(Cyber-Physical) Systems
Market drivers, systems engineering and (emerging) technology enablers

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Dr. Clas A. Jacobson
Chief Scientist, Controls
United Technologies Corporation

AGENDA

Aerospace & building systems, UTC history and current drivers

Evolution from mechanical to electronic systems: functionality

Who Cares?

Systems Engineering: The Missing Competence

Technology Enablers and Needs

KEY POINTS

- Drivers and markets.
  - Energy efficiency: buildings & aerospace. Buildings: achieving >50% over current standards (ASHRAE 90.1) is possible; proof points occur for all sizes and climates; buildings designed using climate responsive design principles. Aerospace: 15% SFC is possible through more electric aircraft.

- What is hard?
  - Buildings: delivery process handoffs are a problem and are where there is a loss of potential for energy savings in design, construction and operation.
  - Aerospace: requirements and verification.

- What are R&D areas?
  - Address Productivity – need design flows and tools (configuration exploration, specification of equipment and controls, automated implementation) – for automation on all parts of delivery chain.
  - Address Risk. Need calibrated models (experimental facilities) and ability to calculate, track and manipulate uncertainty
  - Address Operations – need to understand sensing requirements for diagnostics/prognostics, failure modes and FDIA.

UTC BUSINESSES

UTC Climate, Controls & Security Systems

Carrier

UTC Fire & Security

OTIS

UTC Propulsion & Aerospace Systems

Hamilton Sundstrand

Sikorsky

EVOLUTION: VALUE OF IP

June 21, 1960 I. I. SIKORSKY 2,941,605

AUTOMATIC PITCH CONTROL AND RELEASE

Filed Aug. 29, 1956 3 Sheets-Sheet 1

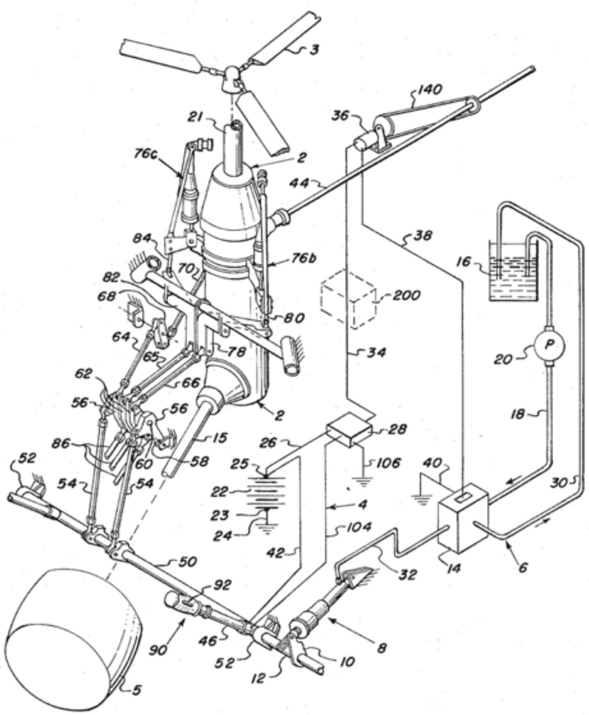


Fig. 1

INVENTOR
IGOR I. SIKORSKY
BY Jack N. McCarthy
AGENT

US 20090281641A1

(19) **United States**
(12) **Patent Application Publication**
Fuller

(10) **Pub. No.: US 2009/0281641 A1**
(43) **Pub. Date: Nov. 12, 2009**

(54) **MULTIVARIABLE CONTROL SYSTEM**

(76) Inventor: **James W. Fuller**, Amston, CT (US)

Correspondence Address:
CARLSON, GASKEY & OLDS/PRATT & WHITNEY
400 WEST MAPLE ROAD, SUITE 350
BIRMINGHAM, MI 48009 (US)

