The Fourth Industrial Revolution « Industry 4.0 »
Aerospace 4.0: Technology and Skills Challenges

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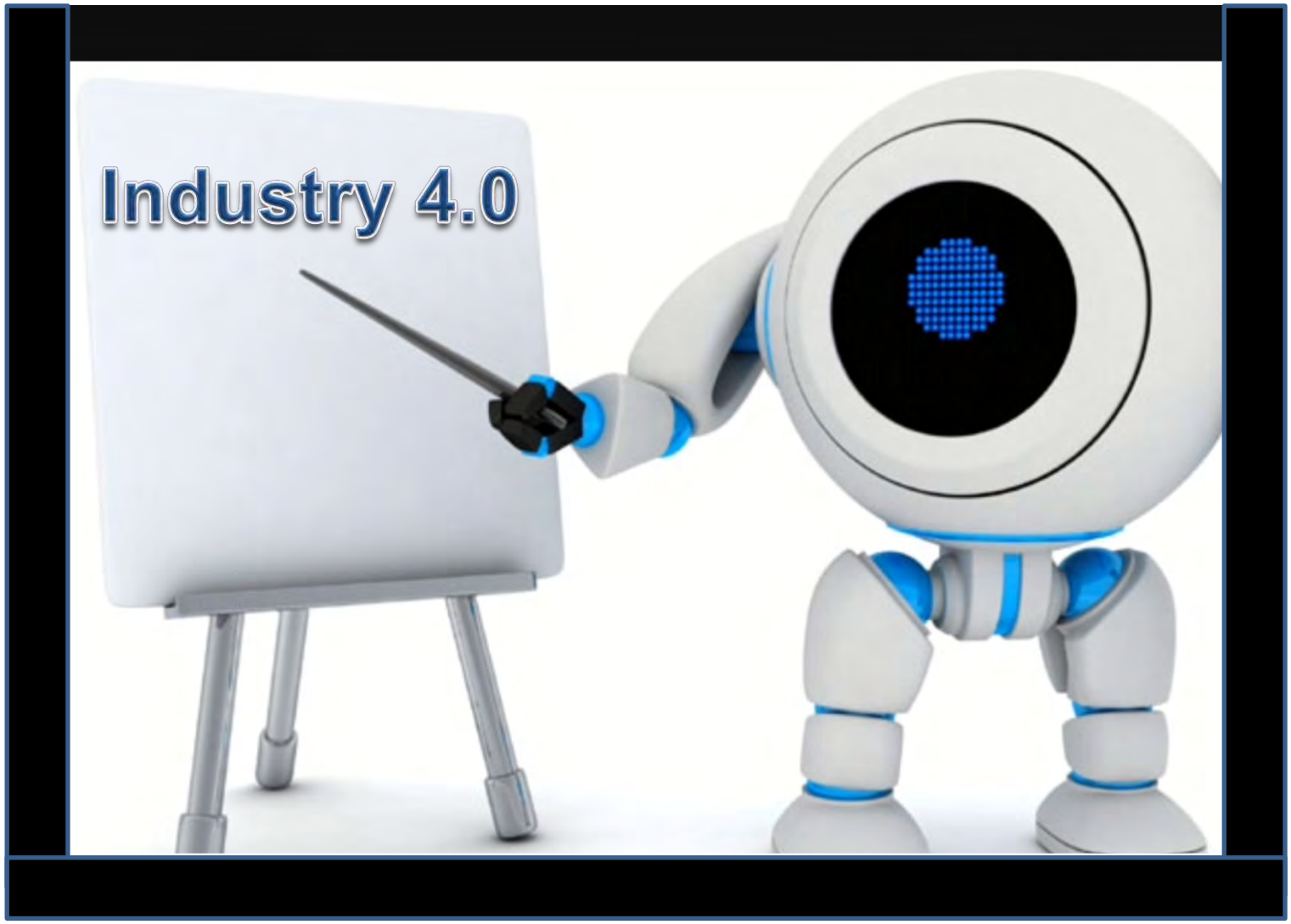
ÉTS Le génie pour l'industrie

AÉROÉTS Le génie pour l'aérospatiale 4.0

OUTLINE

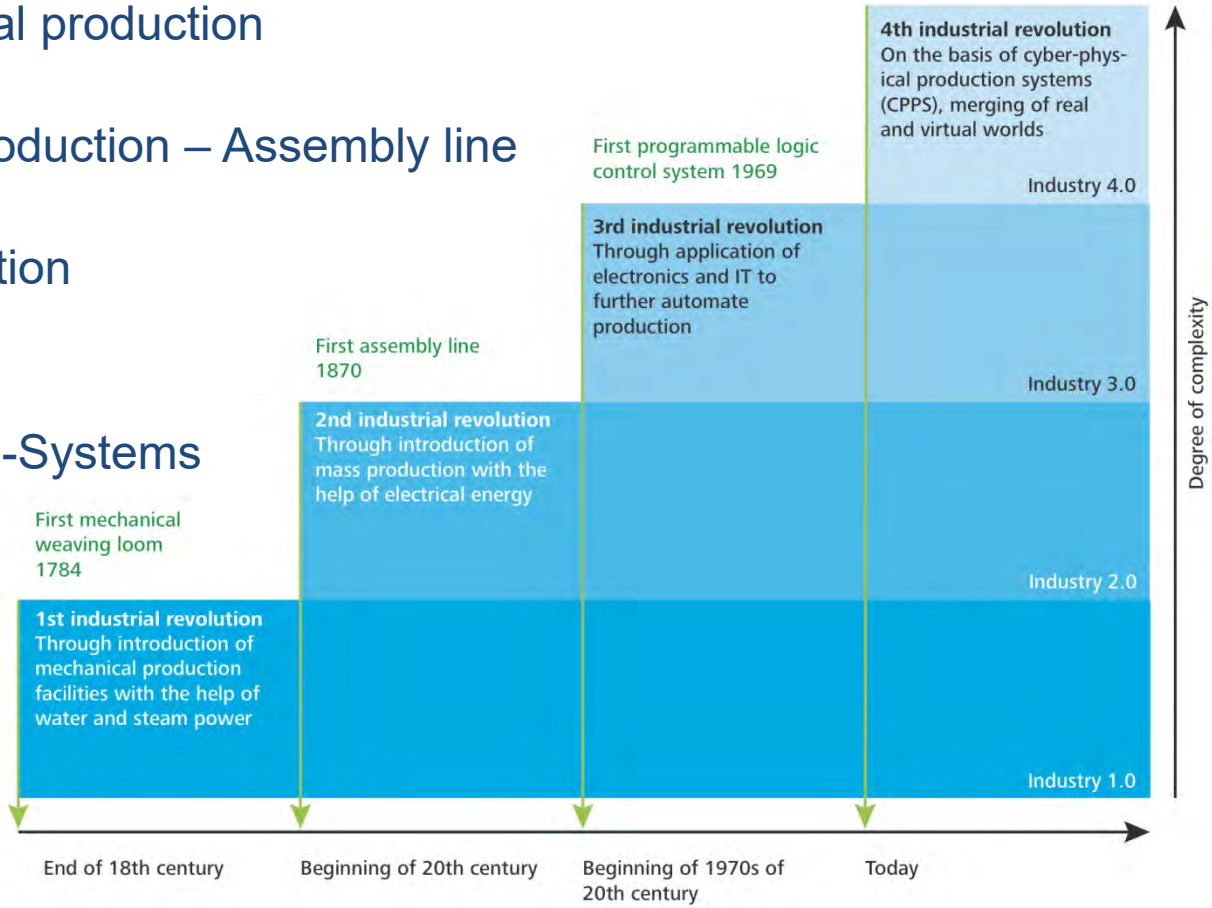
- **Industry 4.0**
  - Origin
  - Landscape: Europe - USA – Canada
  - Workforce
- **Aerospace 4.0 Technologies**
- **Skills Challenges**


Industry 4.0

INDUSTRY 4.0

Industry 1.0 (1784)
Steam power – Mechanical production
Industry 2.0 (1870)
Electric energy – Mass production – Assembly line
Industry 3.0 (1969)
Electronics – IT – Automation

Industry 4.0 (2011)
Cyber-Physics-Production-Systems
Digital-Virtual-Smart



(Deloitte, 2014-15)

Industry 4.0: Nine Technologies (Germany, 2011)

Industry 4.0 (Ref. Aérospatiale 4.0, H. Moustapha, Juillet 2016)

- Big data is the “raw materials and oil” of Industry 4.0 - Connectivity
- Asset knowledge, optimization and management
- Data: sharing, security, reliability, accuracy and variability
- Digital thread: tracking part from cradle to grave
- Artificial Intelligence and data analytics
- Total enterprise and not only manufacturing

FROM:

- Physics to Digital: the “Digital Twin” throughout the product life cycle
- Carbon to Silicon
- Clusters to cloud computing
- Deterministic to probabilistic design
- Experimental to analytical certification
- Mechanical to mechatronics
- Technological to organizational automation

Industry 4.0 (THINK ACT, Nov. 2014)

INDUSTRY 4.0 MEASURING

| VALUE ADDED |

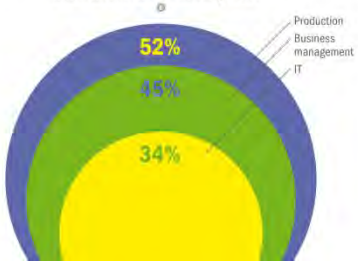
EUR 78 Billion
in productivity gains (23%) are feasible in six German industries between now and 2025. Mechanical and plant engineering, electrical engineering and chemicals in particular stand to benefit from Industry 4.0, along with ITC, the auto industry and agriculture.

| RESOURCE PRODUCTIVITY |

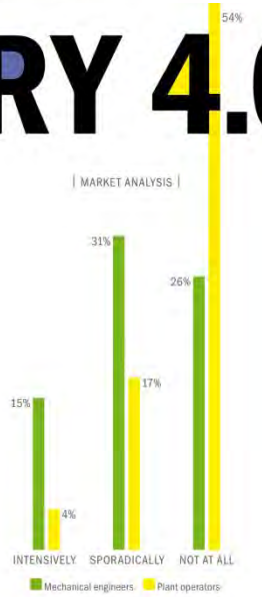
USD 30 BILLION
CAN BE SAVED OVER THE NEXT 15 YEARS IF THE USE OF INDUSTRY 4.0 TECHNOLOGIES ENABLES KEROSENE CONSUMPTION TO BE CUT BY 1%.

| CEO AGENDA |

Established at top management level
Survey: "Who at your company concerns themselves with Industry 4.0?"



| MARKET ANALYSIS |



Supply still has the edge
Survey: "How intensively are you tackling Industry 4.0?"

| GOVERNANCE |

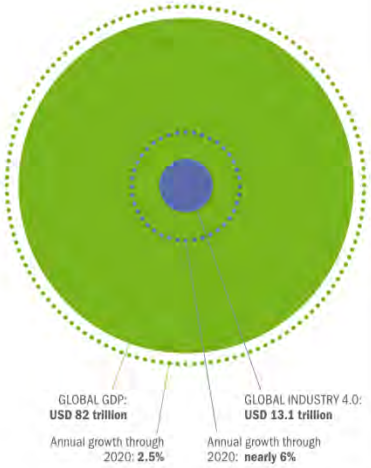
41%
OF RESPONDENT COMPANIES HAVE NOT YET APPOINTED SOMEONE WITH OVERALL RESPONSIBILITY FOR INDUSTRY 4.0 TOPICS.

SOURCES
1 Wikibon, Roland Berger 2 Bitkom/EITO ICT Market Report 2014/15 3 IDC Study "Digital Universe", 2012 4 Bitkom/Fraunhofer IAO, "Industry 4.0 - Economic Potential for Germany", 2014 5 GE Report "Industrial Internet", 2012 6 Experton user study "Industry 4.0", covering German ITC decision makers, 2014 7 IDC, "Industry 4.0 in Germany", survey of German manufacturing companies>100 FTEs, 2014

The fourth industrial revolution is beginning to unleash its potential. *What do businesses and economies stand to gain? And who will the winners be?*

| GROWTH ENGINE |

Industry 4.0 outpacing the global economy



| REGIONAL COMPETITION |

Initial handicap for Europe
Shares of the global ITC market (2013)

USA 27.1%

EU 21.3%

BRIC 18.7%

| DIGITAL UNIVERSE |

62%
of the world's data traffic volume in the year 2020 will come from China and India.

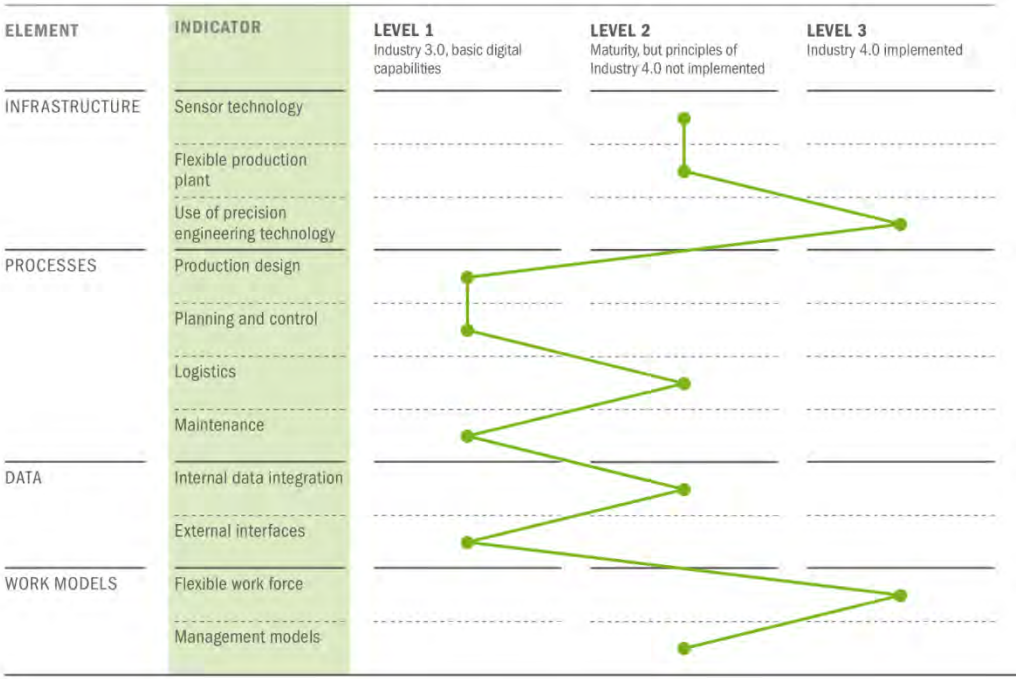
Maturity Model for Industry 4.0 (THINK ACT, Nov. 2014)

| ROLAND BERGER INDEX |

IS YOUR COMPANY READY FOR INDUSTRY 4.0?

