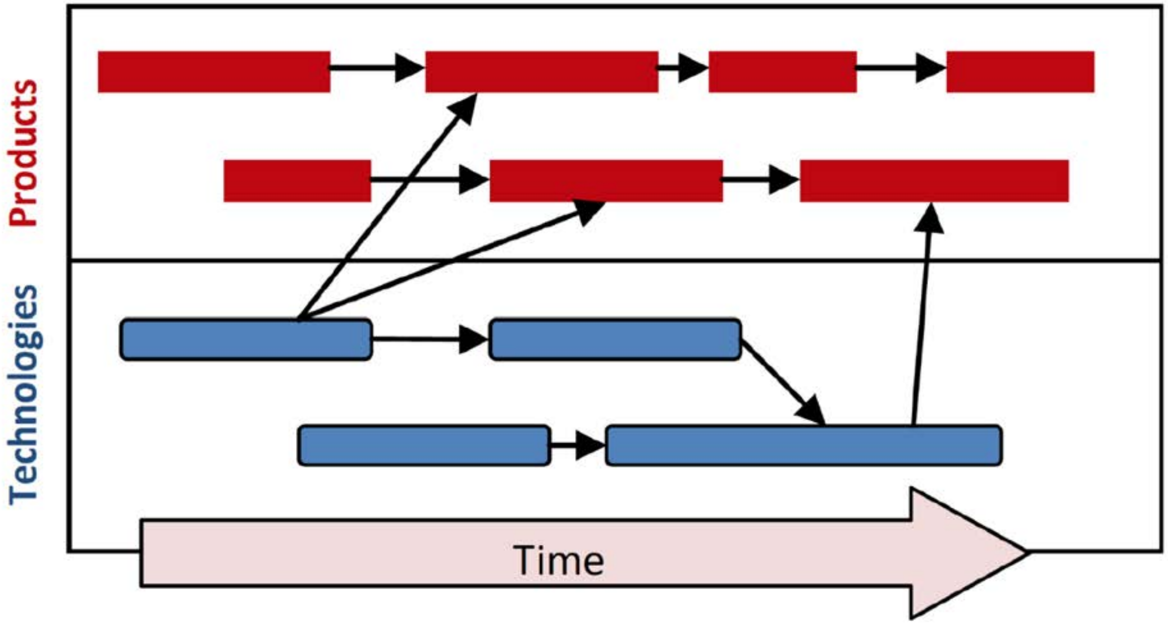
What is a Technology Roadmap?

Example of Technology Roadmap: 2SEA Solar Electric Aircraft

MIT Advanced Technology Roadmap Architecture (ATRA)

16.887/EM.427 New MIT Class

What is a technology roadmap?



“Simple” Technology Roadmap: linking technologies (blue at the bottom) against the products that will implement them (red at the top) along a timeline (x-axis). Source: Bernal et al.

What is the purpose of roadmapping?

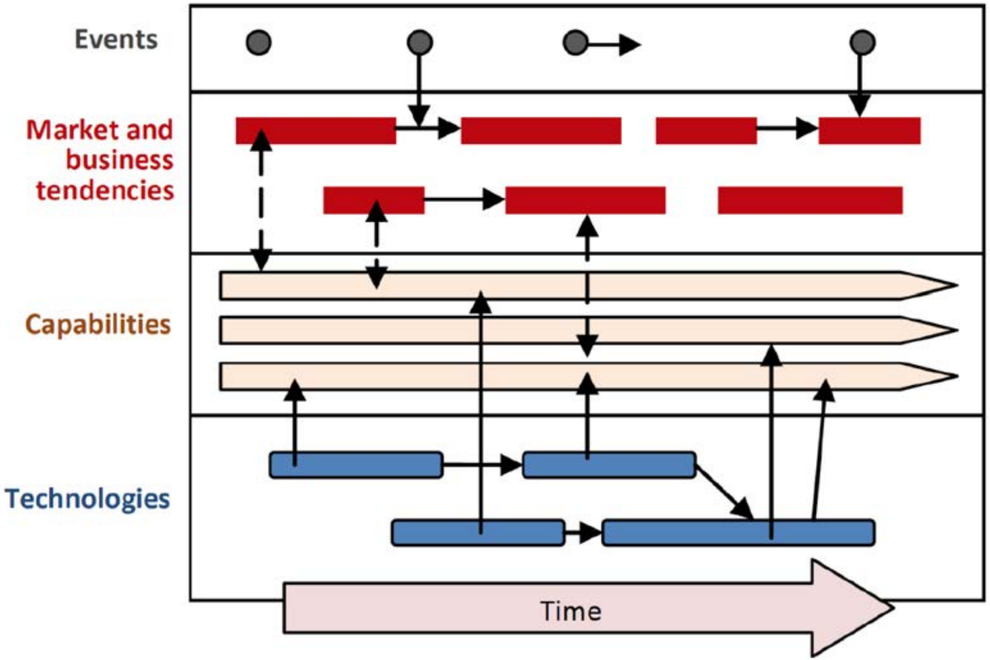
In a nutshell, the purpose of technology roadmaps in an organization is to:

- **Show the relationships** across technologies, capabilities, products/services, and needs
- **Align investments** in technology and in the new development of new capabilities to deliver on future market needs
- Map technologies to products/missions/services and **define a timeline** for maturation and technology adoption

Different flavors of technology roadmaps

Most basic version of roadmap is to map technologies to products and services. Other flavors are:

- Product planning
- Capability development
- Strategic planning
- Long range planning
- Knowledge planning
- Project planning
- Integration planning