(21) Appl. No.: **12/115,574**

(22) Filed: **May 6, 2008**

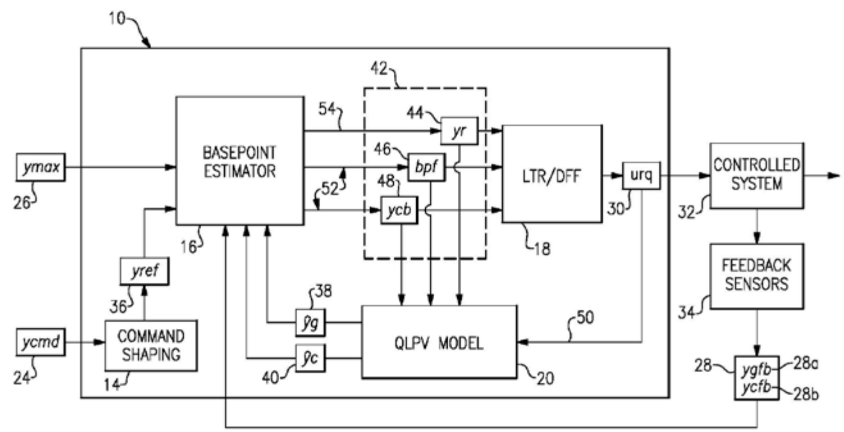
Publication Classification

(51) **Int. Cl.**
G05B 13/04 (2006.01)

(52) **U.S. Cl.** **700/30**

(57) **ABSTRACT**

A method for controlling a multivariable system according to one non-limiting embodiment includes receiving a plurality of limits, receiving a first quantity of goals each having a desired value, and receiving sensor feedback. The method further includes estimating a basepoint in response to the first quantity of goals, the plurality of limits, and the sensor feedback, wherein the basepoint includes a set of values corresponding to an equilibrium point at which a predetermined amount of enabled limits are met and a second quantity of goals are fulfilled according to a goal prioritization scheme. Predicted values from a mathematical model are compared to the sensor feedback, and the estimated basepoint is selectively adjusted in response to a difference between the predicted values and the sensor feedback in order to reduce the difference.



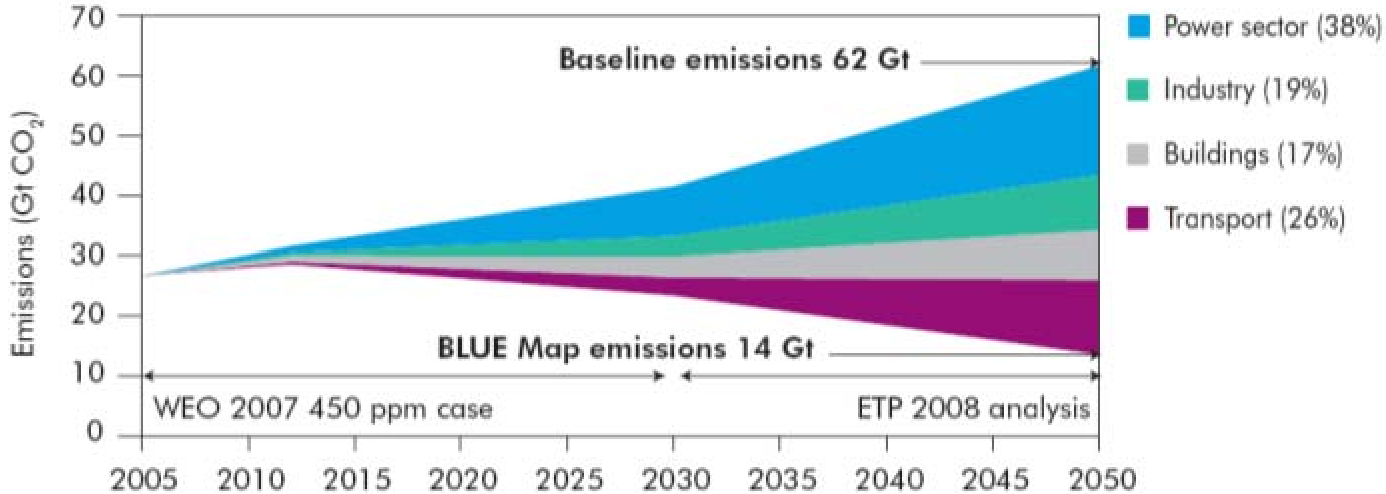
Mechanical controls moving (quickly) to electronic (software) controls

Who cares?