What must companies do to boost their efficiency, quality and speed as they implement Industry 4.0? How can managers tap their company's potential? *On top of its economic maturity index (see p. 39), Roland Berger Strategy Consultants has now also prepared an analytical index for managers and entrepreneurs. The four most important factors are infrastructure, processes, data traffic and work models. These factors enable us to calculate a company-specific maturity index value highlighting how all departments must pull together. Our study is due out at the beginning of 2015.*

COMPANY ANALYSIS BASED ON ROLAND BERGER'S MATURITY MODEL FOR INDUSTRY 4.0
(generic model)



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Industry 4.0 and Age of Disruption (Ref. Deloitte, 2014-15)

Industry 4.0: Challenges and solutions for the digital transformation and use of exponential technologies

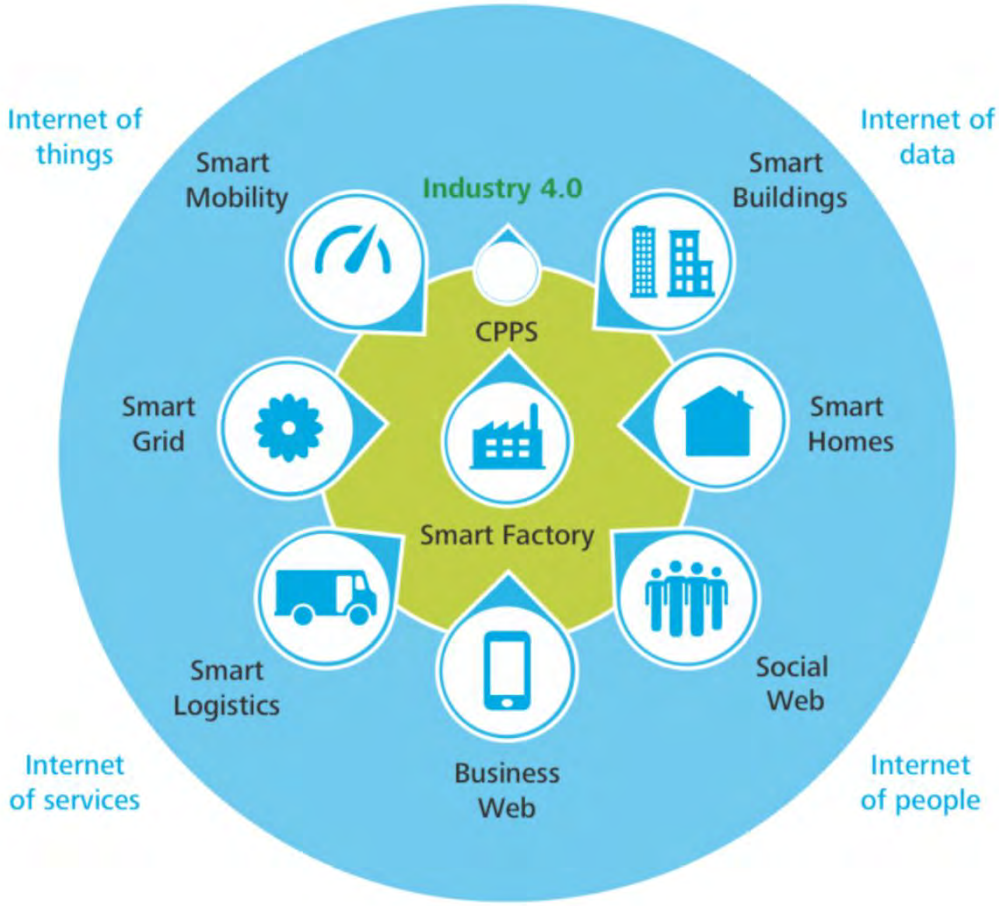
- Vertical networking (of smart production systems, logistics, services, etc)
- Horizontal integration (of business partners and customers across the globe)
- Through-engineering (throughout the entire product life cycle)
- Acceleration through exponential technologies

Age of disruption: Are Canadian firms prepared ?
The five advanced technologies driving disruptive innovation

1. Artificial intelligence (intelligent machines, human know-how)
2. Advanced robotics
3. Networks (big data, internet of things, etc.)
4. Advanced manufacturing (3D printers, nano and bio materials, etc.)
5. Collaborative connected platforms (cloud computing and crowdsourcing)

Internet of Things, People, Data and Services

Internet of Things, Data, Services and People



Artificial Intelligence (AI) and (Big) Data Analytics (DA): What is the Difference?

Artificial Intelligence

Data Analytics

Artificial Intelligence (AI) is a branch of computer science that refers generally to systems that can think and learn as intelligent humans would.

Machine Learning (ML) is a subset of AI that refers to **algorithms** that can learn from and make predictions on data.

Deep learning is a branch of machine learning, rebranding of artificial neural networks using layers of nonlinear processing units.

Data Analytics (DA) is related to the **processing** of data sets in order to build **insights** with a view to monetizing.

Big Data encompasses **software** technologies to collect and store massive, **heterogeneous** and **fast changing** sets of data in order to bring sense and value (money).

Big Data Analytics combines both big data and DA.

Periodic Table of AI

Dm Data mining						
Sr Speech recognition	**Se** Semantics extraction				**Mh** Meta Heuristics	**Pl** Planning
Tm Text mining	**If** Information Fusion	**Sl** Supervised learning	**Ul** Unsupervised learning	**Kr** Knowledge representation	**Cs** Constraint satisfaction	**Ru** Reasoning under uncertainty
Ir Image recognition	**Da** Descriptive analytics	**Pa** Predictive analytics	**Rl** Reinforcement learning	**Rb** Rule based	**Ps** Problem solving	**De** Decision

Smart – Virtual – Digital : Factory – Supply Chain – Design

Smart Factories:

- Goal:
  More automation, better control & optimisation of factory processes
- Means:
  Software, lasers & intelligent devices embedded in machines & factory infrastructure

Factory productivity

- Less waste & energy use
- Increased efficiency
- Fast turnaround
- Better quality

Virtual Factories:

- Goal:
  To manage supply chains; to create value by integrating products & services
- Means:
  Software to holistically interconnect & manage distributed factory assets; new business models & value propositions

Supply-chain productivity

- High-value products
- Jobs
- SC transparency
- IPR security
- CO_2 footprint

Digital Factories:

- Goal:
  To "see" the product before it is produced
- Means:
  Software for the digital representation & test of products & processes prior to their manufacture & use

Design productivity

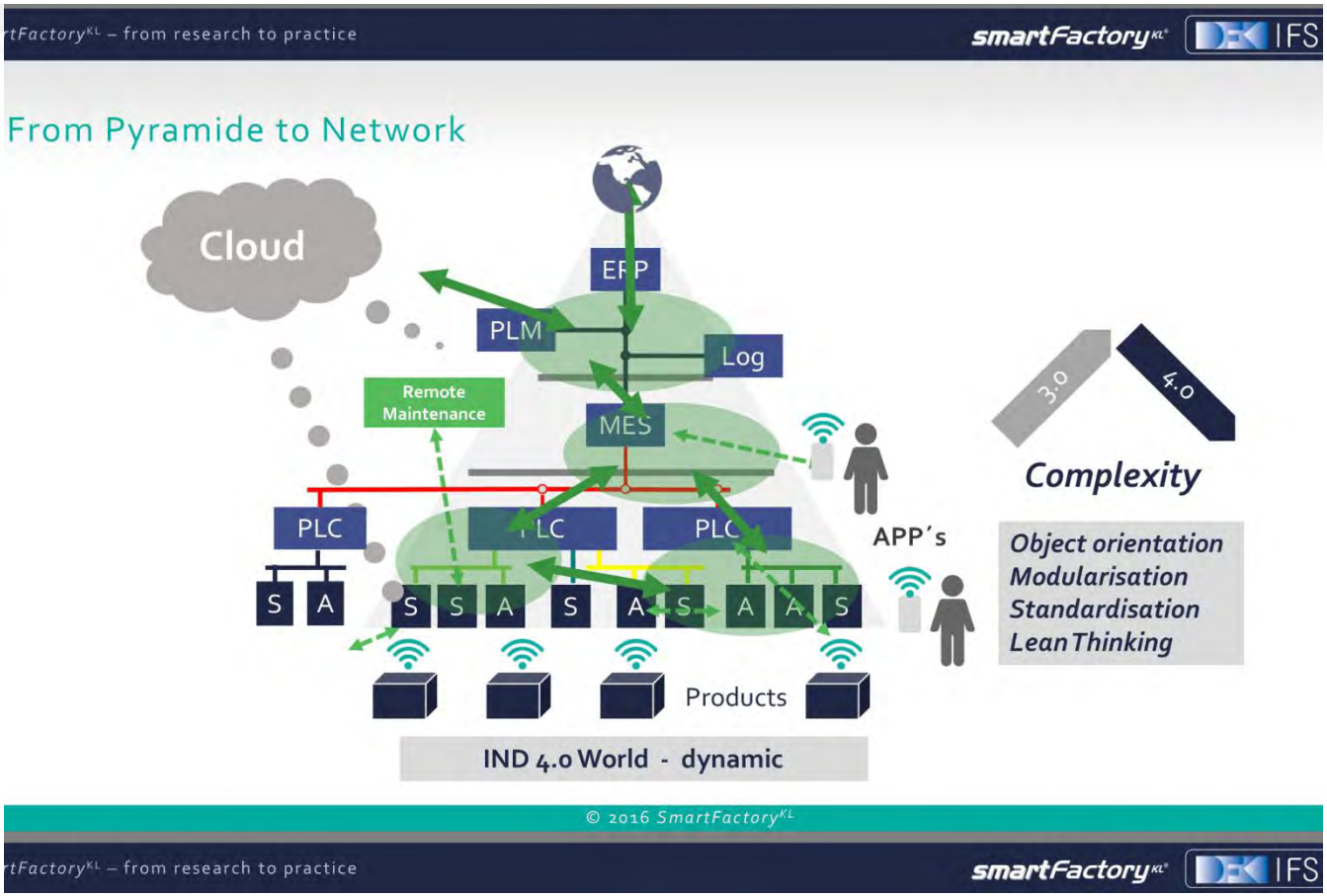
- Less design errors
- Better & efficient products
- Less waste + rework
- Faster time-to-market

Automation and robotics leveling the playing field for labor cost

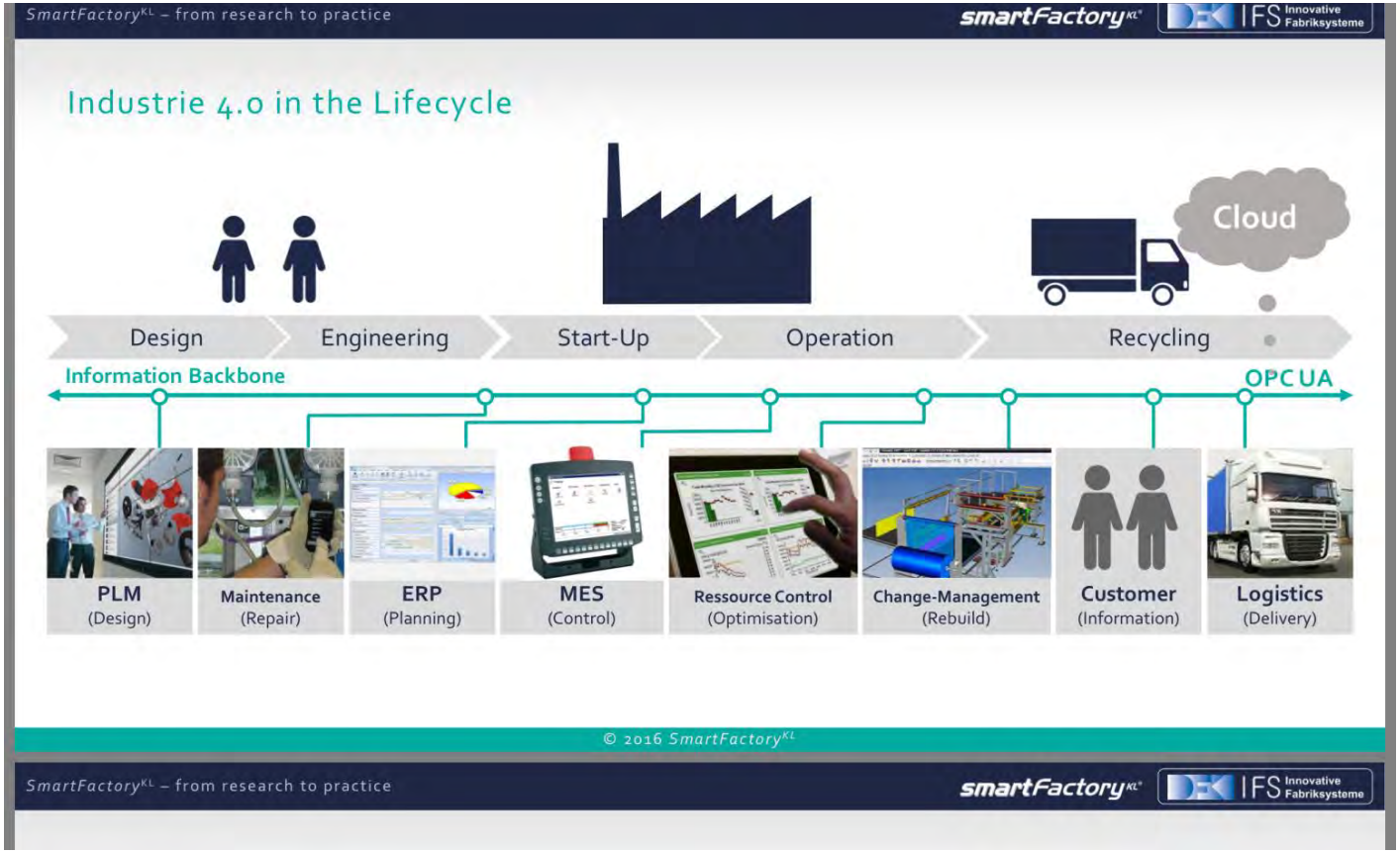
→ From Offshoring to Reshoring

Industry 4.0
Europe

Germany Smart Factory
Birth of Industry 4.0 (2005)