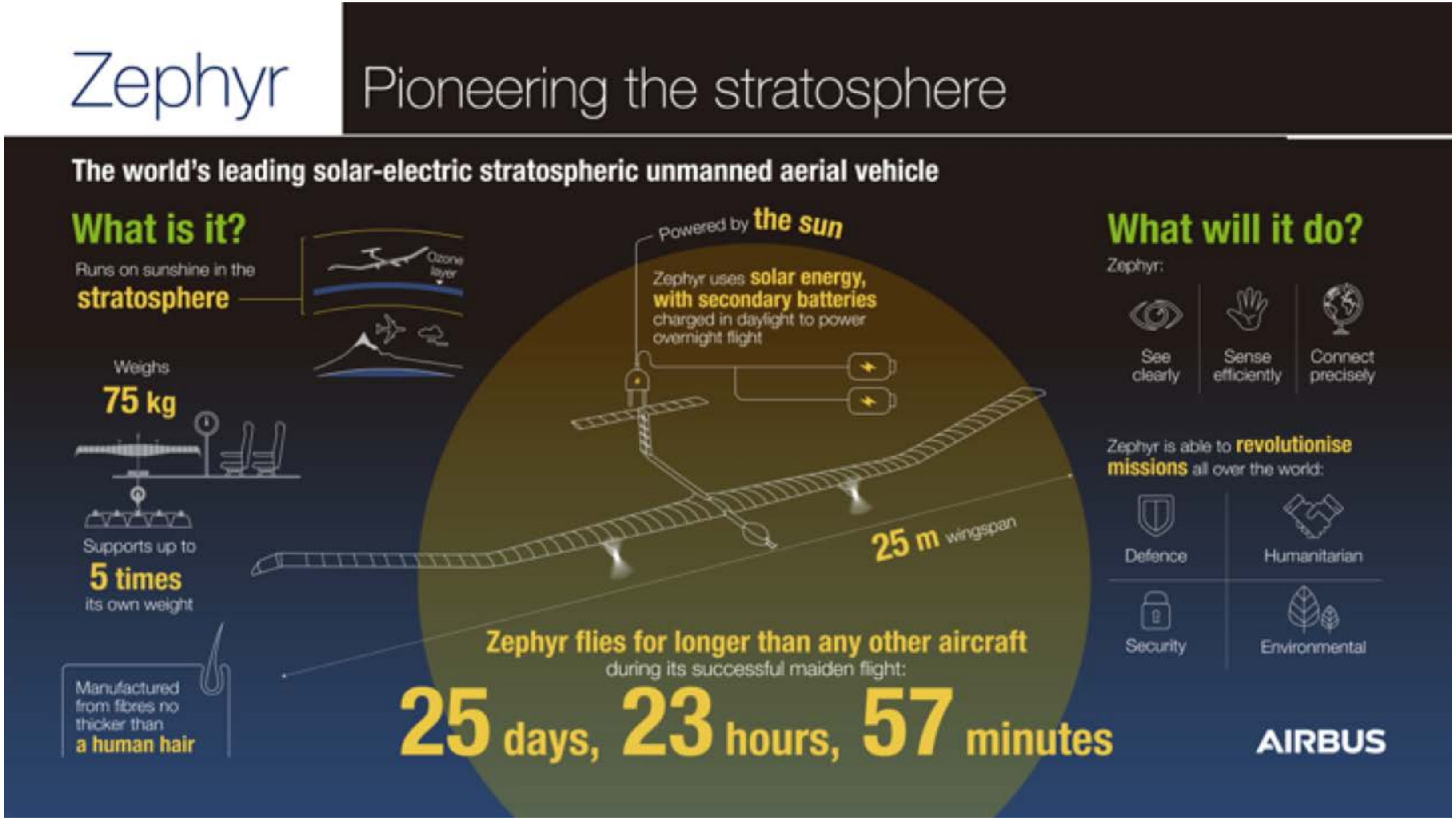
What is your experience with technology roadmapping?

What is your level of experience with technology roadmapping?

- I have not seen a technology roadmap yet
- I have seen technology roadmaps but not been involved in creating them
- I have helped create one or more technology roadmaps
- I have led the development of a technology roadmap
- I have led the development of an R&D portfolio including roadmapping
- I am not sure

http://tiny.cc/TechRM

Sample Roadmap: 2SEA (solar electric aircraft)

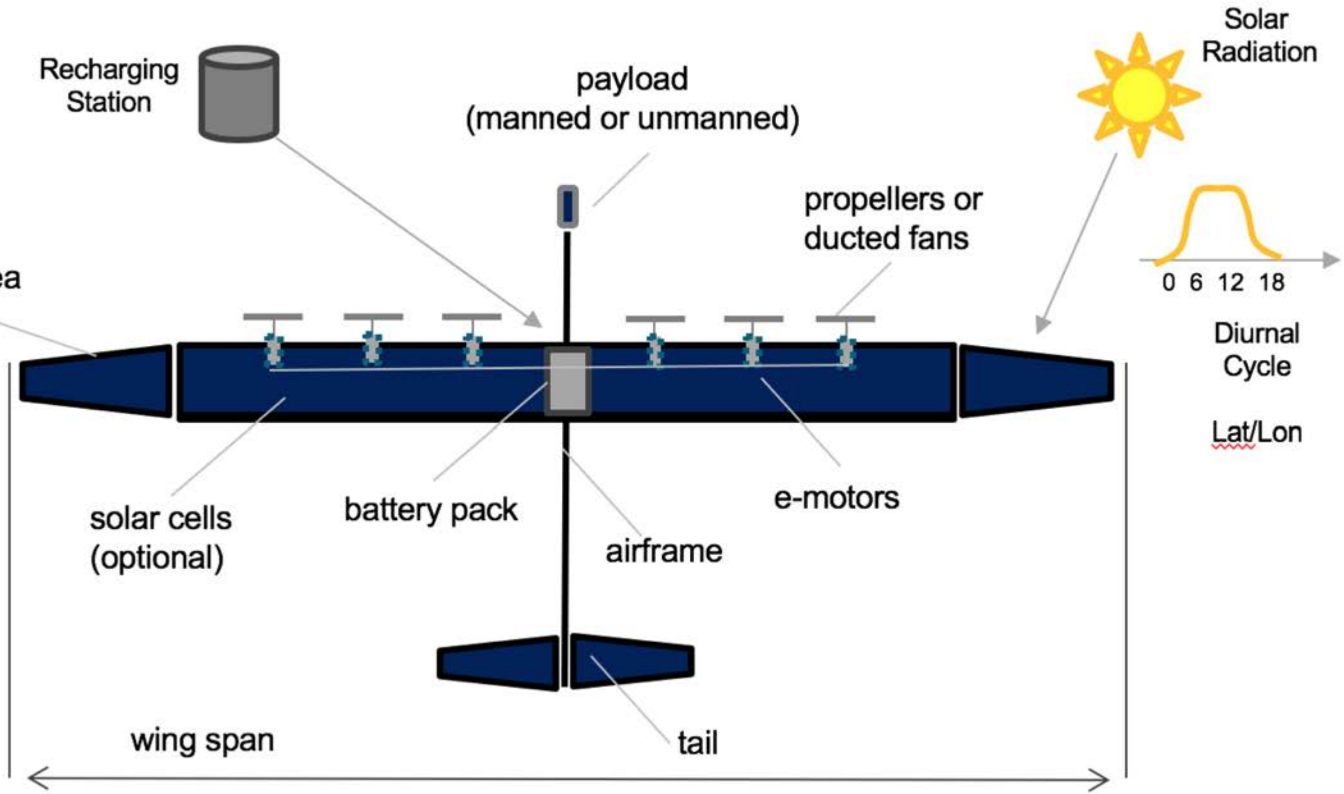



Zephyr
Pioneering the stratosphere

2SEA - Solar Electric Aircraft - roadmap outline

1. **Roadmap Overview**
2. **DSM Allocation (interdependencies with others roadmaps)**
3. **Roadmap Model using OPM (ISO 19450)**
4. **Figures of Merit (FOM): Definition, name, unit, trends *dFOM/dt***
5. **Alignment with Company Strategic Drivers: FOM Targets**
6. **Positioning of Company vs. Competition: FOM charts**
7. **Technical Model: Morphological Matrix and Tradespace**
8. **Financial Model : Technology Value (*Δ*NPV)**
9. **List of R&T/R&D Projects and Prototypes**
10. **Keys Publications, Presentations and Patents**
11. **Technology Strategy Statement (incl. “arrow” chart)**
12. **Roadmap Maturity Assessment (optional)**