Energy…buildings & aerospace examples

HOW BUILDINGS FIT INTO THE BIG PICTURE

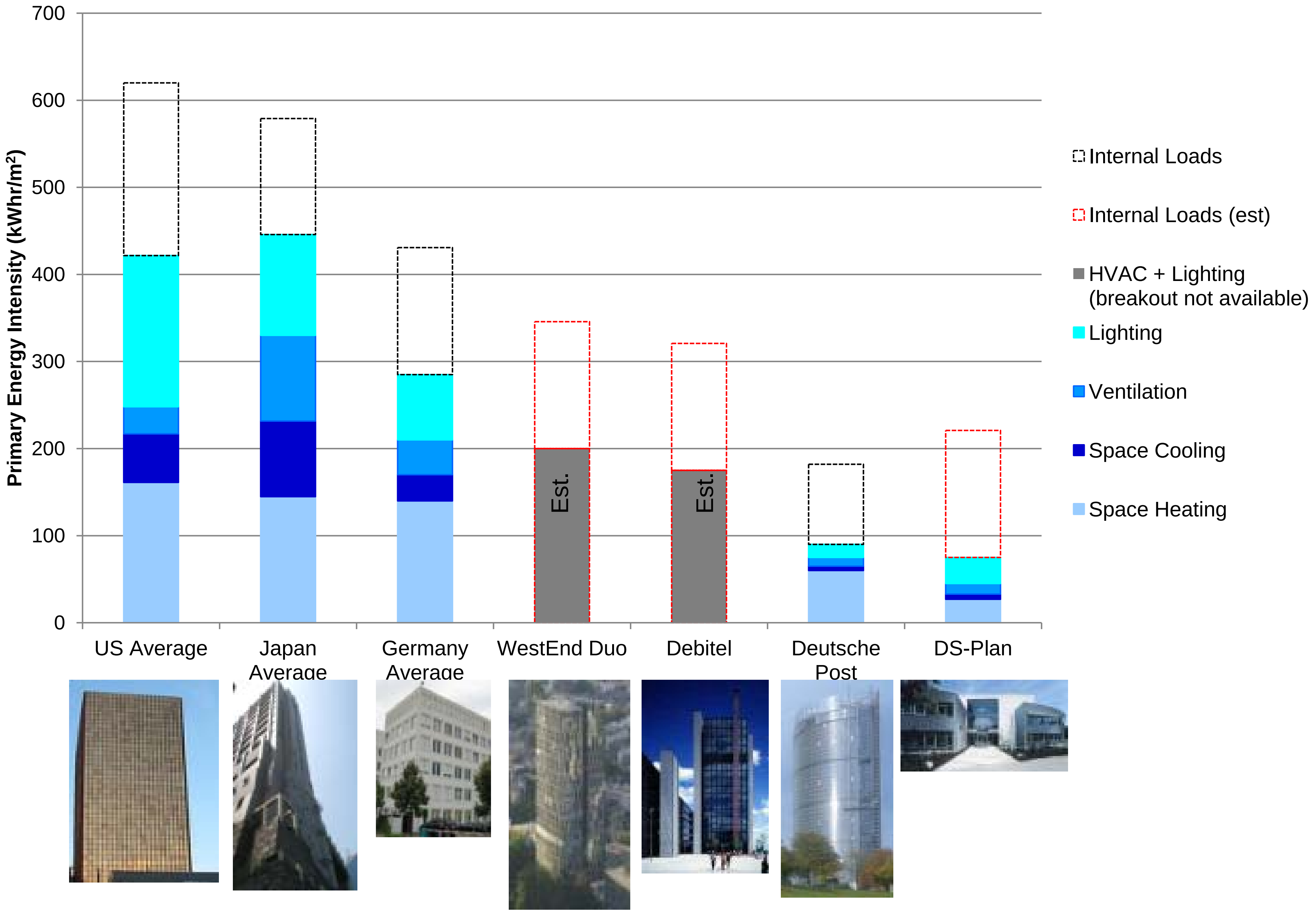
IEA Estimates of Emissions Abatement by Source/Sector



Sector	2050 BAU	2050 Blue MAP	Reduction
Power generation	--	--	18.2
Industry	23.2	5.2	9.1
Buildings	20.1	3.1	8.2
Transport	18	5.5	12.5
Total	***62***	***14***	***48***