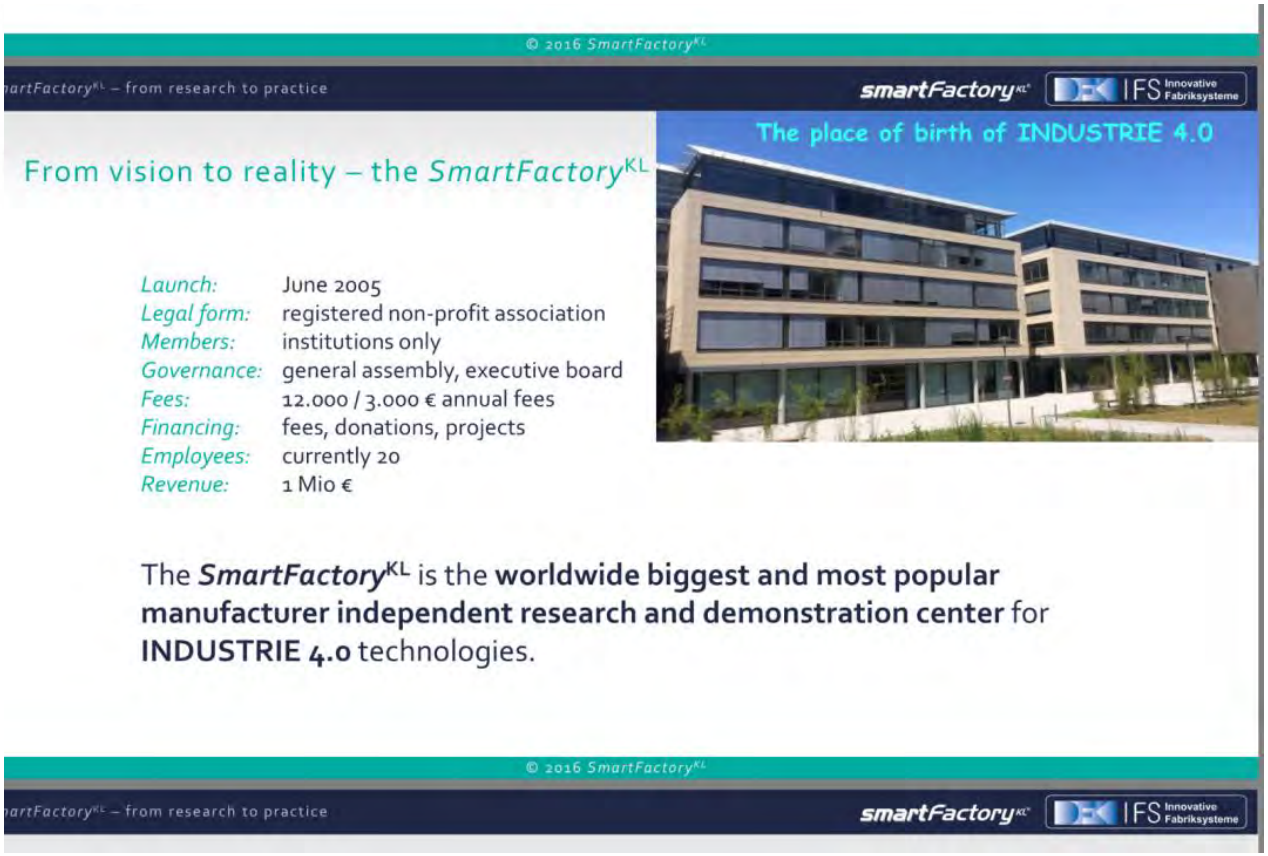


Industry 4.0 Life Cycle (Germany Smart Factory)



Europe Manufacturing Institutes

Germany Smart Factory (2005)



Europe MANUFUTURE and Factories of the Future (FoF)

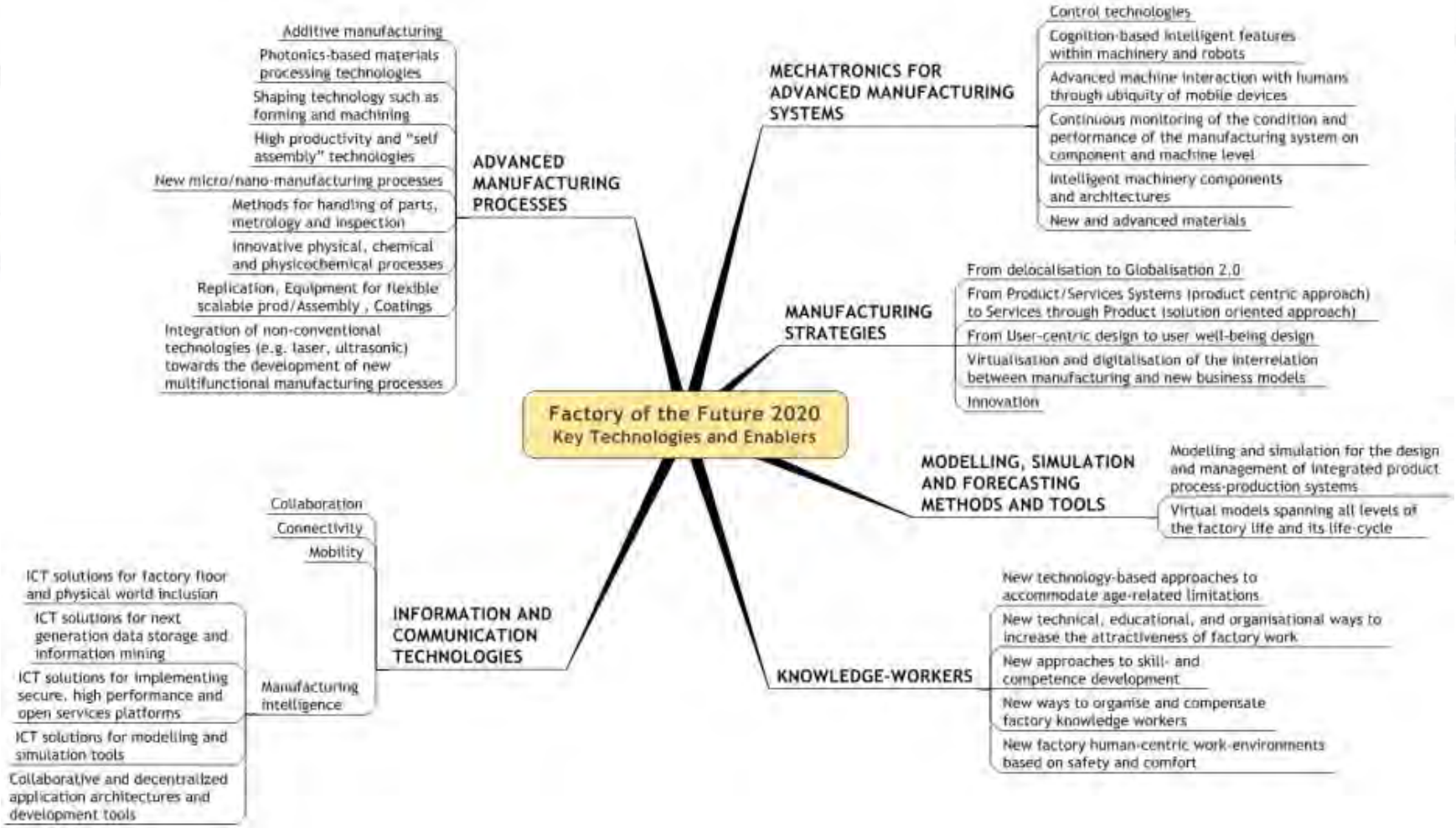
1. Sustainable manufacturing
(eco-factory, green products, renewable resources, environmental-neutral materials, maintenance of production equipment, re-use of equipment, adaptive & responsive human machine interaction, human-centred production site)

2. High performance manufacturing
(flexible adaptive production equipment, systems & plants, high precision micro-manufacturing machines & systems, tools for production planning & in-situ simulation for open reconfigurable & adaptive manufacturing systems, zero-defect manufacturing)

3. Exploiting new materials through manufacturing
(net-shape manufacturing for engineered metallic & composite materials, new material functionalities through manufacturing processes, renovation & repair, product design using sustainable material process technologies)

4. ICT-enabled intelligent manufacturing
(artificial intelligence, big data, internet of things, cloud computing, crowd sourcing, smart, digital and virtual factory)

Europe MANUFUTURE and Factories of the Future (FoF)



Siemens Factory Automation

SIEMENS

Factory Automation @ 5 TIA Topics
Common features create real added value

Totally Integrated Automation creates real added value in all automation

Integrated Engineering	Industrial Data Management	Industrial Communication	Industrial Security	Safety Integrated
				
Benefits:	**Benefits:**	**Benefits:**	**Benefits:**	**Benefits:**
Consistent, **holistic** engineering over the entire product development and production process.	**Access** to all the important **data** occurring in productive operation – along the entire value chain and across all levels.	Integrated communication based on **international**, cross-vendor **standards** that can be flexibly combined.	Systematic **minimization** of the danger of an internal or external **attack** on plants and networks.	**Reliable protection** of personnel, machinery, and environment due to seamless integration of safety technologies into the standard automation.

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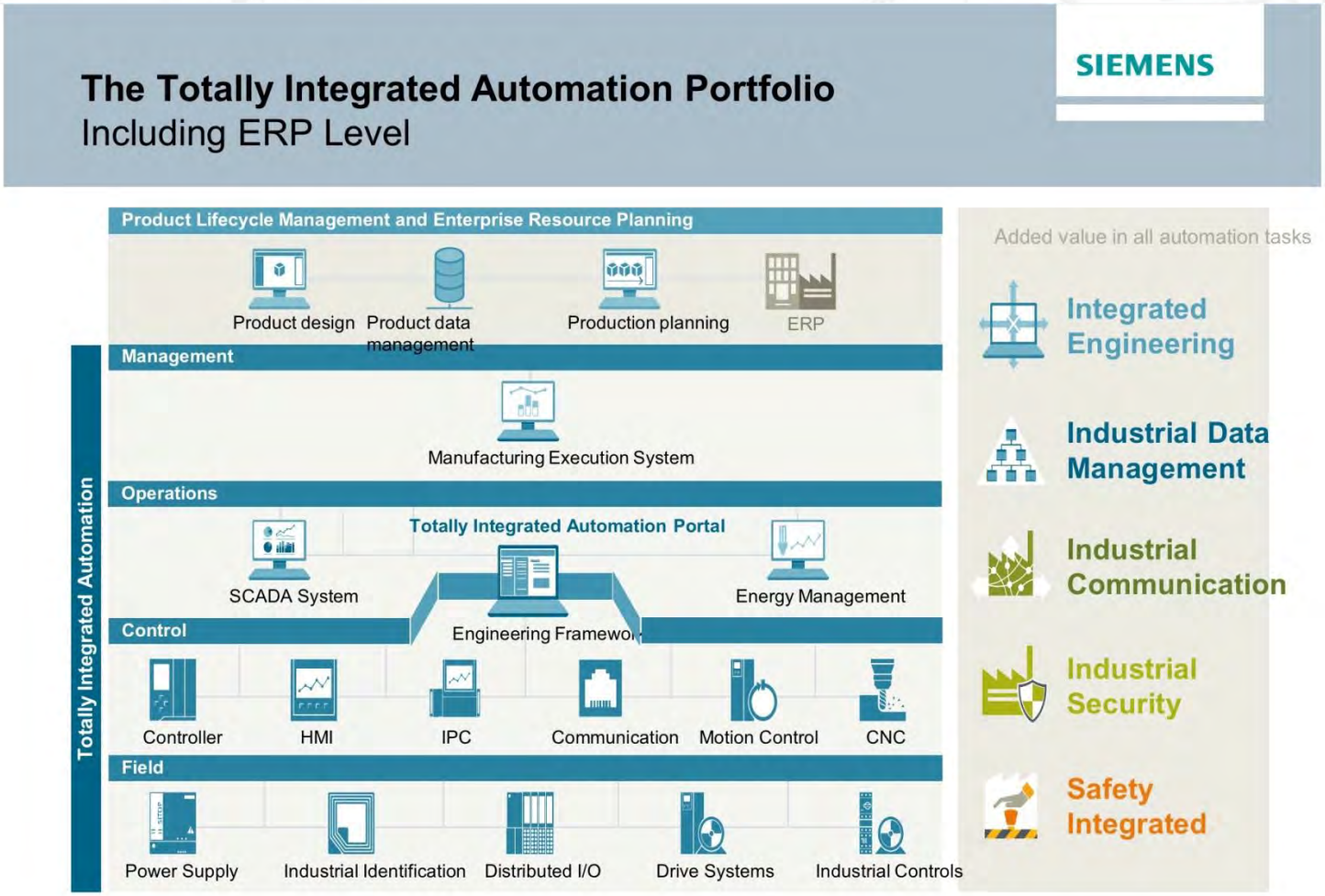
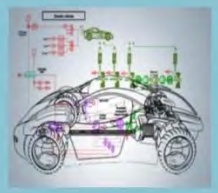
Siemens Integrated Automation