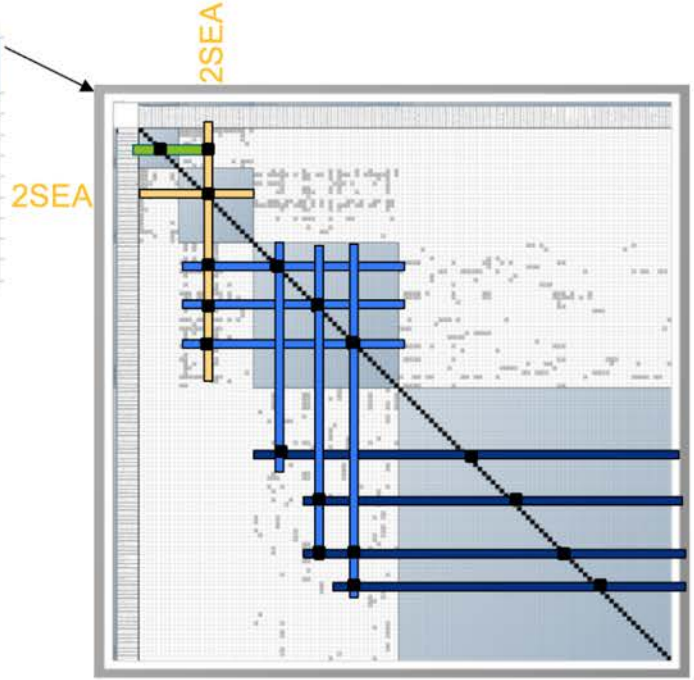
1 Roadmap Overview



Working principle and architecture of a solar-electric aircraft

2 Design Structure Matrix (DSM) Allocation

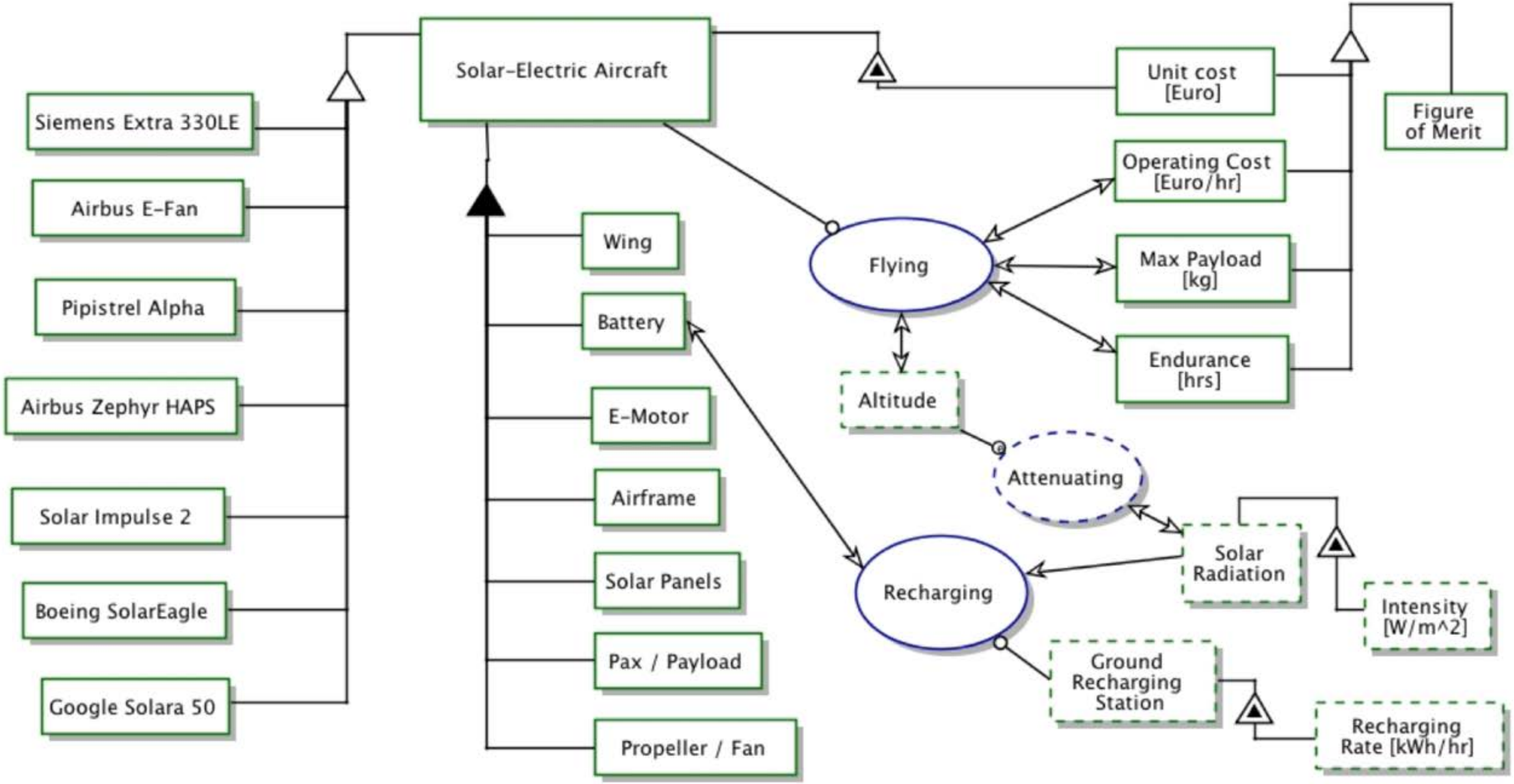
	1ELE	2SEA	3CFP	3HEP	3EPS	4CMP	4EMT	4ENS	4STO
1ELE		1							
2SEA	1		1	1	1				
3CFP		1				1			
3HEP		1					1	1	
3EPS		1					1	1	1
4CMP			1						
4EMT				1	1				
4ENS				1	1				
4STO					1				