Source: IEA Energy Technology Perspective 2008

OFFICE BUILDING PRIMARY ENERGY

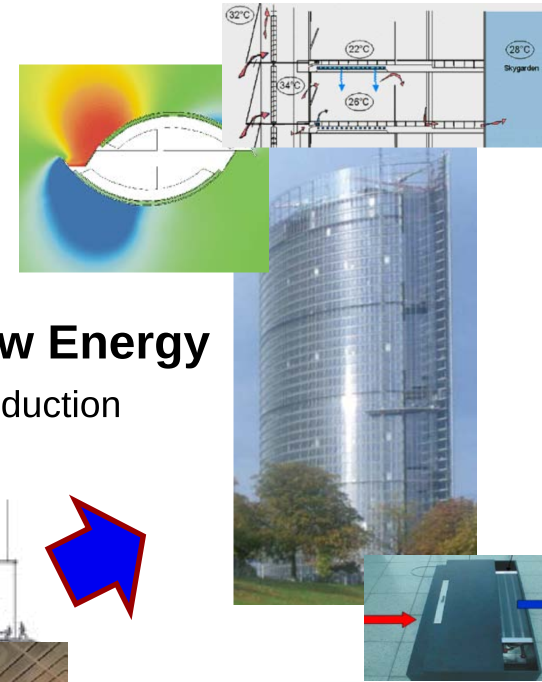


HIGHLY EFFICIENT BUILDINGS EXIST…

Energy Retrofit
10-30% Reduction

Cityfront Sheraton
Chicago IL
1.2M ft^2, 300 kWhr/m^2
5753 HDD, 3391 CDD
VS chiller, VFD fans, VFD pumps
Condensing boilers & DHW

Very Low Energy
>50% Reduction



Bonn Germany
1M ft^2, 75 kWhr/m^2
6331 HDD, 1820 CDD
No fans or Ducts
Slab cooling
Façade preheat
Night cool