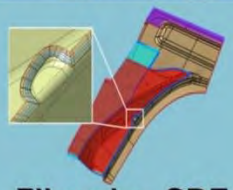


Siemens PLM Software

SIEMENS

Siemens PLM Software Business Segments

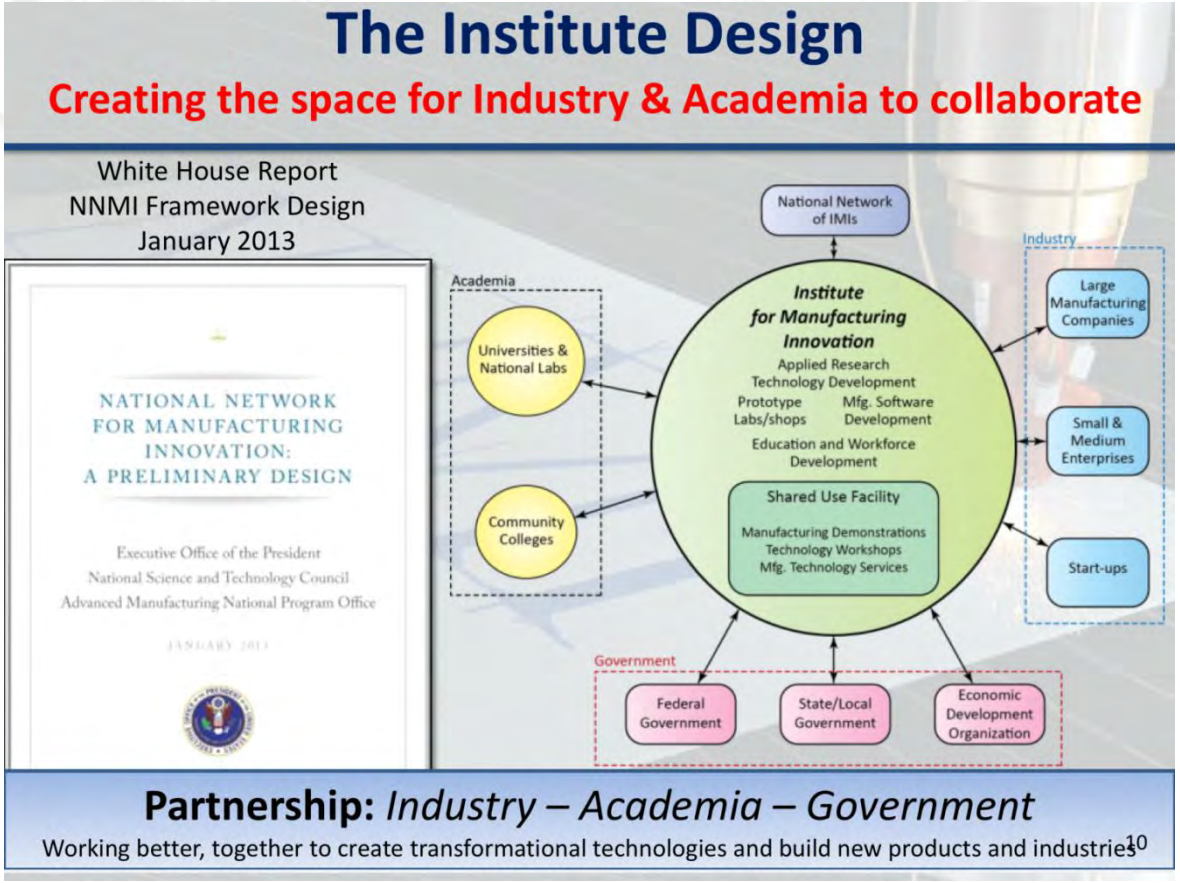
Product Engineering	Lifecycle Collaboration	Simulation and Test	Manufacturing Engineering
			
NX	Teamcenter	LMS	Tecnomatix

Specialized Engineering	Mainstream Engineering	Product Driven Services	Digital Enterprise Realization
			
Fibersim, SDE Syncrofit, QPE	Solidedge, Femap, CAM Express	Advantedge	SIMATIC IT, IBS, Preactor, WinCC

Industry 4.0
USA

USA National Network for Manufacturing Innovation

<u>NNMI ($1Billion) Vision:</u> "Institutes of manufacturing excellence where some of the most advanced engineering schools and the most innovative manufacturers collaborate on new ideas, technology, methods and processes"

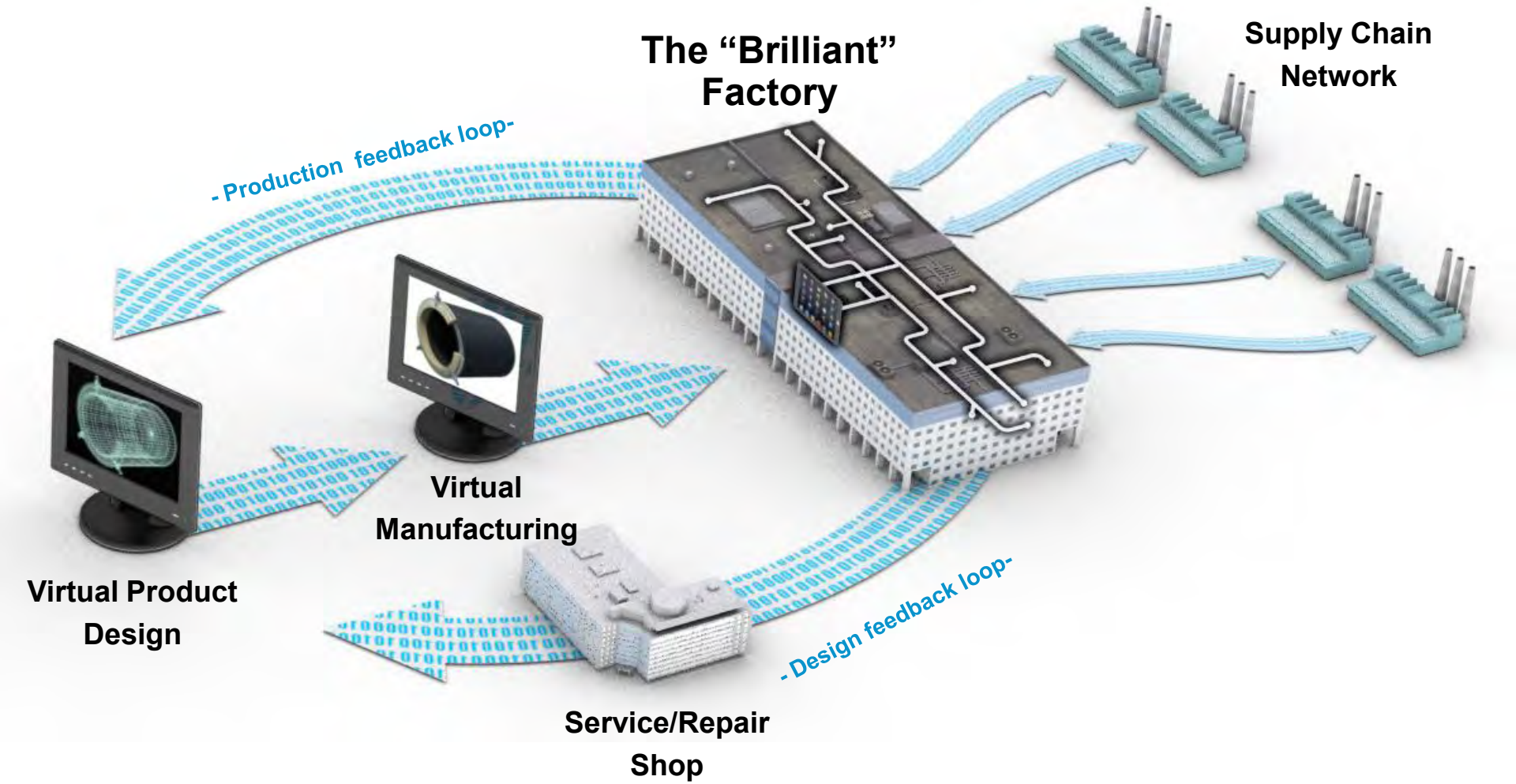


USA National Network for Manufacturing Innovation

USA Manufacturing Institutes

USA DMDII (2015)

GE Brilliant Factory



A "digital thread" forms the 21st Century Assembly Line for Smart Manufacturing

imagination at work

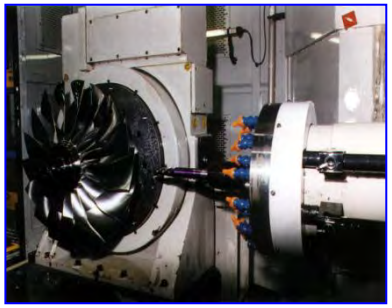
Industry 4.0 Canada

Industry 4.0

Started Before 2005

Industry 4.0

Factory or Enterprise ?



Pratt & Whitney Canada
Digital Enterprise (2000)

Common Architecture

Customer Demand Fulfillment Process

Customer Relationship Management (CRM)

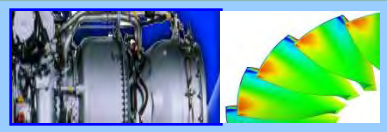
Enterprise Resource Planning (ERP)

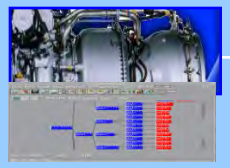
Supply Chain Management (SCM)

Product Development Process

Product/Process Management

Product Creation Simulation





Digital Product

3D model
Analysis
Drawing
NC data
Inspection

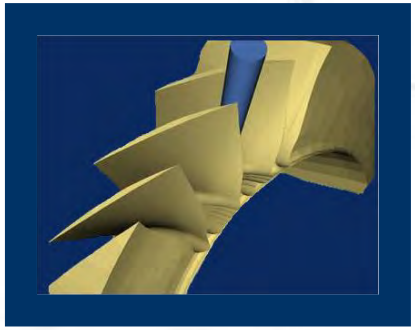
Manufacturing /Maintenance Simulation

As Sold, As Designed, As Planned, As Produced, As Maintained

P&WC Advanced Manufacturing Center (2016)

ICEMAN "Intelligent CElls MANufacturing" (2012)

- Closed door machining
- In process measurement
- Dynamic compensation
- Trend monitoring
- Process monitoring
- Process control assurance
- Traceability of quality and process data
- Model, simulate, measure, and optimize
- Predictive maintenance systems
- Machine performance data capture



Industry 4.0 Factories

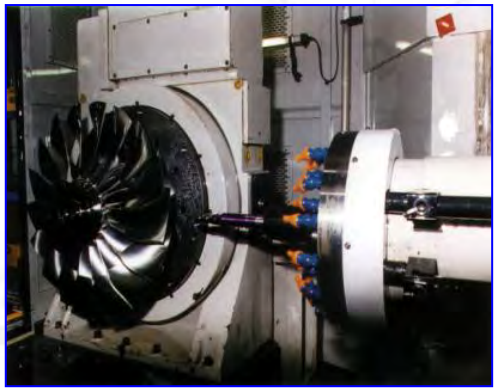
P&WC	Digital Enterprise (2000) – ICEMAN (2012)
Germany	Smart Factory (2005)
Siemens	Digital Factory (2012)
GE	Brilliant Factory (2014)
EU	Factory of the Future (2013)
USA	National Network of Manufacturing Innovation (2013)

Industry 4.0 Buzz Words:
Big Data – Internet of Things – Data Analytics – Digital Twin , etc.

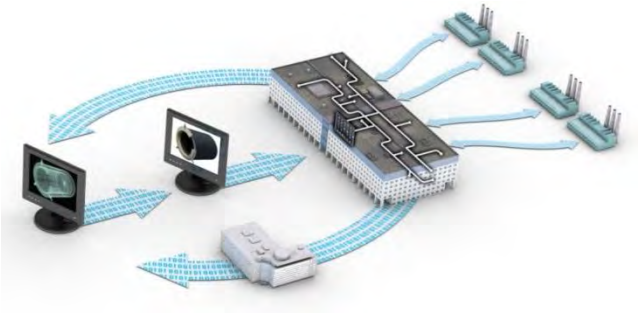
Industry 4.0: Factory or Enterprise ?

(AéroMontréal Forum, H. Moustapha, Apr. 26, 2016)

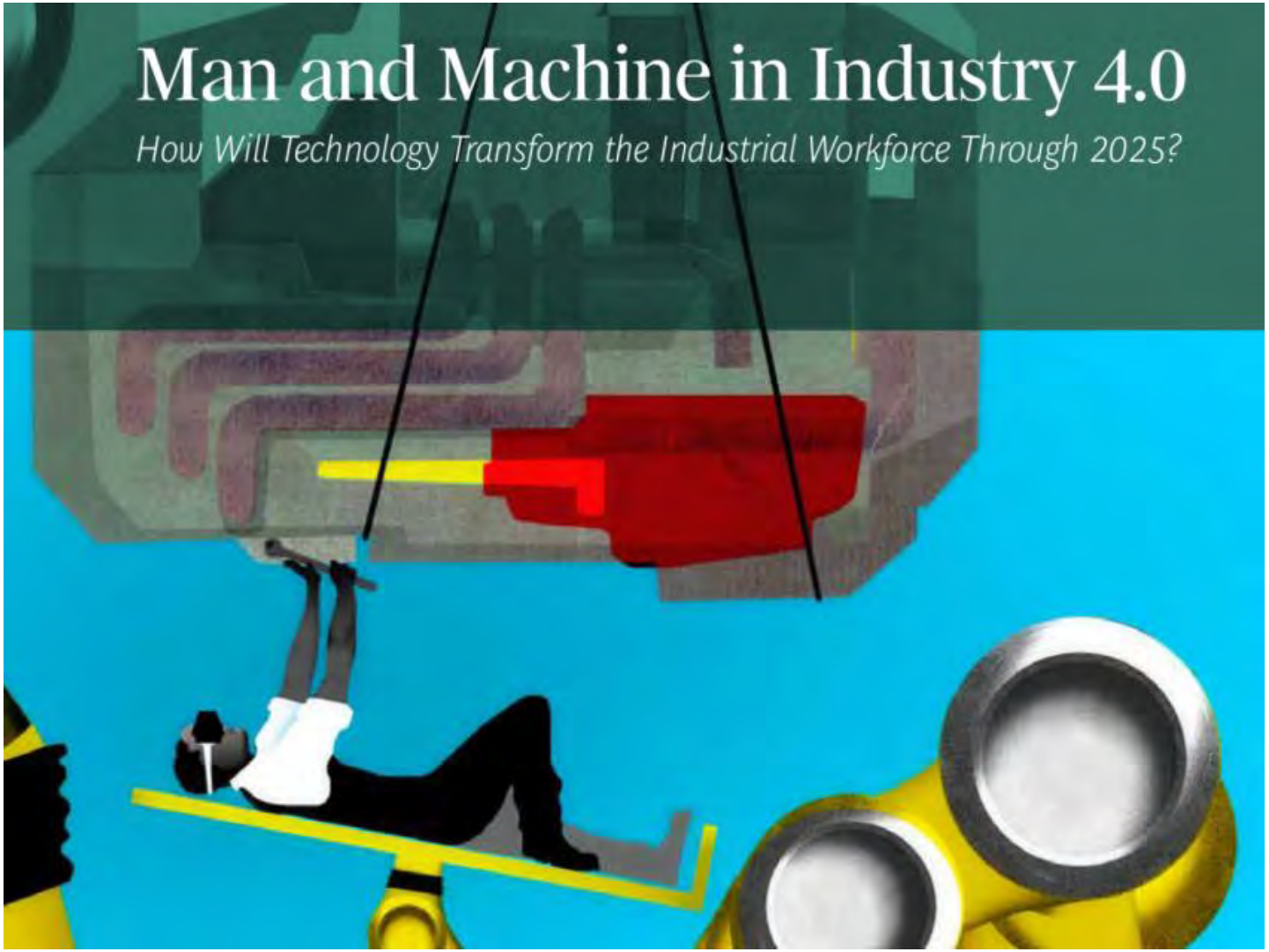
Industry 4.0 is not only about FACTORY



It is the total ENTERPRISE



Industry 4.0 Workforce



(Ref.: BCG, Sept. 2015)