2SEA-Tree

1ELE Electrification
- 2SEA Solar Electric Airplane
  - 3CFP Carbon Fiber Polymers
  - 3HEP Hybrid Electric Propulsion
  - 3EPS Non-Propulsive Energy Management
    - 4CMP Composites
    - 4EMT E-Machines
    - 4ENS Energy Sources (PV)
    - 4STO Energy Storage (Batteries)

3 Roadmap Model using Object-Process-Methodology (OPM)



4 - Figures of Merit (FOM)

FOM name	Units	Description
Unit Cost	**[€]**	Unit cost to manufacture the aircraft (incl. amortization of R&D)
Operating Cost	**[€/FH]**	Cost per flight-hour, including all variable cost (e.g. energy recharging, battery replacement), and maintenance
Maximum Payload	**[kg]**	Useful payload that can be carried (includes cargo, payload, sensors and comm equipment) and pax
Endurance	**[hrs]**	Time-aloft without recharging on the ground
Energy Storage Density	[kWh/kg]	Energy stored onboard per unit mass of energy storage devices (e.g. batteries)
Recharging Rate	[kWh/hr]	Rate at which batteries can be recharged on the ground
Electrical Max Power	[kW]	Total maximum electrical power generated on board by e-machines, for both propulsive and non-propulsive use
Photovoltaic Cell Efficiency	[%]	Conversion efficiency from incoming photon flux to useable electric current (electron flux)
Availability	[hrs/y]	Expected number of flight hours the aircraft is available for service per year (excludes maintenance downtime)

6 Positioning of Company vs. Competition: FOM charts


Siemens Extra 330LE


Airbus E-Fan


Pipistrel Alpha Electro

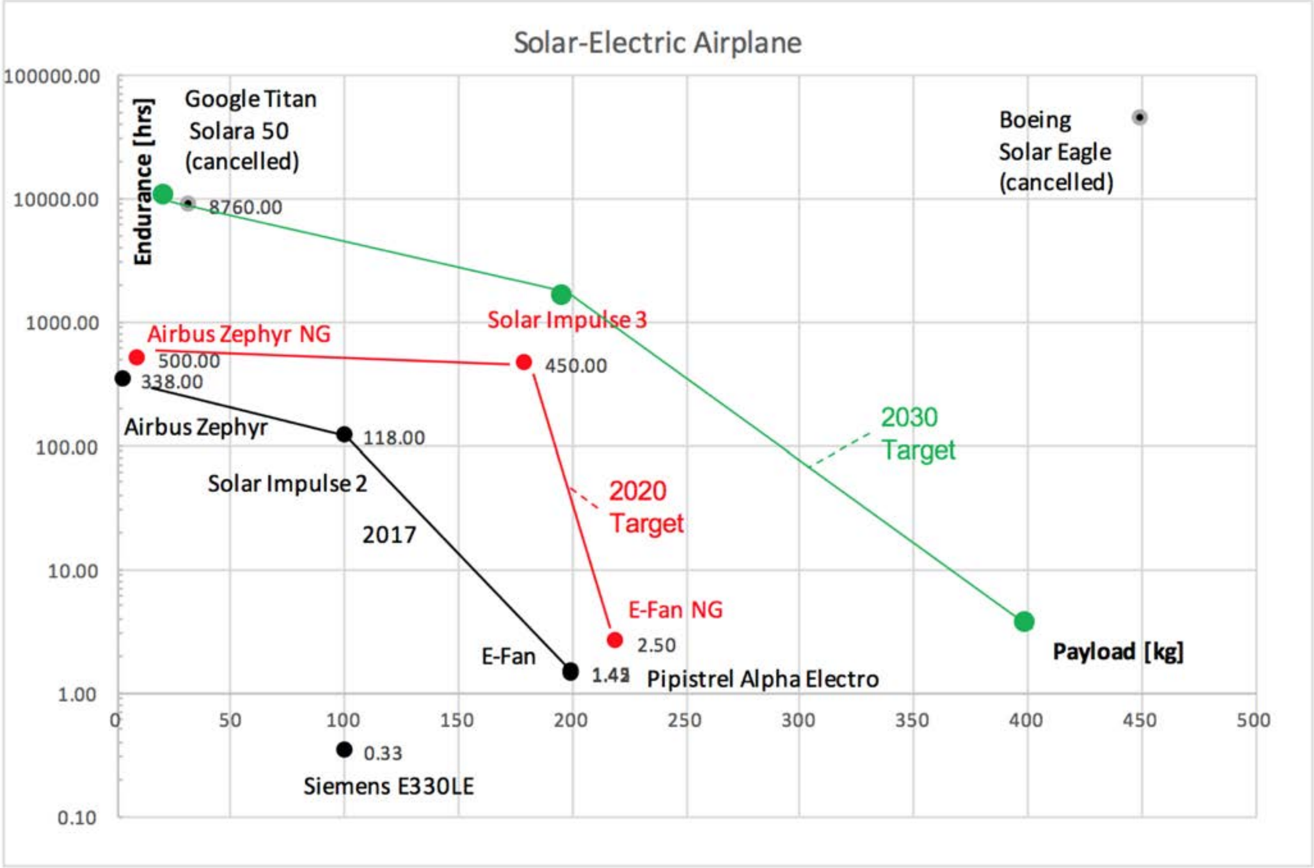

Airbus Zephyr 7


Solar Impulse 2

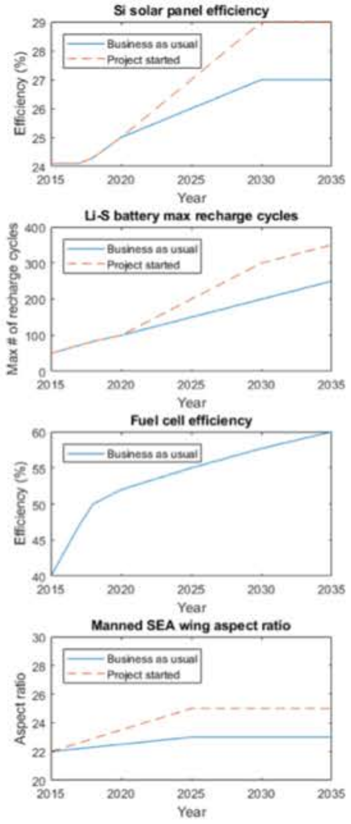

Google Solara 50 (cancelled)