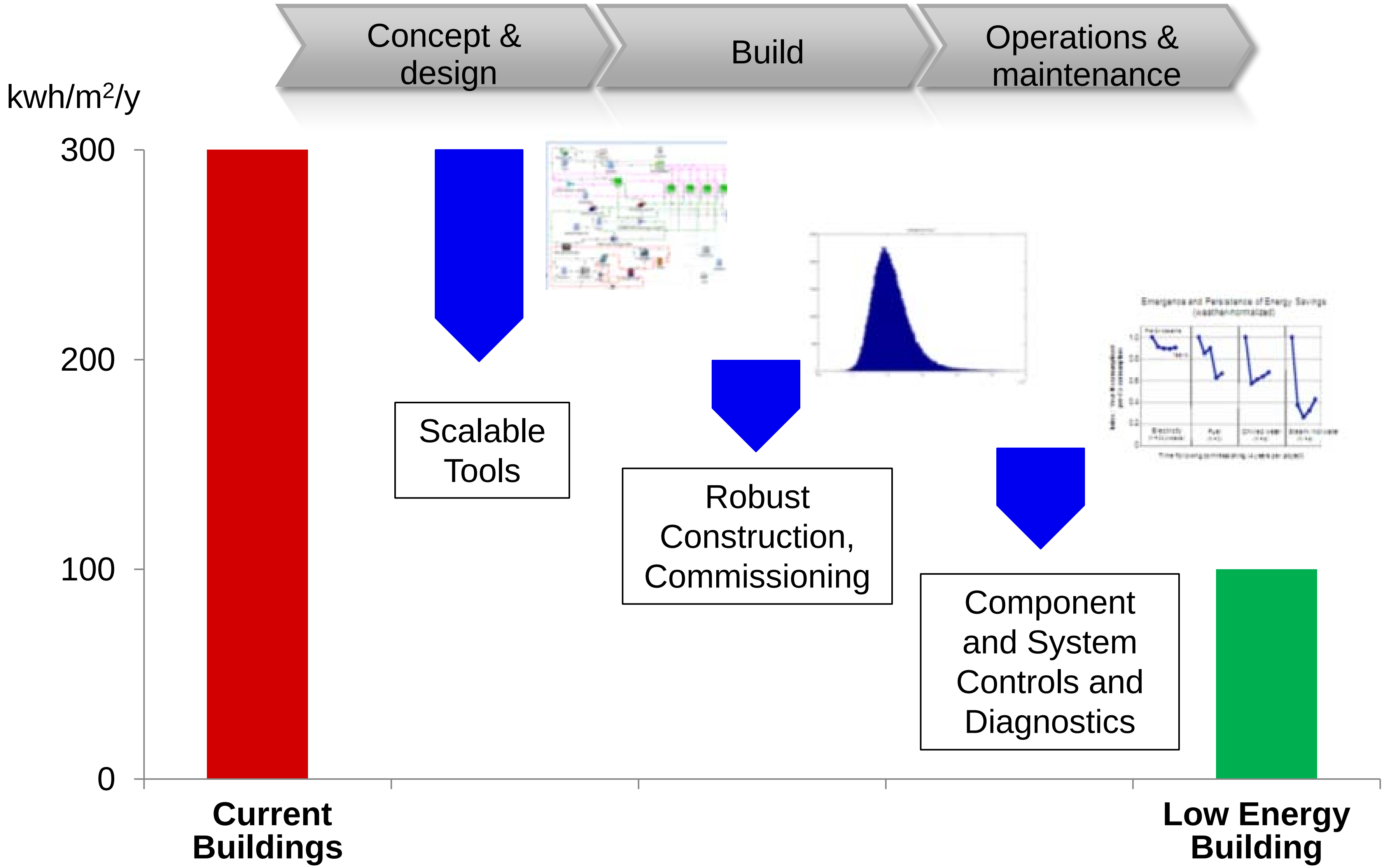
LEED Design
20-50% Reduction

Tulane Lavin Bernie
New Orleans LA
150K ft^2, 150 kWhr/m^2
1513 HDD, 6910 CDD
Porous Radiant Ceiling, Humidity Control
Zoning, Efficient Lighting, Shading

