How I&C evolution (and some revolutions) will help ITER evolve into Demo

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Trends: Two Industries and a Need

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A Developing Need

Magnetically Confined Fusion R&D

- Growing Control Complexity
- About to jump from "Operator Integrated" to "System Integrated"

Two Industries

Industrial Process Control

- Control Networks
- Distributed Control
- Intelligent Local Loops

Aerospace Control

- Silo'ed to Federated to Integrated Systems
- Multilevel Software Security
- Emerging Autonomous Operation

Magnetic Fusion: Types and Progress

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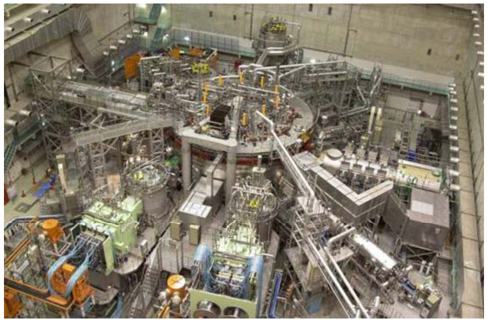
Past Dominated by Two Experiment Types

Steady State

(Relatively) Low Pressure and Temperature

Early Stellerators

EBT's, etc.



Large Helical Device,
Nagoya, Japan
Photo courtesy UC Davis

Pulsed

Higher Pressure and Temperature

Tokamaks

Pinches, etc

TFTR, Princeton, US
Photo courtesy PPPL

Recent experiments are pointing to a change

Recent Trend

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Increasing understanding of plasma behavior is converging experiment types

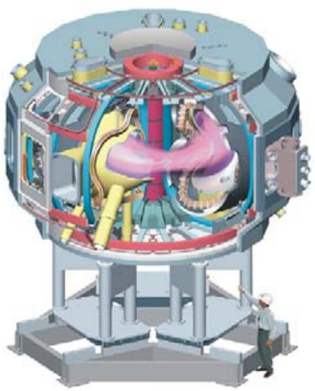

Figure courtesy of PPPL

Stellerators: Pushing out the limits of steady state stability

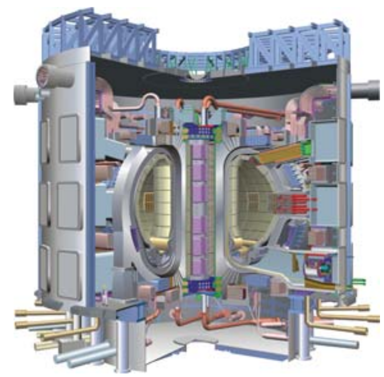

Figure courtesy of the ITER Project

Tokamaks: Pushing out the limits of confinement time

DEMO

Steady state with high energy density

Industrial Process Control

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The plasma physics community has long been good at mining the industrial process control industry for concepts, hardware, and software

e.g. JET Controls

- CAMAC
- Programmable Logic Controllers
- Optical Data and Control Networks
- Standardized Interface Modules
- Local Closure of Simple Loops

1960's era controls
Photo courtesy of UKAEA

Portion of JET controls
Photo courtesy of UKAEA

However, most experiment controls still federated

Federated Control

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Federated Control

- Organized by functional system
- Physically distributed control hardware
- Closed loop control within functional systems
- Functional systems may or may not converge on a universal data and control network
- <u>Integration across functional systems performed by one or more humans</u>
- <u>Therefore, limited ability for functional system interaction for behavior optimization</u>

Aerospace Control

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True "survival of the fittest"*

- Unfit aircraft shot down
  - In combat
  - In Congress
  - In the marketplace
- Development by Punctuated Evolution
  - Long periods of incremental improvements
  - Punctuated by short periods of revolution

* With a few glaring exceptions created by politicians

Control Development Dynamics

Evolution

Usually pushes limits of existing, understood systems

Revolution

Usually involves stealing seemingly unrelated technologies and forcing them into a control task in unexpected ways

Aerospace Control Examples

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Evolution

- 8000 psi hydraulics instead of 5000 psi hydraulics
- ADA code instead of assembler code
- Object-oriented programming instead of spaghetti code

Revolution

- Mechanical Controls to Fly-by-Wire to Fly-by-Light
- Thrust Vectoring
- Integrated instead of Federated Architectures
- Morphing Aircraft
- Self-Repairing Flight Controls
- Autonomous Aircraft

Convergence

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Understanding of plasma behavior has developed to the point that experiments now need, and can effectively use, integrated control systems

Aerospace has developed the skills to create those control systems

How similar are they?

Overlap Example

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Control Requirements Overlap between JET and F/A-18 E/F

- Plasma Instabilities – 10s of μs to 10s of ms
  - Boeing Controls – ms in flight to < μs in actuation
- Reactor Control Physical Layer – Fiber Optic
  - Boeing Controls Physical Layer – Fiber Optic
- Reactor Network – ATM
  - Message Size – Very Small
  - Message Number – Very Large
- Boeing Network – Fibre Channel and WDM
  - Message Size – Medium
  - Message Number – Medium
- Reactor Control OS Environment – VX-Works
  - Boeing Control OS Environment – VX-Works

Aerospace Skills Examples

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- Unmanned Combat Air Vehicle
- Software Enabled Control
- Open Control Platform Extensions for Hybrid High Confidence Control
- Intelligent Damage Adaptive Control System
- Fly-by-Light Advanced System Hardware
- Vehicle Management System Integration Technologies for Affordable Life Cycle Costs
- Propulsion Controlled Aircraft
- Open Systems Architecture/Condition Based Monitoring
- Reconfigurable Control of Tailless Fighter Aircraft
- On-Line Flight Control Diagnostic System
- Reconfigurable Control and Fault Identification System
- Integrated Tactical Aircraft Control
- JSF Prognostics and Health Management
- Automatic Air Collision Avoidance System
- Control Augmentation for the Renault F-1 Team
- Control of Multi-mission UAV Systems
- Automated Aerial Refueling

Benefits to DEMO

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Control Optimization: across systems, for multiple operation modes

Adaptive Control: systems compensate for changes in other systems

Plant Health Monitoring: minimizes downtime

Plant Health Prognostication: schedule downtime for minimal impact

Highly Reliable Control: economically and legally necessary

Secure Control: prevent intrusions

Verifiable Control Software: necessary for Highly Reliable Control

Verifiable Self-Learning Control Software: needed for cost control

Software Re-use: needed for cost control

Commercial Software Exploitation: needed for cost control