Name	Developer	First Flight [year]	Mass [kg]	Payload [kg]	Pax [-]	Endurance [hrs]	Motor Powe [kW]	Wing Span [m]
Extra 330LE	Siemens	2016	1000	100	1	0.33	260	8
E-Fan 2.0	Airbus	2014	600	200	2	1.45	50	11
Alpha Electro	Pipistrel	2015	550	200	1	1.42	50	10.5
Zephyr 7 HAPS	Airbus	2010	53	2.5	0	338.00	0.9	22.5
Solar Impulse 2	EPFL	2015	2300	100	1	118.00	52	71.9
SolarEagle	Boeing	defunct	2700	450	0	43800.00	?	130.5
Solara 50	Titan-Google	defunct	159	32	0	8760.00	7	50

6 Positioning of Company vs. Competition: FOM charts



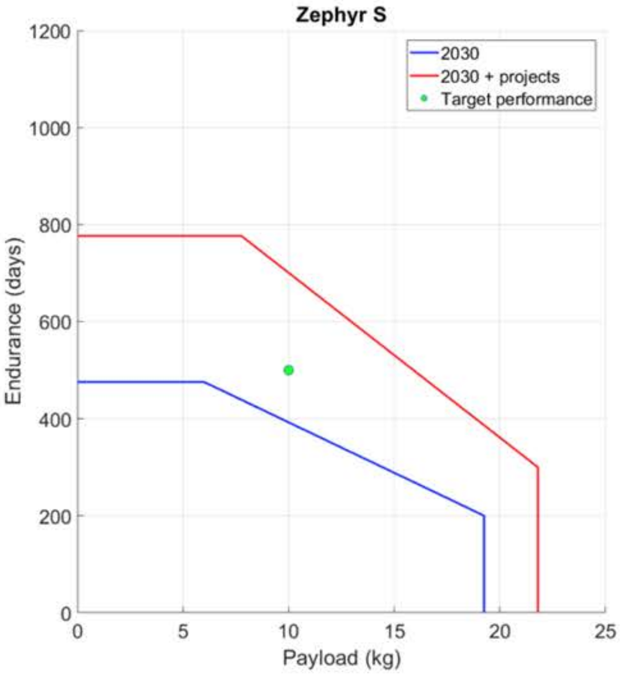
9 List of R&T (R&D Projects) and Prototypes



Product-specific technical model (i.e. *transfer function*)

$$Product\ FOMs = (y_1, y_2, ..., y_m)$$
$$Technology\ FOMs = (x_1, x_2, ..., x_n)$$

$$(y_1, y_2, ..., y_m) = f(x_1, x_2, ..., x_n)$$



Credit: S. Salgiero (MIT | Aero Astro)

R&T Project Selection for 2SEA

Target requirement: HAPS (i.e. Zephyr) with 10 kg of payload and 500 days of endurance by 2030.

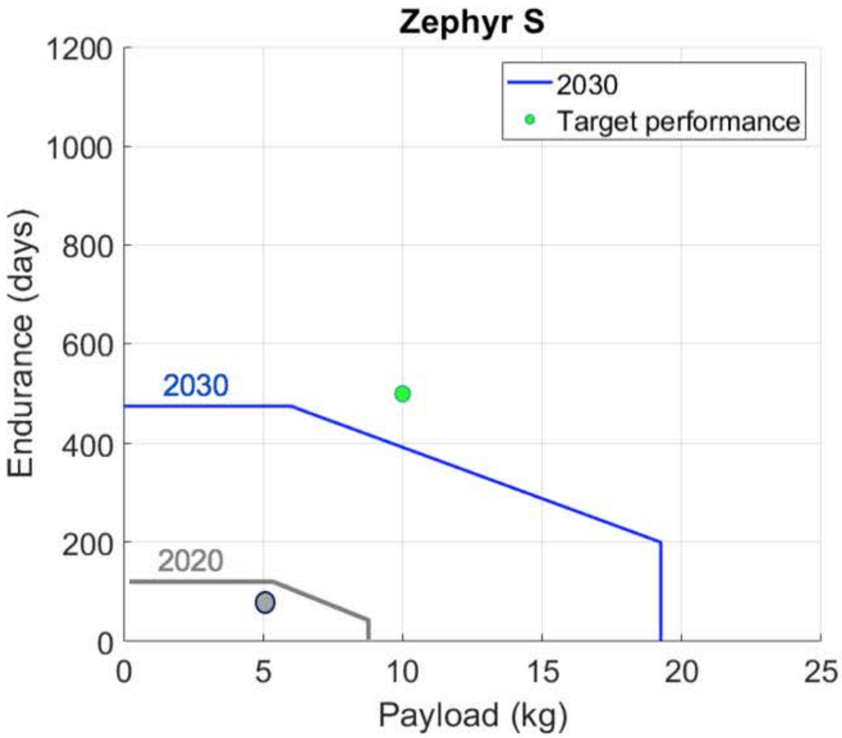
R&T projects available:

1)Li-S battery improvements,

2)Solar cell improvements,

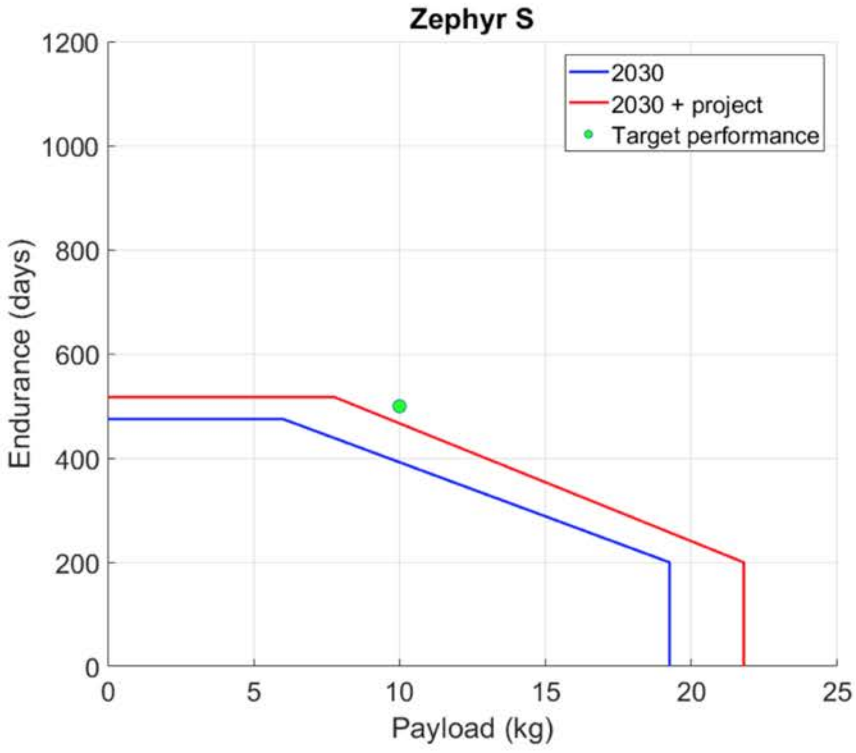
3)Structural improvements

Unable to meet target by 2030 with no projects.