- Different types of equipment for space conditioning & ventilation
- Increasing design integration of subsystems & control

ENERGY EFFICIENCY (GAPS) IN BUILDINGS

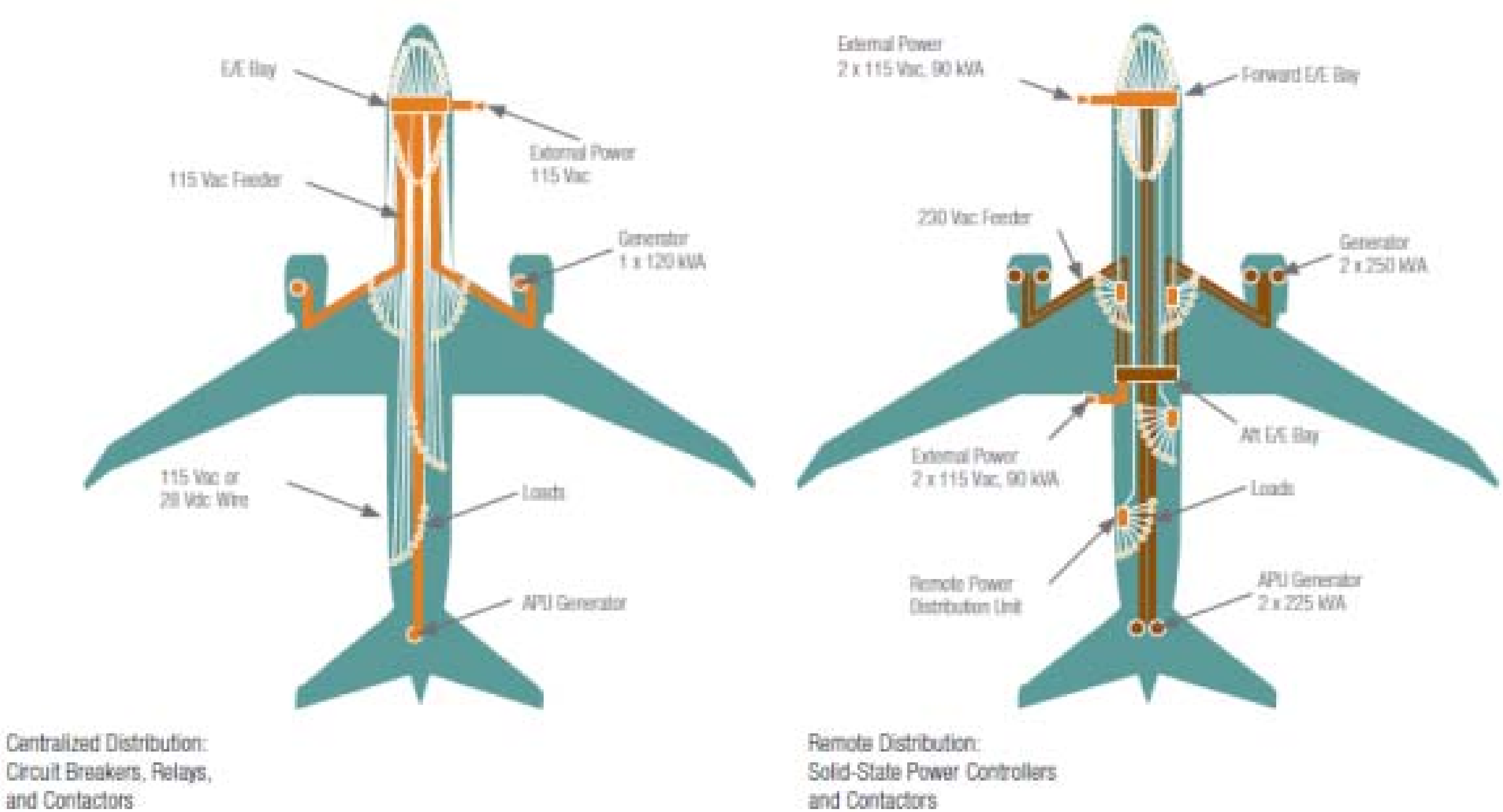
Energy and operational savings over building lifecycle