Industry 4.0 Workforce of Tomorrow (BCG, Sept. 2015)

- Net increase of 350,000 jobs by 2025 for Germany
  - Greater use of robotics and computerization will reduce the number of jobs in assembly and production by 610,000
  - Creation of 960,000 new jobs in IT and industrial data science
- Retrain workforce
- Revamp organization models
- Strategic recruiting and workforce planning
- Education systems to respond to Industry 4.0 needs, provide broader skill sets and close the gap in IT skills

"50% of U.S. workers have a high probability of seeing their jobs automated over the next 20 years" (Oxford University, 2013)

The Workforce of the Future (Ref.: GE, Sept. 2016)

Technological Unemployment Theory (Keynes, 1930)
Economizing the use of labor is outrunning the pace at which we can find new uses for labour

- Innovative business models, process improvements and technological breakthroughs brought into question job sustainability
- Jobs transformed and workers adapted with new advances in automation and technology
- Disruptive technologies created opportunities for jobs that are more strategic
- Over two centuries of innovation, the global economy has provided more and better jobs
- Transition and adjustments have not been painless
- Keeping the status quo to protect the current skillset is suicide for brands in technology and manufacturing
- The need for firms to continuously innovate to win does not equate to a net job loss, but rather a transition to the type of skillsets workers need

Surviving the Technology: Bank Teller vs ATM

Industry 4.0 Workforce Needs (Ref.: BCG, Sept. 2015)

Big-Data-Driven Quality Control:

Algorithms based on historical data identify quality issues and reduce product failures

Robot-Assisted Production:

Flexible humanoid robots perform other operations such as assembly and packaging

Self-Driven Logistics Vehicles:

Fully automated transportation systems navigate intelligently within the factory

Production Line Simulation:

Novel software enables assembly line simulation and optimization

Smart Supply Network:

Monitoring of an entire supply network allows for better supply decisions

From Labor to Capital Intensive
From Offshoring to Reshoring

Industry 4.0 Workforce Needs (Ref.: BCG, Sept. 2015)

Predictive Maintenance:

Remote monitoring of equipment permits repair prior to breakdown

Machines as a Service:

Manufacturers sell a service, including maintenance, rather than a machine

Self-Organizing Production:

Automatically coordinated machines optimize their utilization and output

Additive Manufacturing of Complex Parts:

3D printers create complex parts in one step, making assembly redundant

Augmented Work, Maintenance and Service:

Fourth dimension facilitates operating guidance, remote assistance and documentation

Embeded E-Learning Tools in Real World Situations

Aerospace 4.0

AÉROÉTS
Engineering for Aerospace 4.0

Aviation Challenges & Opportunities

New Markets

Globalization

Exchange Rates

Oil Prices

Environment

New Products

Pricing

Costs

Capacity

Workforce

Plus Collaboration and Partnership

Expected Fleet Growth
30,000 New Aircrafts (2010-2030)

Air Transport

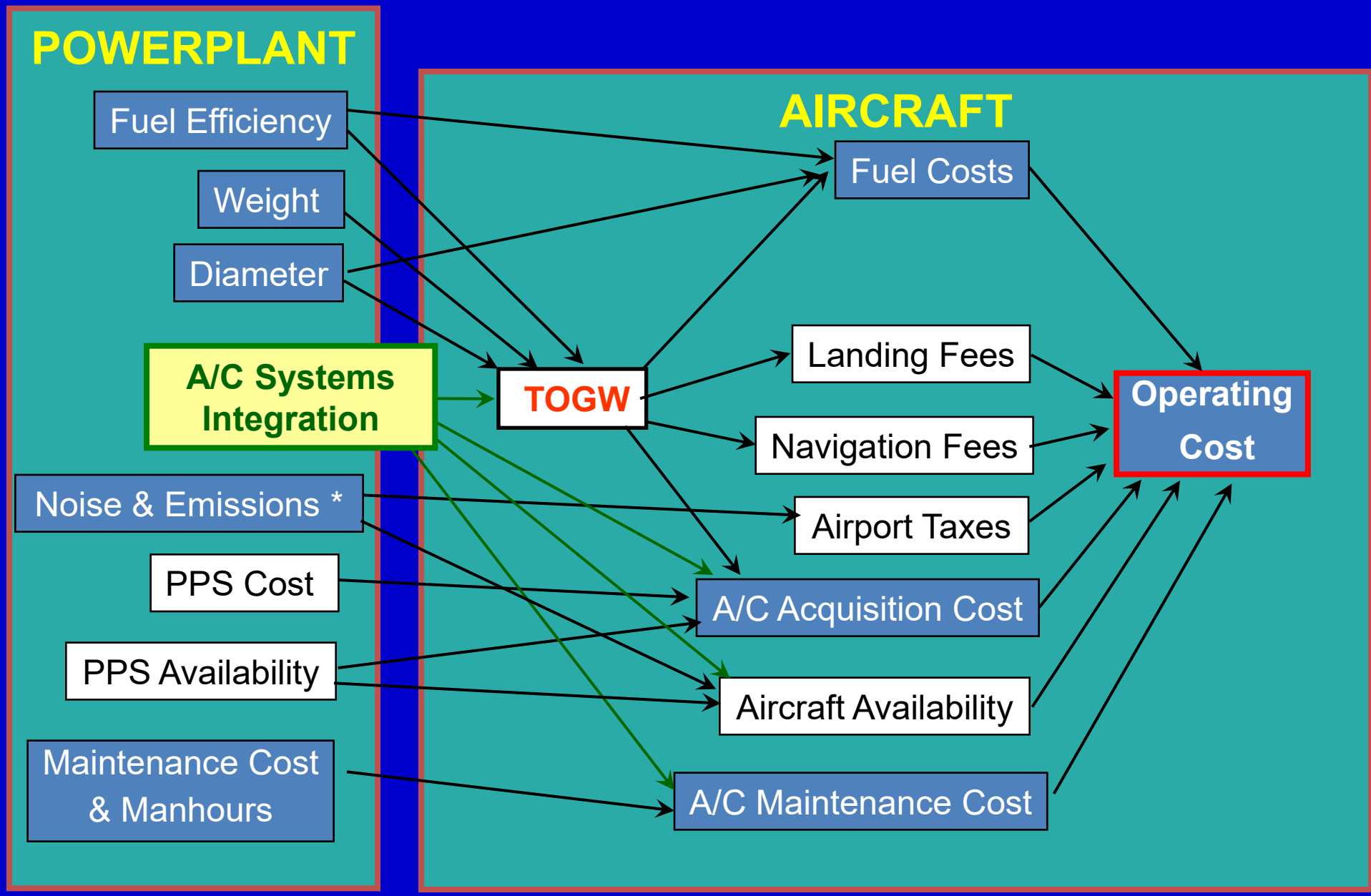
Business Aviation

1970's Fleets

2010 Fleets

1970-2010: World's commercial fleets have multiplied by a factor of 6

Reducing Aircraft Operating Cost

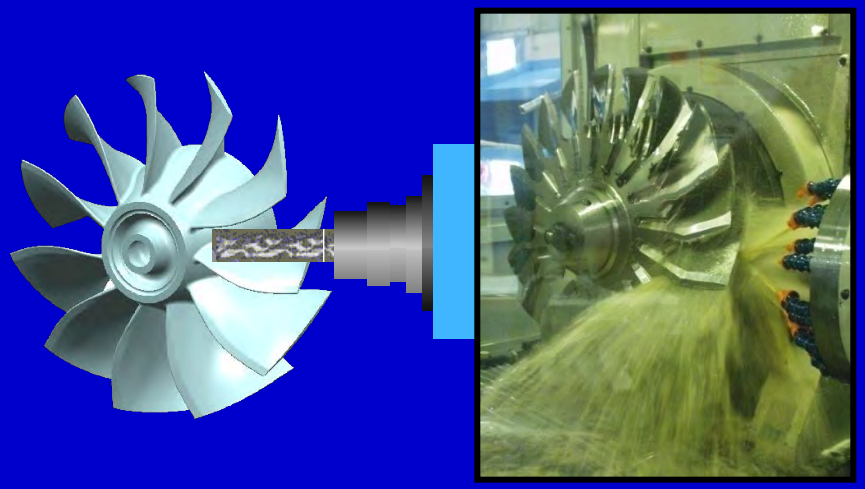


Manufacturing Technology

Low Cost Game Changers

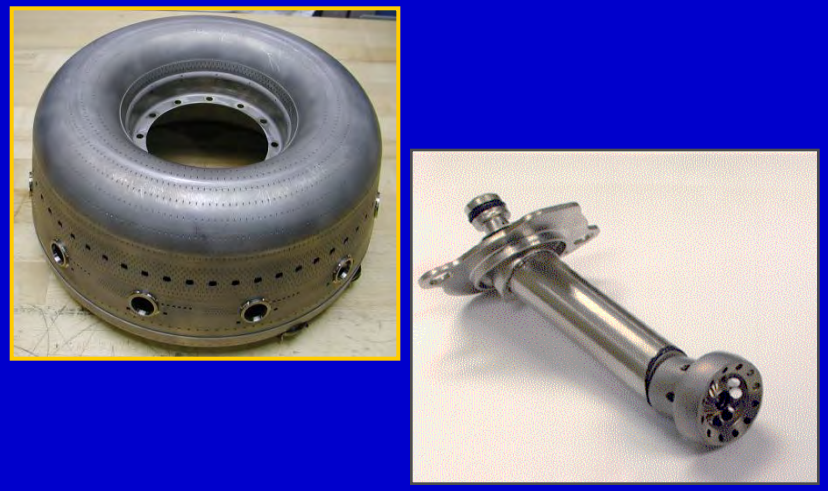
Turbine Vane – Laser Drilling – Fast EDM

Flank Milling - IBR



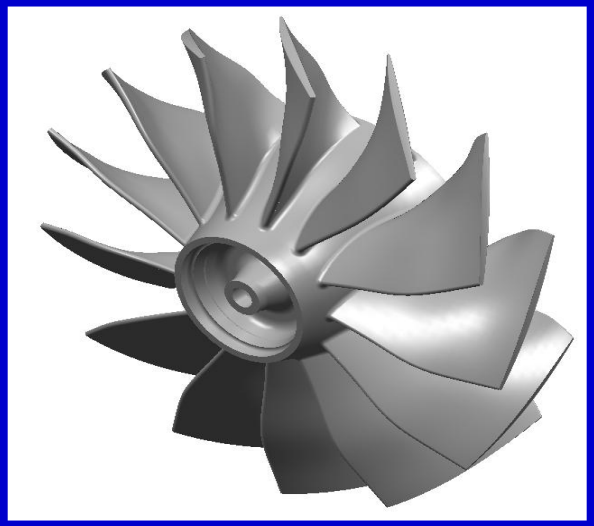
Diffuser – 240 parts to 1

Combustor and Fuel Nozzle



Advanced Concepts

Compressor Impeller



Fans (IBR)