Structural Improvement Project

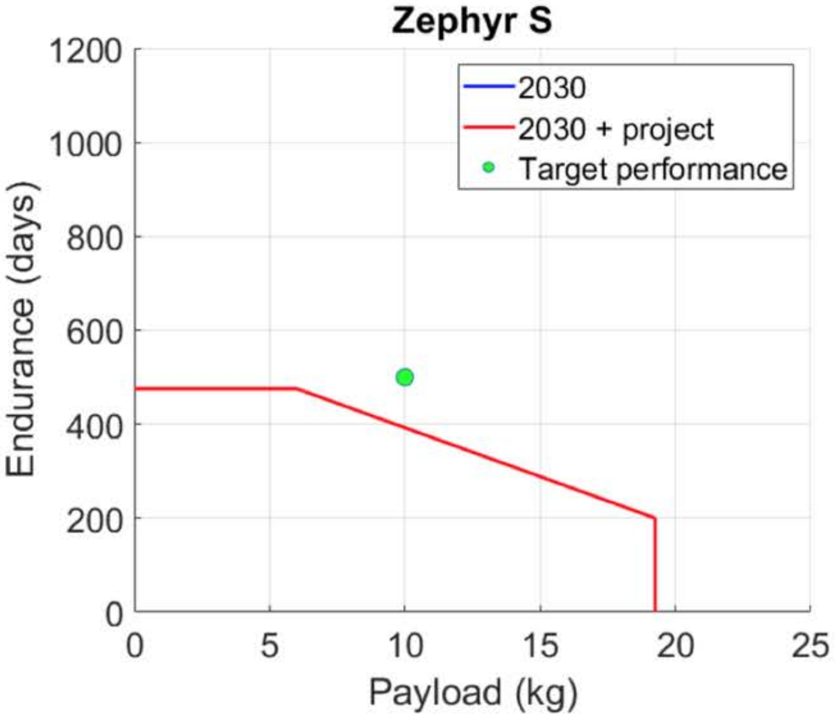
Unable to meet target by 2030 with Structural Improvements alone.



Solar Cell Improvement Project

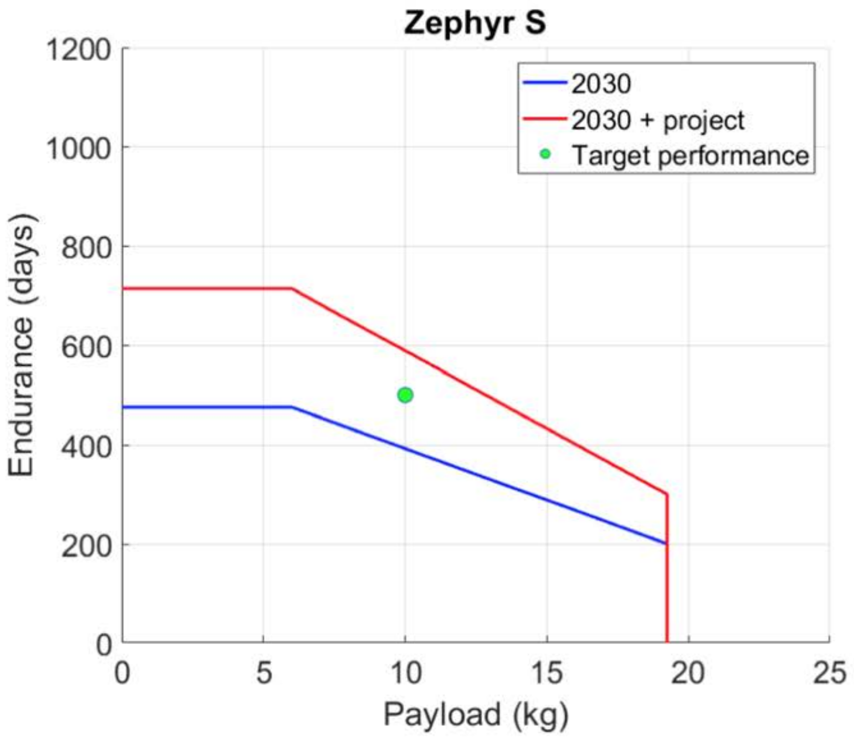
Unable to meet target by 2030 with solar cell improvement alone.

No change in aircraft performance with increased solar cell efficiency. Battery capacity is the limiting factor.



Li-S battery improvement project

Able to meet target by 2030 with Li-S battery improvements alone.