MORE ELECTRIC AIRCRAFT

>15% more fuel efficient
No bleeds…distributed control

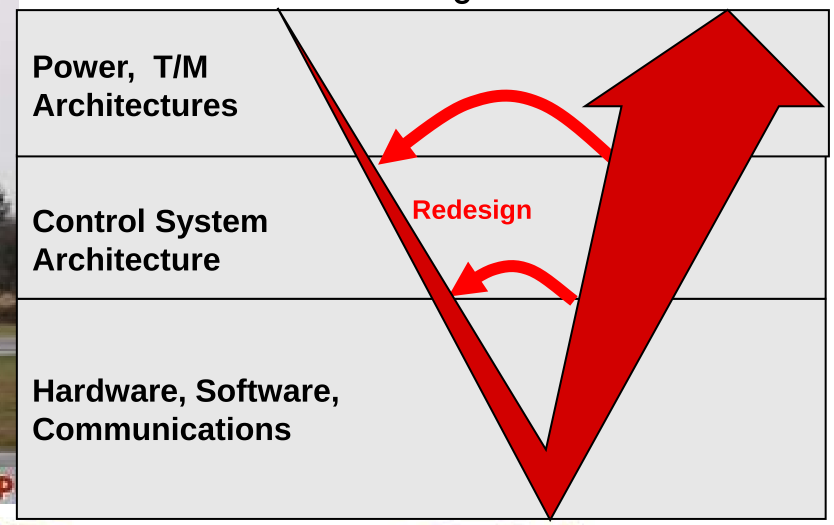
TRADITIONAL

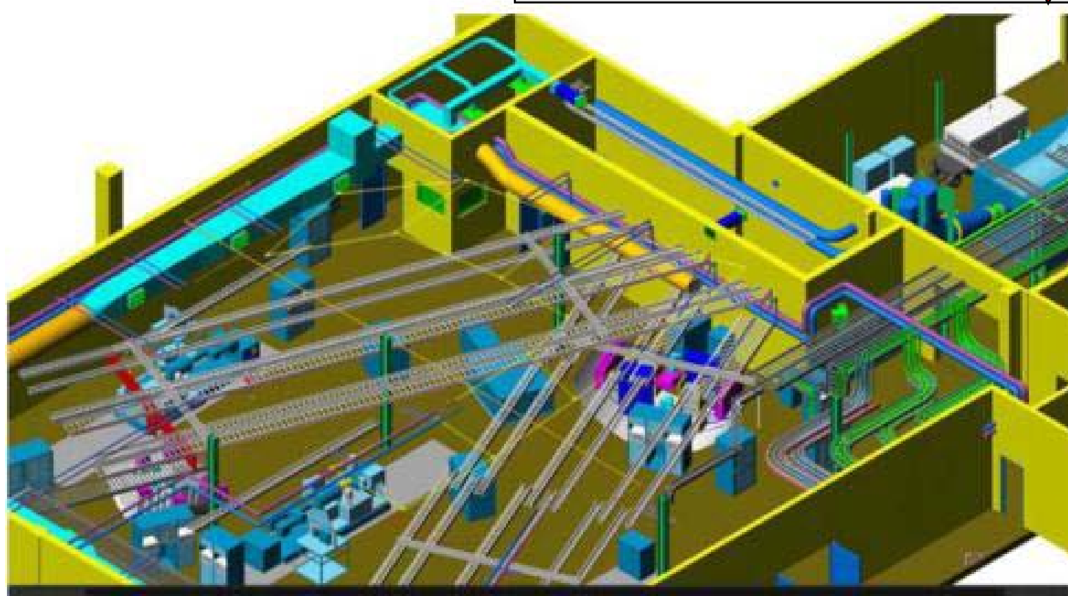


Source: *787 No-Bleed Systems:* Saving Fuel and Enhancing Operational Efficiencies by Mike Sinnett, Director, 787 Systems, Boeing, 2007