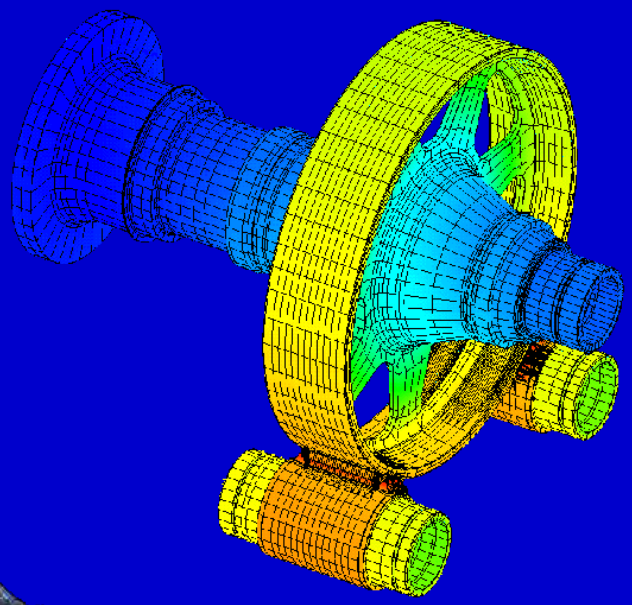
Fuel Nozzle

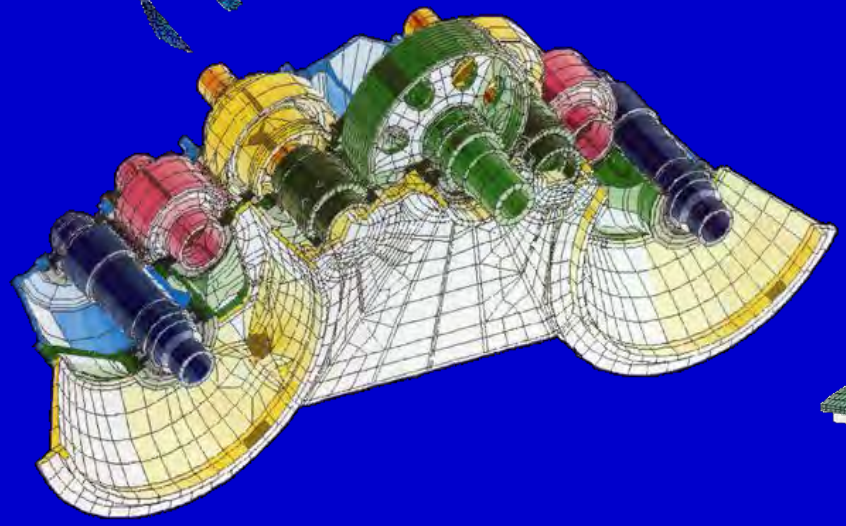
Diffuser Vanes

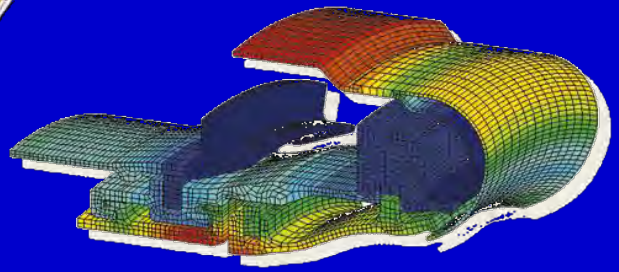
Hot Streak

Stress & Thermal 3D Analysis

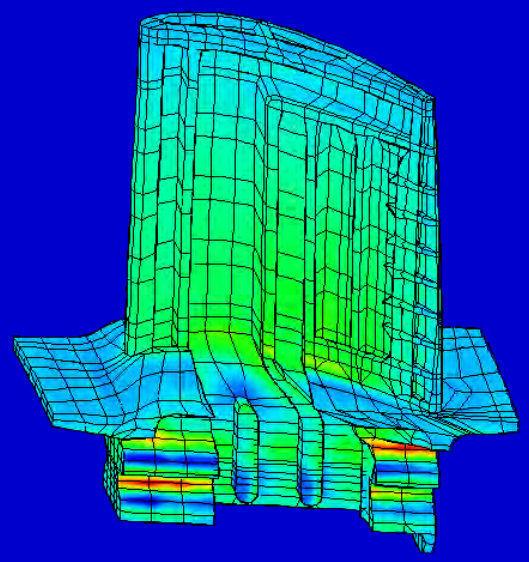
- Optimized for life, weight and cost
- Reduced spin-pit testing



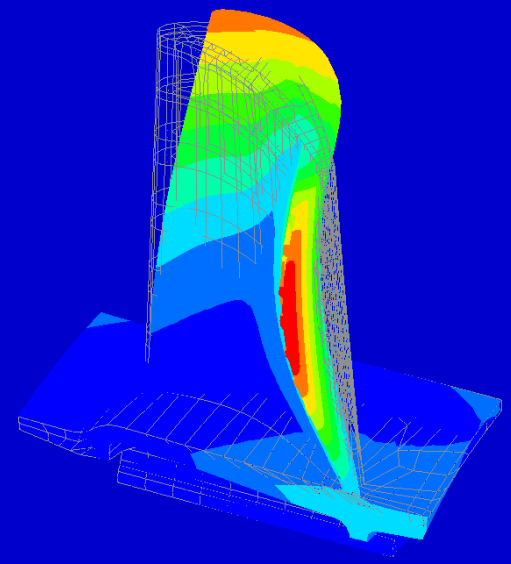




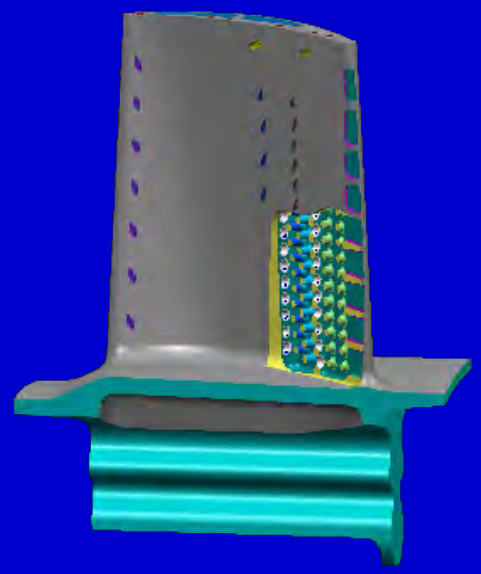
Multi-Disciplinary Optimization
Simultaneous Analyses of a Component