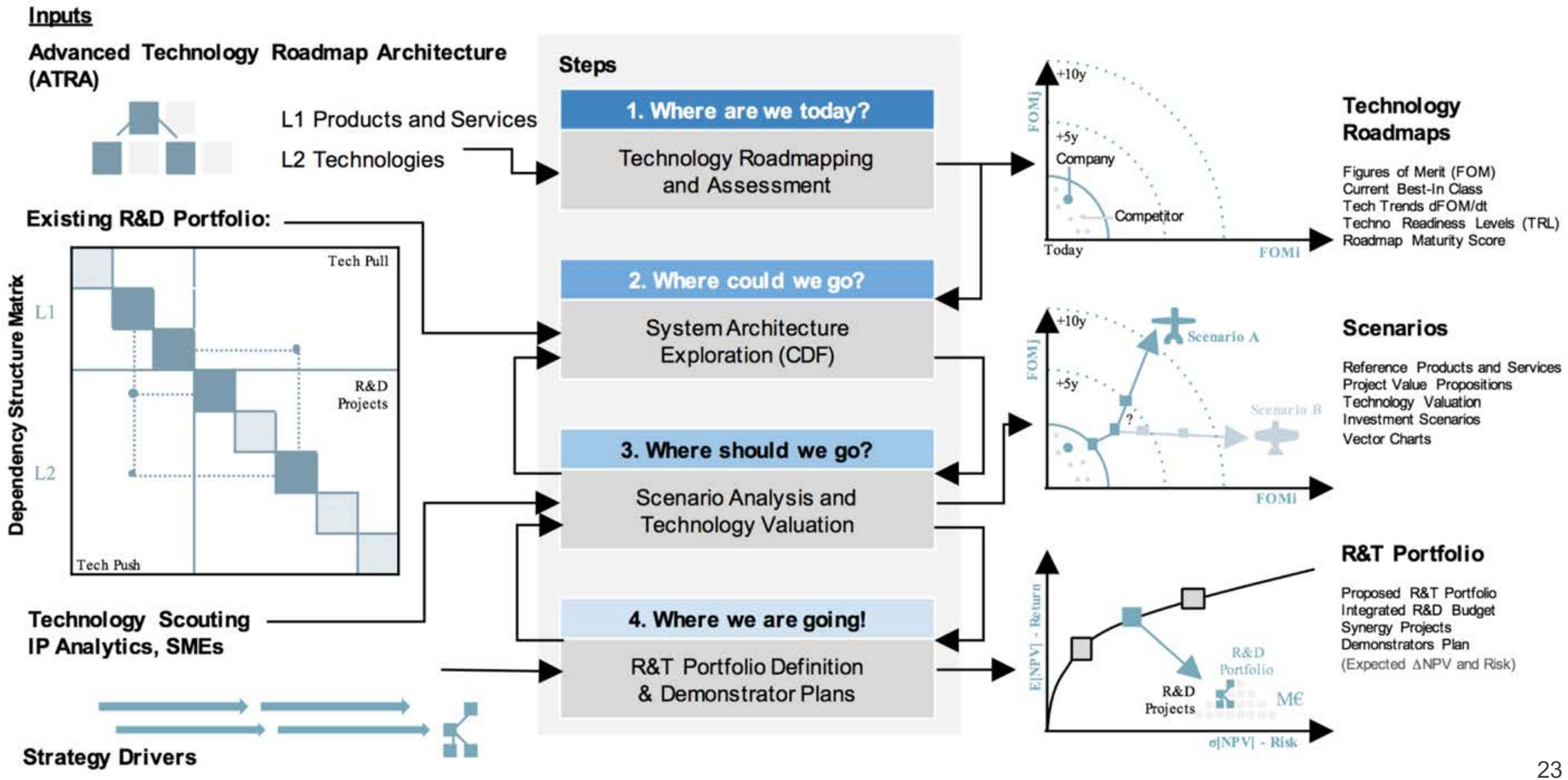


2SEA Project Portfolio

1. A ***Li-S battery improvement project*** with the FOM target of raising the number of charge-discharge cycles from 100 to 500 by 2025. This project will be allocated to the linked *4STO Energy Storage Roadmap* and executed with a partner who specializes in lithium chemistry-based battery development and certification (with shared IP).

1. A ***flight demonstrator project*** will be launched as part of the 2SEA roadmap to demonstrate a 10 kg payload and 365 day (one full year) capability by 2027 as a prototype, with an intended EIS of a commercial 500day-10kg-capable product and associated profitable service by 2030.

MIT Advanced Technology Roadmap Architecture (MIT-ATRA)



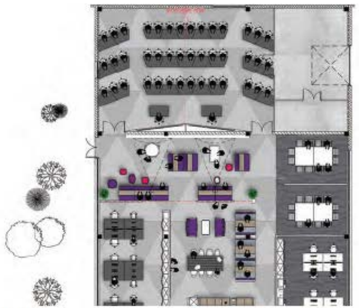
Step 1: Where are we today?

Dr. Martin Latrille, Airbus

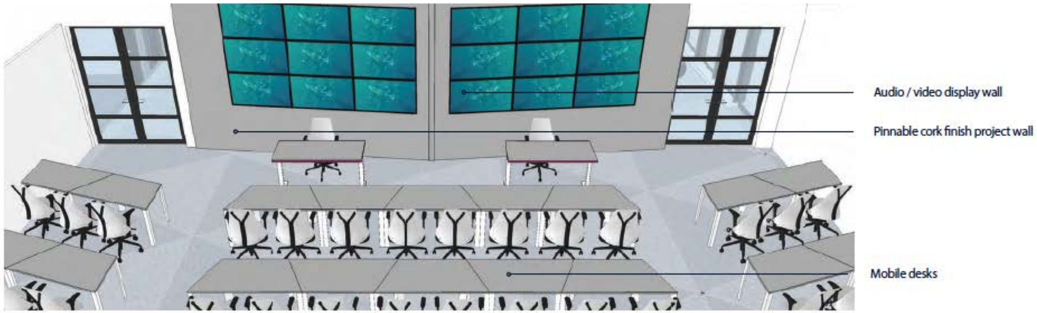
Step 2: Where could we go?