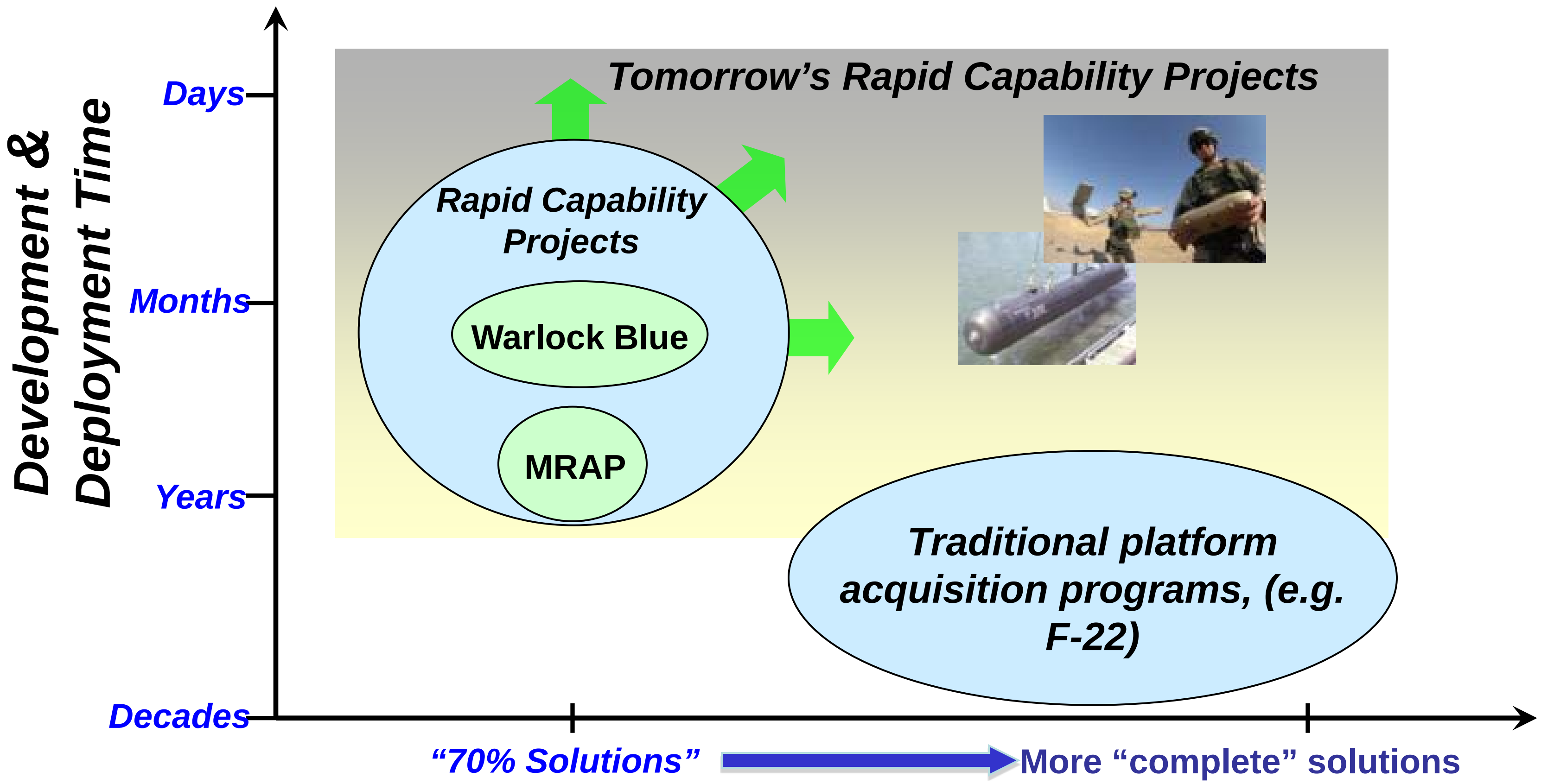
TESTING, DESIGN FLOW & REQUIREMENTS

Design Flow Burden on Integration & Testing





Rapid Capability "Toolbox"



"Performance", "Sustainability", "Adaptability", "Robustness" of Solution

DDR&E Rapid Capabilities Toolbox study will identify tools to enable more rapid, adaptive, robust, and sustainable solutions to the warfighter

DoD SOFTWARE PRODUCIBILITY ISSUES

…the management of engineering risk in unprecedented large and ultra-scale systems.


Preliminary Observations on DoD Software Research Needs and Priorities

A Letter Report

Committee on Advancing Software-Intensive Systems Producib

Computer Science and Telecommunications Board
Division on Engineering and Physical Sciences

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…software quality assurance for defense systems.

…the reduction of requirements-related risk

Systems Engineering & Controls

Definition

Systems engineering is a methodology for product system level design, optimization and verification that:

1. Provides guarantees of performance and reliability against customer **requirements** while achieving business cost and time-to-market objectives;

2. Produces modular, extensible **architectures** for products incorporating mechanical components, embedded systems and application software;

3. Exploits **model-based analytical tools and techniques** to determine design choices and ensure robust system performance despite variations caused by product manufacturing, integration with other products and customer operation; and

4. achieves these objectives through the coordinated execution of a prescriptive, repeatable and measurable **process**.

The Charge…and Response

What is new in CPS?

What are technology areas that will have impact?

What are enabling technologies?

Current practitioner workflows → Design V; huge system test time; large (loop) design iterations

Main development challenges → Requirements; Design Flows; Verification; Integration

Enabling Technologies: → Platform Based Design; Contract based design; Co-design of controls/protocols

INVESTMENTS

Drivers

Increasing functionality being embedded in software – blurring the distinctions between "systems" and "software."

Architectural design (and exploration) key need – especially when compounded by issues of legacy, systems trades, fragmented supply chain.

V&V key issue in development cycle. Need to develop software in ways that fit with the system. V&V for heterogeneous domains encompassing software/systems and electro-mechanical systems.

Recommendations

Focus on languages for formal requirements capture for software and systems (domain specific requirement languages, e.g. SysML based)

Focus on compositional techniques for interconnection of software/hardware components.

Focus on enabling trade space exploration/optimization in architecture to encompass software, systems and electro-mechanical systems.

Focus on design flows that have refinement structure to enable tracking and incremental V&V.

Focus on integration of different platforms – avoid "one size" for modeling languages or integration frameworks.

Enabling technologies (investable to year to TRL6)

1-2 years: Languages for formal requirements capture and refinement to software/hardware.

2-4 years: Design flow for heterogeneous systems (including legacy and supply chain constraints)

5+ years: Compositional methods for cross domain software generation