Stress Analysis

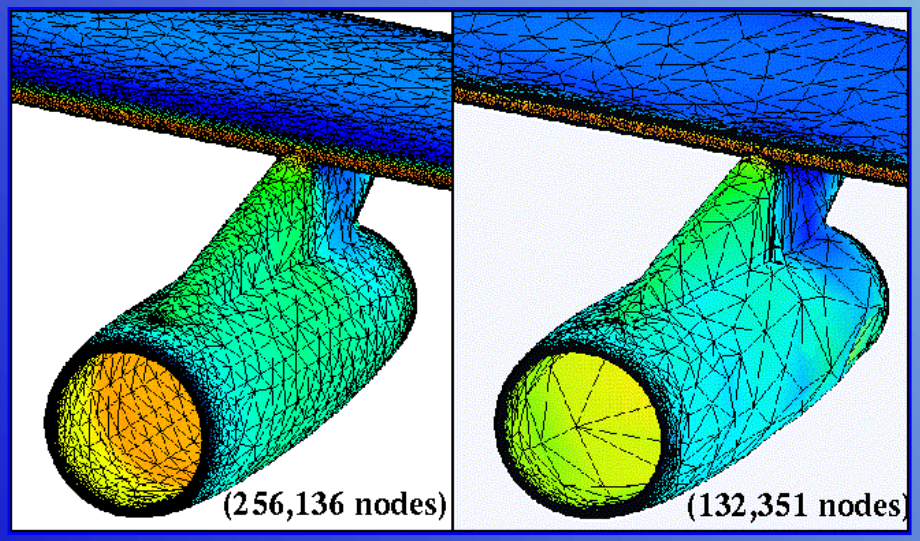


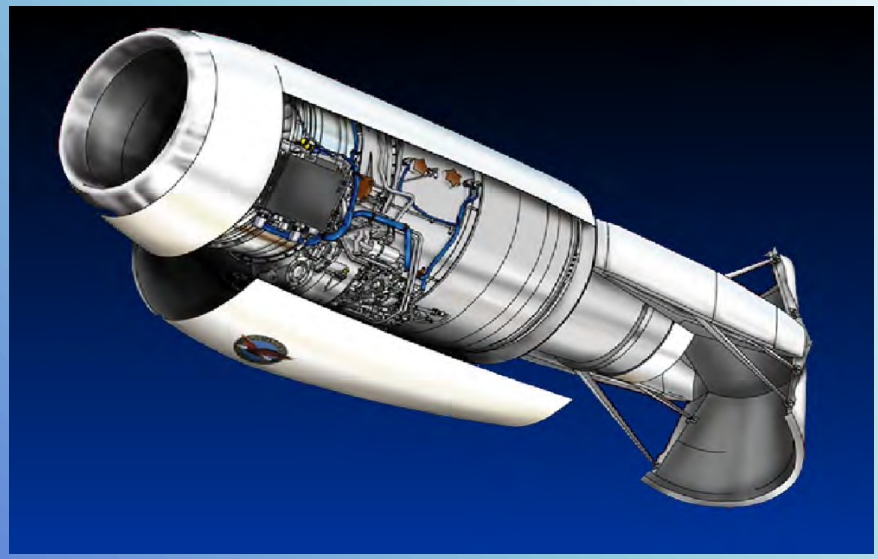
Dynamic Analysis



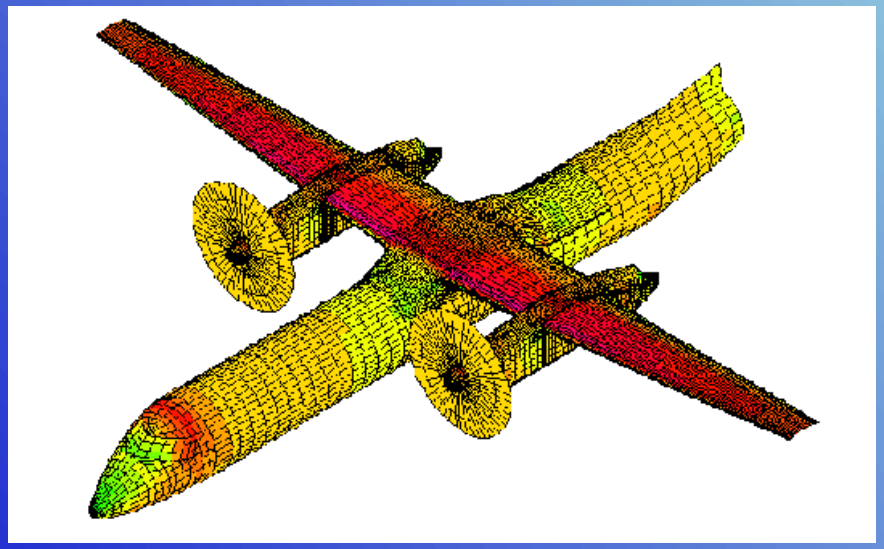
Aerodynamic &
Cooling Analysis

Integrated Aircraft Power System Simulation and Optimization





Power Plant - Aircraft Analysis

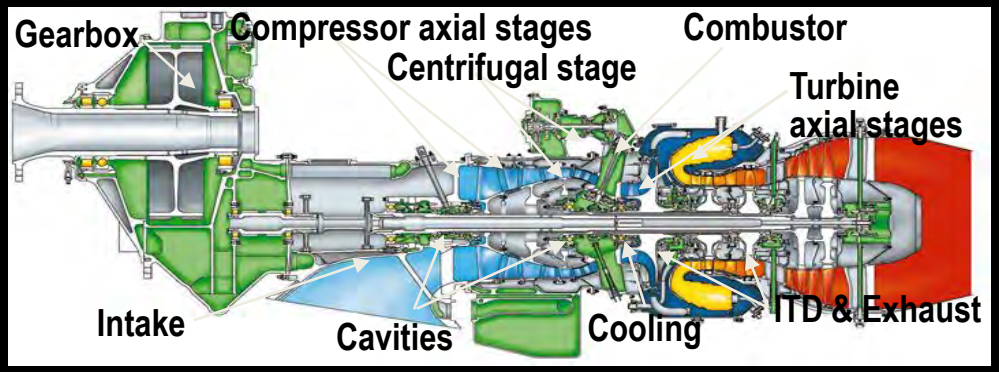


Design & Manufacturing Cross Technologies Integration: Components to Aircraft

Design Process

LARGE SYSTEM LEVEL

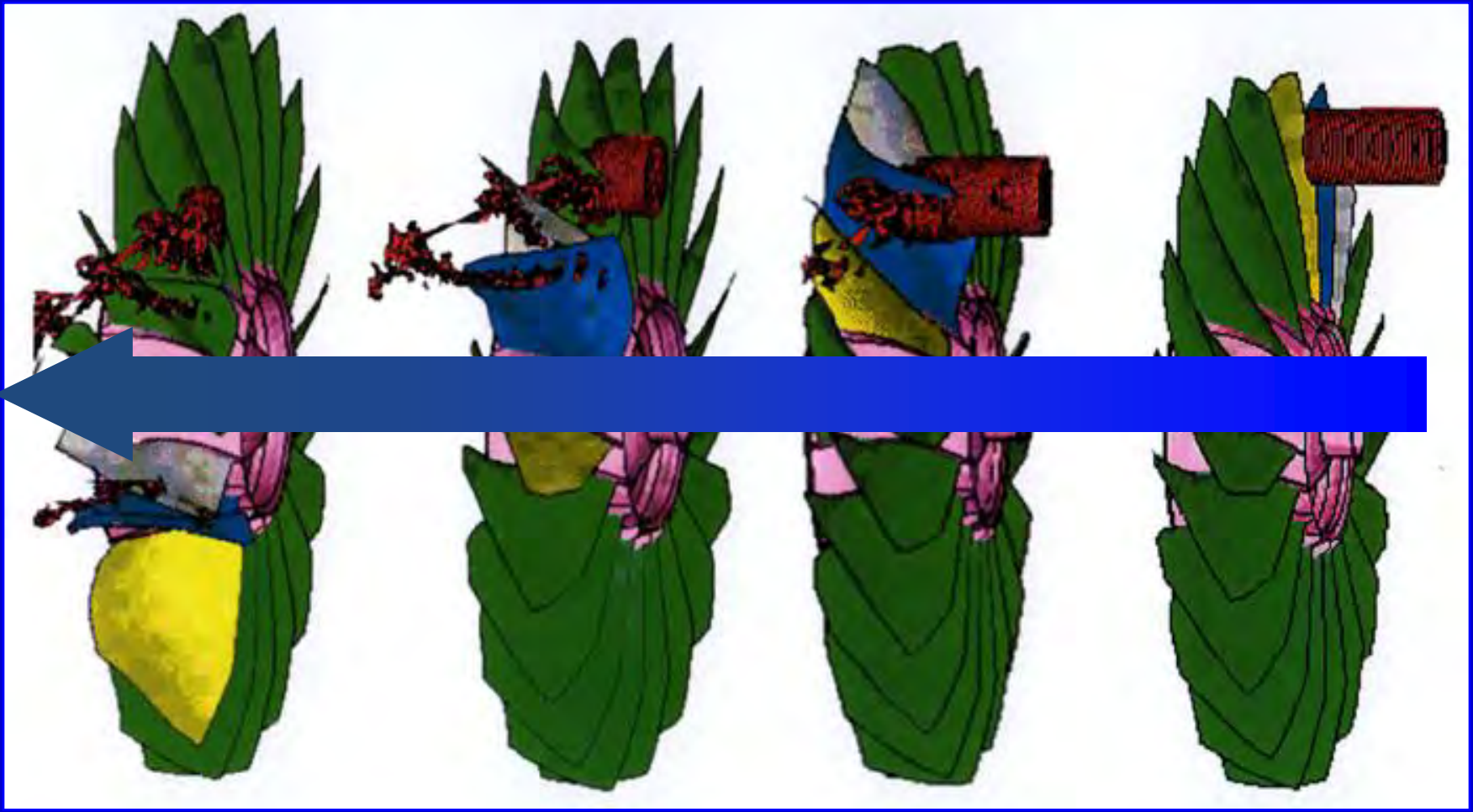
SYSTEM LEVEL



SUBSYSTEM LEVEL

Manufacturing Process

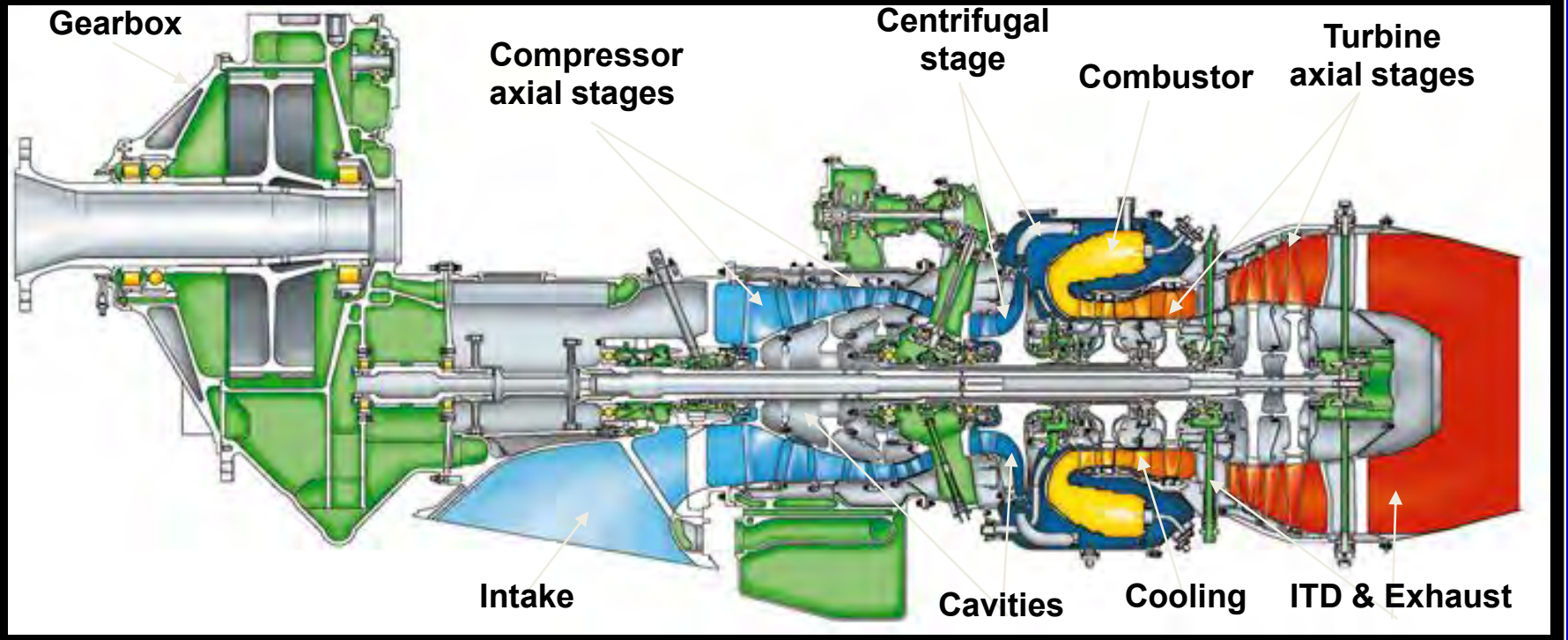
Fan Bird Strike Tests
"Analytical Certification"



Reduced Development Cost

PW150 Engine - 6000 SHP

All major components analyzed with 3D analytical tools



First 3 Year Program (1990)

Green Engine

Has lowest possible
Emission Impact

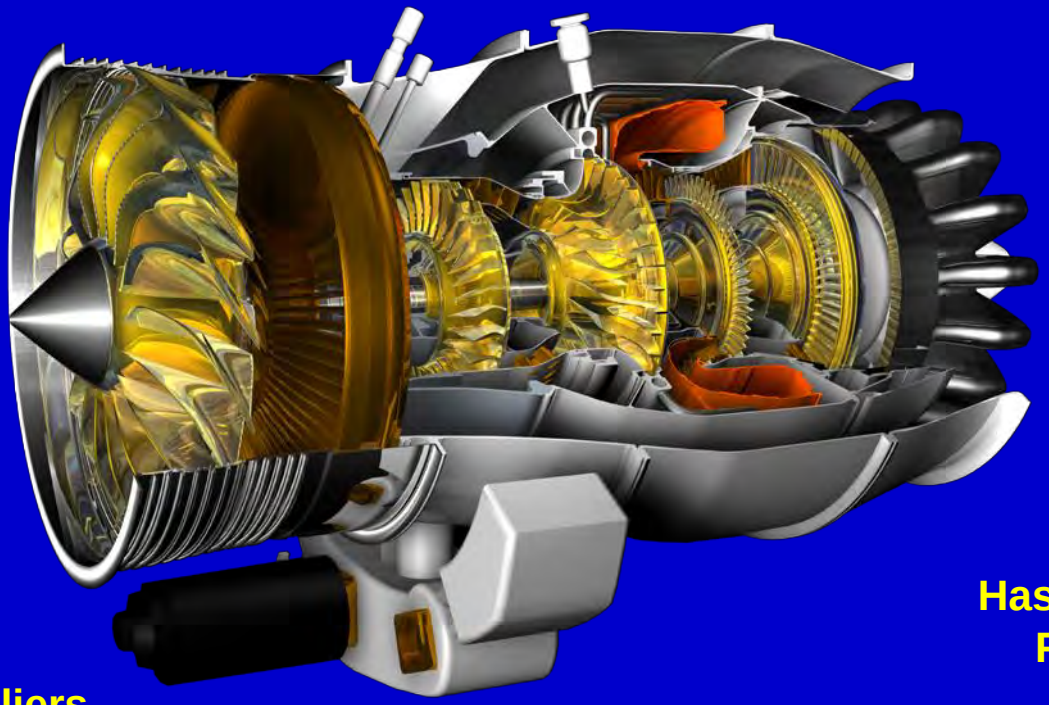
Has lowest possible
Noise Impact

Is manufactured and
serviced using
Green Processes

Is Material Efficient
(Metal Buy-to-fly)

Contains
Green Materials

Involves Green Suppliers
and Partners



Is designed with
Human Factors
in mind

Is Energy Efficient
during use
(Fuel Burn)

Has least possible
Factory Impacts

Is Designed for
Serviceability, Reusability, Recyclability

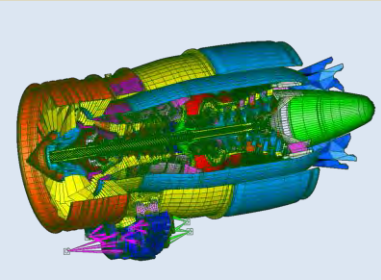
Demystifying Industry 4.0

"Humans, computers, machines and products collaborate digitally and communicate seamlessly through integrated and optimized processes across the total product value stream within an enterprise, and upstream and downstream of the enterprise"

(Ref. Aérospatiale 4.0, H. Moustapha, Juillet 2016)

Aerospace 4.0™: Addressing the Total Enterprise

Design and Development



Supply Chain Network

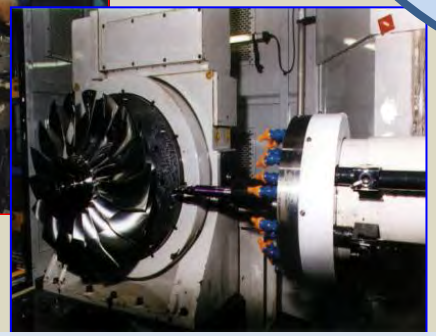
Smart and Digital Enterprise

Simulation

Integration

Optimization

Manufacturing and Production



Maintenance and Customer Support

As Sold, As Designed, As Planned, As Produced, As Maintained

Total Enterprise: "Aerospace 4.0 KPI"

AÉROÉTS
Le génie pour l'aérospatiale 4.0

1. **Design** — Multidisciplinary Design Optimization "MDO" (CAD+)
2. **Development** — Simulation Life Management "SLM"
3. **Manufacturing** — Multidisciplinary Factory Optimization "MFO" (CAM+)
4. **Product** — Product Development Process "PDP"
5. **Resources** — Enterprise Resources Planning "ERP"
6. **Customers** — Customer Relationship Management "CRM"
7. **Suppliers** — Supply Chain Management "SCM"
8. **Enterprise** — Product Lifecycle Management "PLM"

And Workforce

Technology: "Aerospace 4.0 KPI"

AÉROÉTS
Le génie pour l'aérospatiale 4.0

1. Simulation
2. System Integration
3. Internet of Things
4. Cloud Computing
5. Cyber Security
6. Augmented Reality
7. Big Data
8. Additive Manufacturing
9. Autonomous Robots
10. Etc.

A Total Enterprise Industry 4.0 Integrated R&D Program

SIEMENS

Design and Development

McGill/Mike & ETS/Hany
Siemens/Paul
($2M)

Manufacturing

ETS/Mohammad & Waterloo
Siemens/Ali
($3M)

Siemens AGT PLM 2020

Integration and Coordination

ETS/Hany
Siemens/Benoit

Supply Chain

Concordia/Nadia & ETS/Roland
Siemens/Andrew

($2M)