Airbus Toulouse 35

Concurrent Design Facilities



Proposed Layout

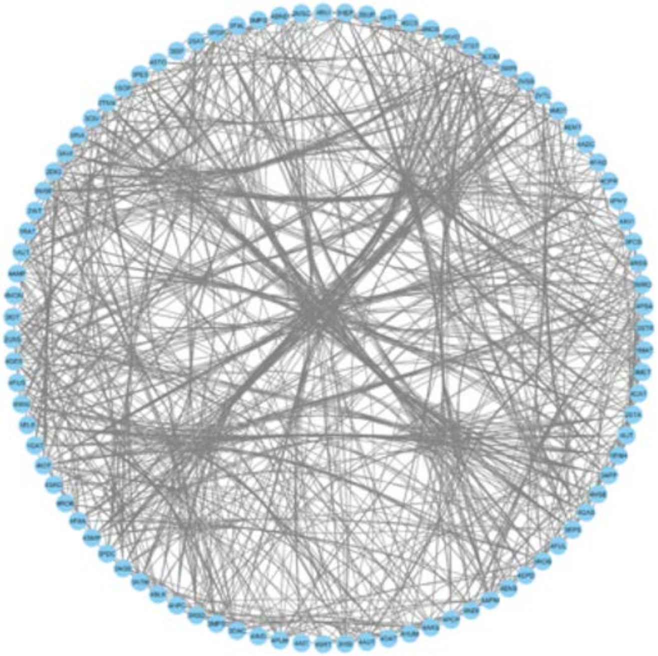


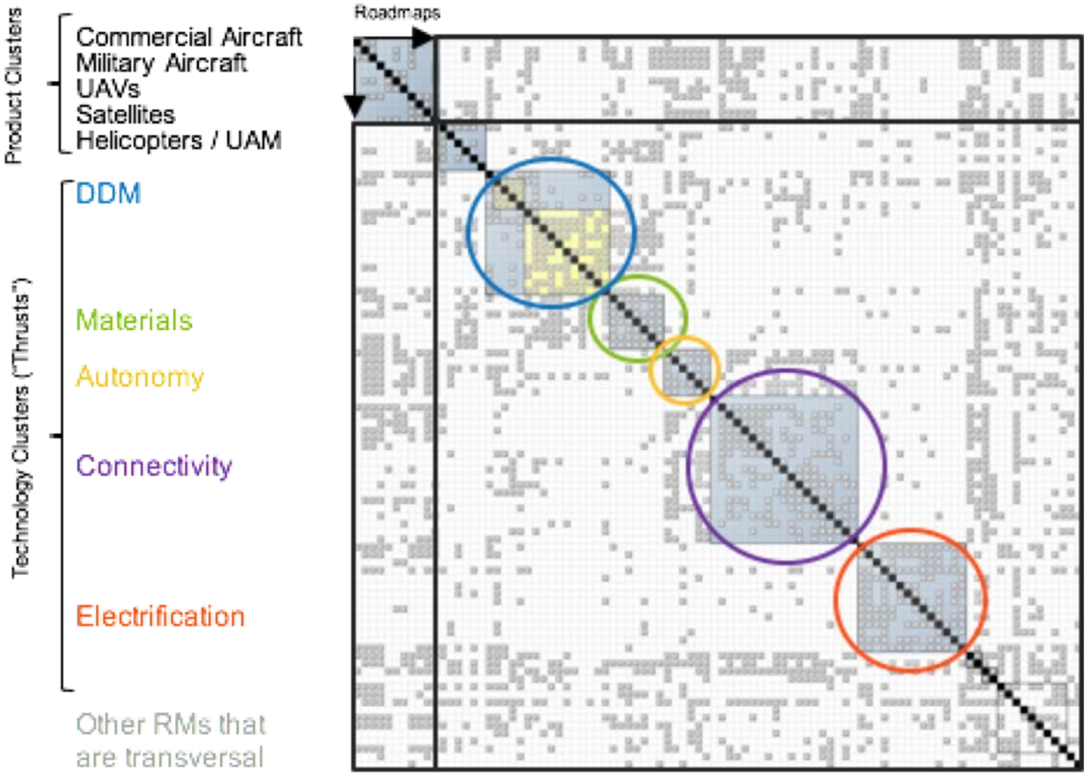
View Showing CDF

unispace

Think Create Make

Step 3: Where should we go?





Step 4: Where we are going !

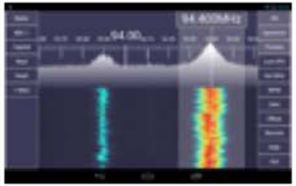
Electrification

2MW-class Hybrid-Electric Propulsion

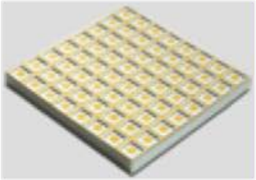
Fault-Tolerant Electric VTOL

Connectivity

Software Defined Radio

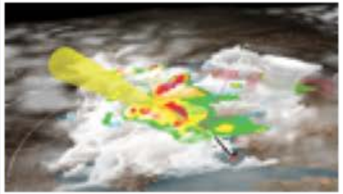


Conformal Antenna Arrays



Autonomy

Adaptive Mission Planning Systems



Single Pilot Operations

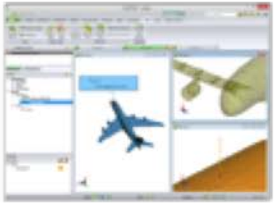
Materials

Additive 3D Manufacturing with Metals

Dry-Fiber (Out-of-Autoclave) Composites

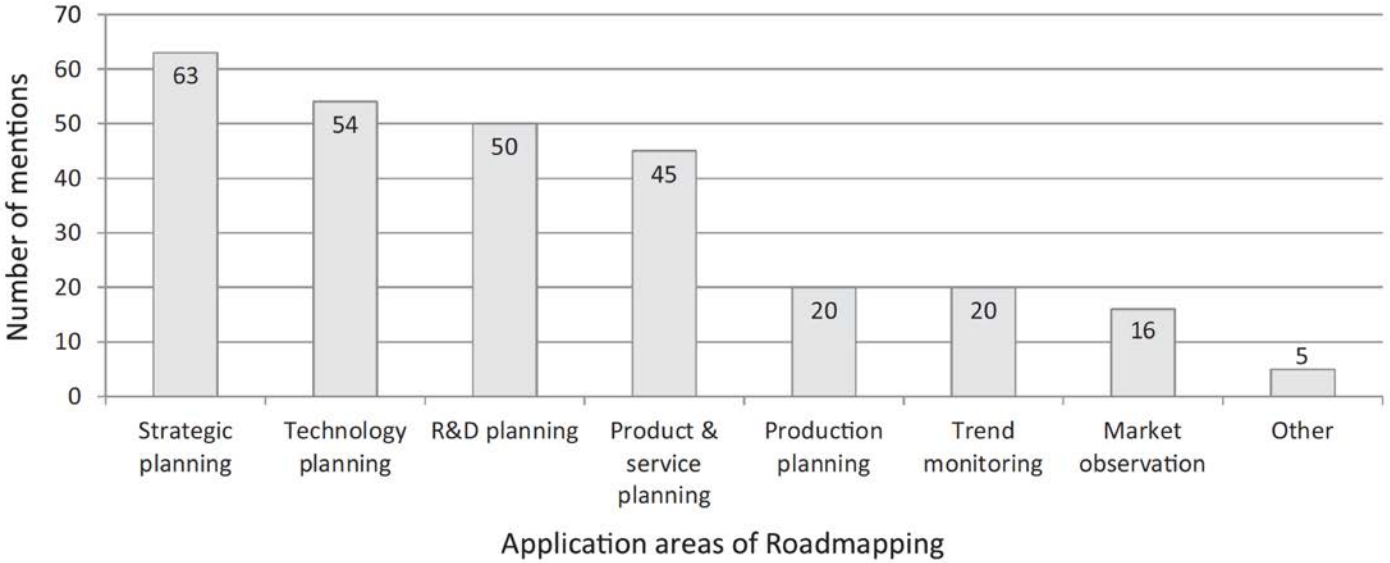
Digital Design and Manufacturing (DDM)

Model-Based Systems Engineering



Collaborative and Reconfigurable Robotics

How is technology roadmapping used today?



Frequency of application areas for roadmapping (*N*=81 German companies; multiple responses possible).
Source: Schimpf and Abele (2019)

New MIT Class: 16.887/EM.427
Technology Roadmapping and Development

- First Offering this semester
- 80 Students enrolled (50 for credit)
- 17 Technology Roadmaps under Development (see below)
- Supported by MIT | Aero Astro and SDM

	Matter	Energy	Information	Money	Organisms
Transform	7, Additive Mfg, 17, Hybrid Propulsion	3, Wind Power, 17, Hybrid Propulsion	12, Data Analytics and ML 13, Deep Learning and Computer Detection		9, Plant Genetic Improvement
Transport	11, Autonomous Driving/Transport		1, Wireless, 16 Optics		11, Autonomous Driving/Transport 15, High-Speed Rail
Store	2, Cryo Fuels, 4, Inventory Mgmt for Oil and Gas	10, Batteries	4, Inventory Mgt		
Exchange			5, Wearables	14, E-Commerce and Auctions	
Regulate	6, Ballistic Vest; 8 Autonomous O&G				

Questions?