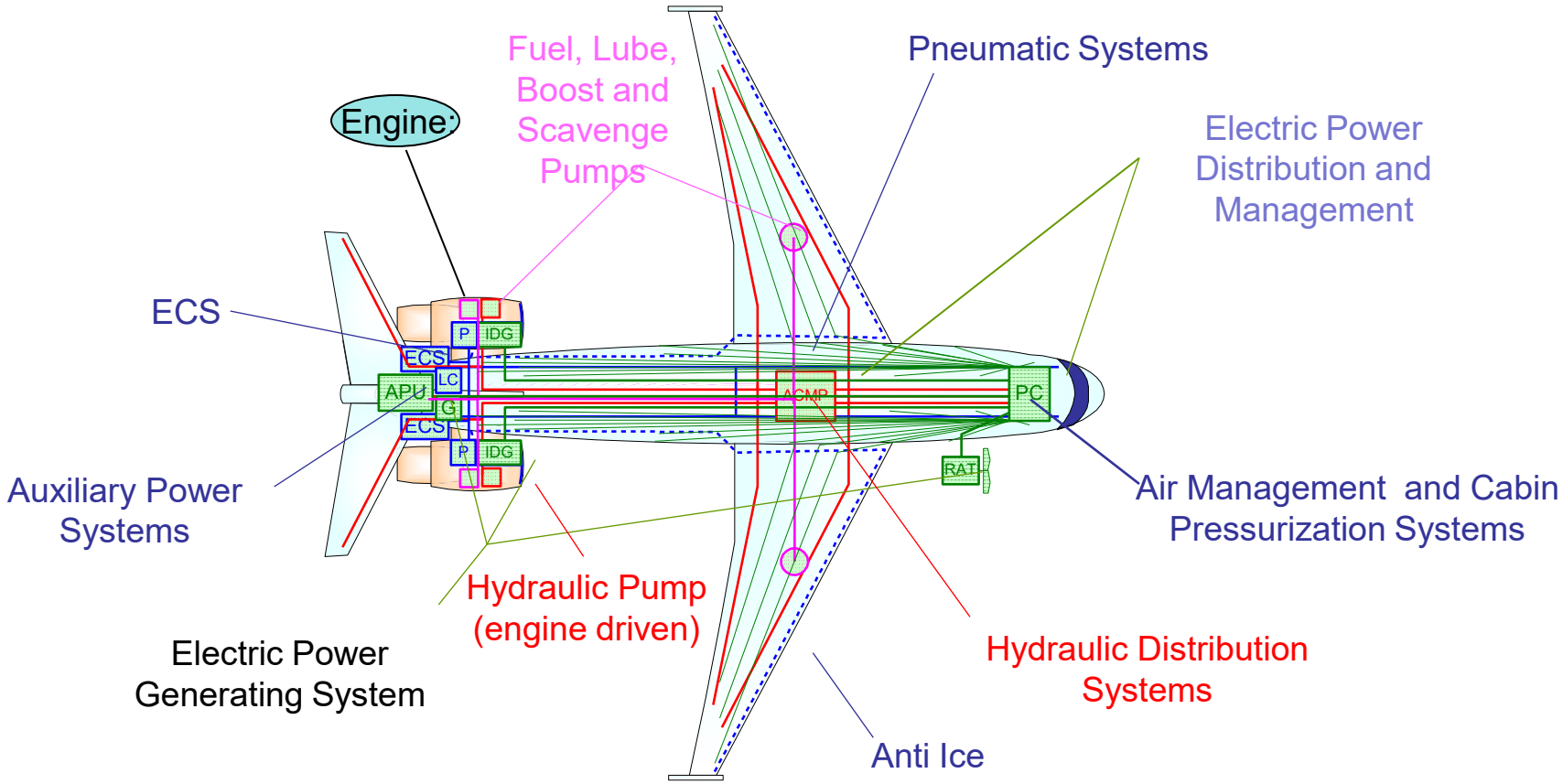
Production and R&0

Concordia/Nadia & ETS/Roland
Siemens/Katherine

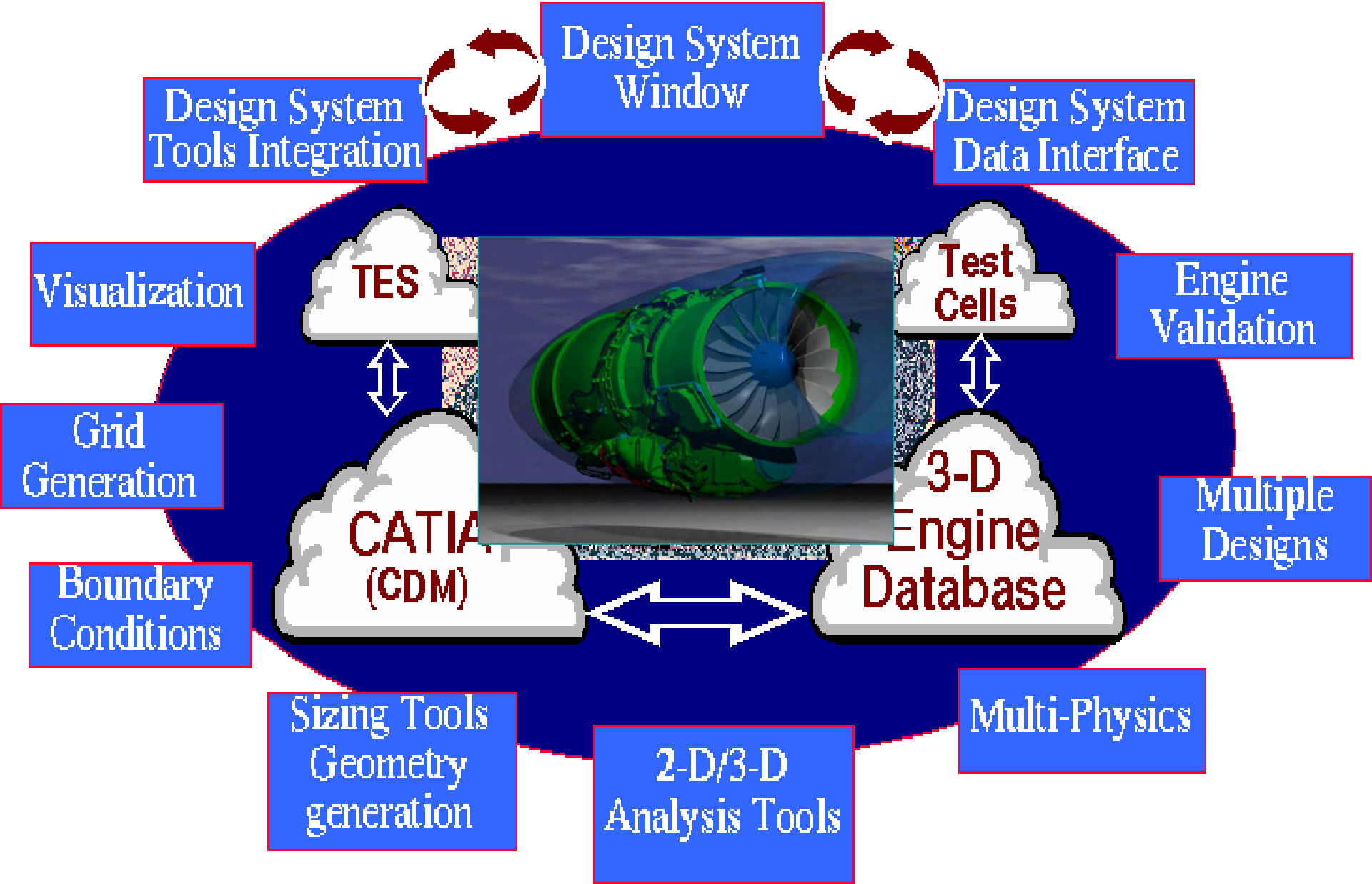
Total: $7M/5 years

Integrated Aircraft Power Systems Simulation and Optimization

Propulsion Systems | Electrical Systems | Fuel Systems | Hydraulics Systems | Pneumatic Systems



Virtual Engine
"Numerical Test Cell"



Top Three Manufacturing Technologies

1. Intelligent Manufacturing Systems “IMS” and “MFO”:

- Multidisciplinary Factory Optimization “MFO”
- Closed door machining
- In process measurement
- Dynamic compensation
- Trend monitoring
- Process monitoring
- Process control assurance
- Traceability of quality and process data
- Modeling and simulation of machining
- Predictive maintenance systems
- Machine performance data capture
- Managing “Big data”
- Etc.

Top Three Manufacturing Technologies

2. Robotics:

- Precision robotics
- Human Robot Interaction (HRI)
- Artificial Intelligence (AI)
- Collaborative robots (cobots)
- Robot optimization algorithms
- Networks integrating intrinsic sensors
- Etc.

3. Additive Manufacturing (AM):

- Increasing the number of AM-ready materials
- Optimally designing, through simulation, AM-specific components to meet functional, economic and environmental requirements of targeted applications
- Reliably predicting final characteristics of AM-built components through material, process and post-process modeling
- Modeling material behavior during the AM process
- Etc.

OUTLINE

- **Industry 4.0**
  - Origin
  - Landscape: Europe - USA – Canada
  - Workforce
- **Aerospace 4.0 Technologies**
- **Skills Challenges**

Specialist vs Generalist

"SPECIALIST" ROLE

What
We deliver

Product Quality
Product meets needs

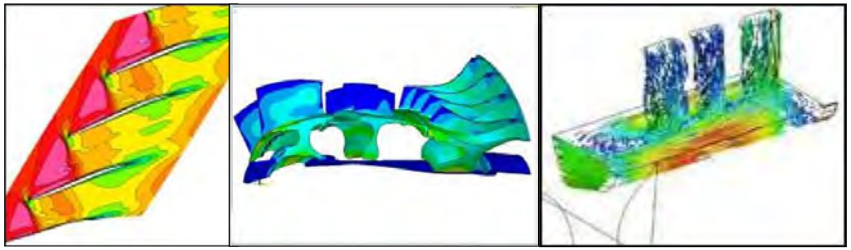
Design Reviews
Technology Development
KPI Management
Gated Review

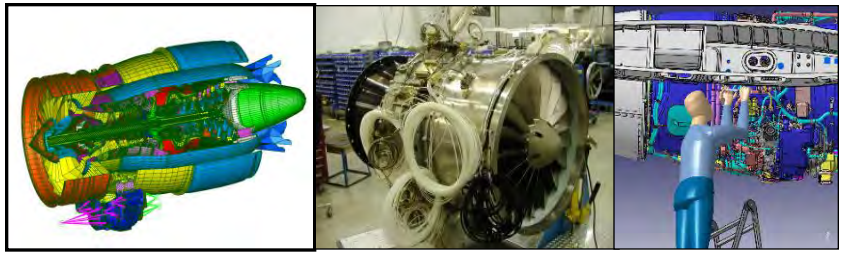
"GENERALIST" ROLE

How
We deliver it

Execution Efficiency
On time & on cost
Minimum waste

Lean Engineering
Systems Integration
Project Management
Process Management





Industry & Workforce Evolution

INDUSTRY NEEDS

FROM		TO
More Specialist	→	More Generalist
Stability	→	Mobility
Expertise → Time Based	→	Expertise → Tool Based
Hands on	→	Simulation
Limited Data	→	Data Rich
Face Time Communication	→	Global Collaboration

WORKFORCE NEEDS

Industry Needs: Agile Engineering

- Business engineers
- Cost, Cost, Cost: Value Engineering
- Process innovation – Lean Enterprise
- Three-dimensional thinking
- Risk definition and management
- Integrate, integrate and integrate
- Systems engineering
- Global competencies

Industry Training Needs

Where Universities can help

Core Technical Education

Design Systems
Ansys
CATIA

Generic technical
Fatigue, damage tolerance
Basic Controls
Design of experiments
Measurement quality
Uncertainty analysis

Activity Management
Time
Contract
Process
Project

Communication
Technical presentations
Reports
Prudent business writing

Legal
Intellectual Property
Export Control
Certification Regulations

Industry 4.0 Work Force Needs: Industrial Data Scientists and Robot Coordinators

Industrial Data Scientist:

- ICT skills
- Artificial Intelligence (AI)
- User interface design
- Advanced analytics (optimization)
- Root-cause-analysis skills
- Statistical programming

Automa-nation: Will robots take your job?

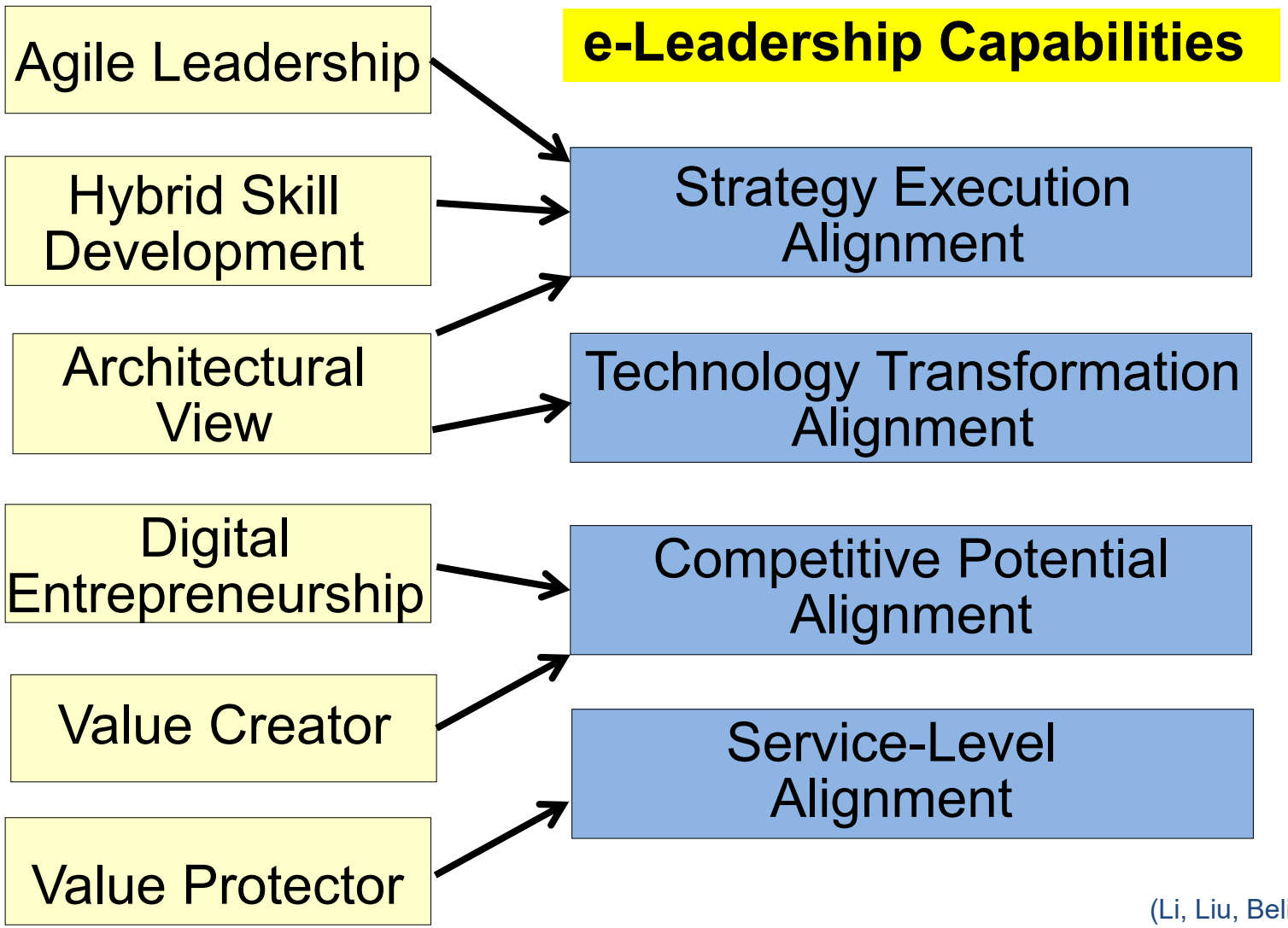
A new report suggests 42% of the Canadian job market is at risk

Robot Coordinator:

- Oversee robots and respond to malfunction
- Emergency maintenance tasks
- ICT skills

ICT Skills Need to be Integrated in all Technicians, Engineering and Business Curricula

The Digital Leadership



(Li, Liu, Belitski, Ghobadian & O'Reagan, 2016)

Competencies : "Aerospace 4.0™ KPI"

AÉROÉTS
Engineering for Aerospace 4.0

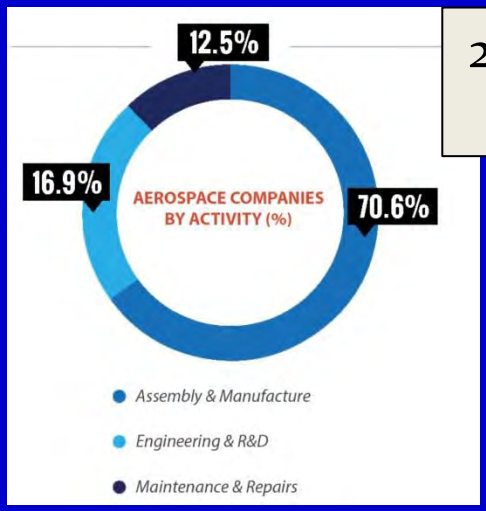
1. Simulation
2. System Integration
3. Data Scientists
4. Artificial Intelligence
5. Advanced Analytics
6. Statistical Programming
7. Digital Leadership
8. Intelligent Manufacturing Systems
9. Robot Coordinator
10. Etc.

Aerospace 4.0: Short Courses

- Introduction to Industry 4.0 and Work Force Needs
- Multidisciplinary Design Optimization “MDO”
- Multidisciplinary Factory Optimization “MFO”
- Machining Simulation
- Intelligent Manufacturing Systems “IMS”
- Product Lifecycle Management “PLM”
- Virtual Testing
- Analytical Certfication
- Artificial Intelligence (AI)
- Advanced Analytics
- Data: sharing, security, reliability, accuracy and variability
- Root-Cause-Analysis
- Statistical Programming
- Advanced and Collaborative Robotics
- Additive Manufacturing
- Case Studies

Aerospace: An Emerging Mexican Industry since 2000

260 Factories including Boeing, Bombardier, Honeywell, Safran, etc.



2011 Aerospace Exports: $4.3 Billion 2020 Target: $12 Billion

Western Aerospace Manufacturing Heading to Morocco

Morocco is Quietly Becoming the Next Big Hub in Global Aerospace Manufacturing (Aviation Week, January 2017)

How Morocco Has Become An Aerospace Star and Created the Newest Aerospace Manufacturing Cluster (Aviation Week, Oct. 2016)

Morocco's Aviation Industry Spreads its Wings (CNN, December, 2015)

BOEING

AIRBUS

BOMBARDIER

GE Aviation

SAFRAN

Mexico did it – Morocco is doing it

« Egypt Can » do it

التعاون بين الصناعة والجامعة

ذعم - مصر تستطيع

Establish Egypt as a Middle East Aviation Center for Manufacturing, Maintenance, Research and Development

Hany Moustapha, July 2017