DEVELOPMENT OF GENERIC COUPLING BETWEEN TRANSPORT AND FREE-BOUNDARY EQUILIBRIUM CODES WITH BREAKDOWN MODULES FOR PULSE DESIGN TOOLS

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General Scope

Improve Pulse Design Tools for core plasma physics discharge design and controller testing

Motivation

In a Digital Twin Environment (DTE), are required:

- ▷ Trajectories and actuator schemes for discharge design.
- ▷ Fast, reliable tools for real-time control testing.

Pulse Design Tools (PDT) meets these needs. Key aspects are:

- Portability and modularity for DTE integration.
- Mixed-fidelity and validation with more accurate codes.

Activities

1. PDT extensions by coupling and integrating physics codes.
2. Coupling between breakdown and PDT.
3. Development of a surrogate model for plasma fueling.
4. Synthetic diagnostics and reconstruction testing.

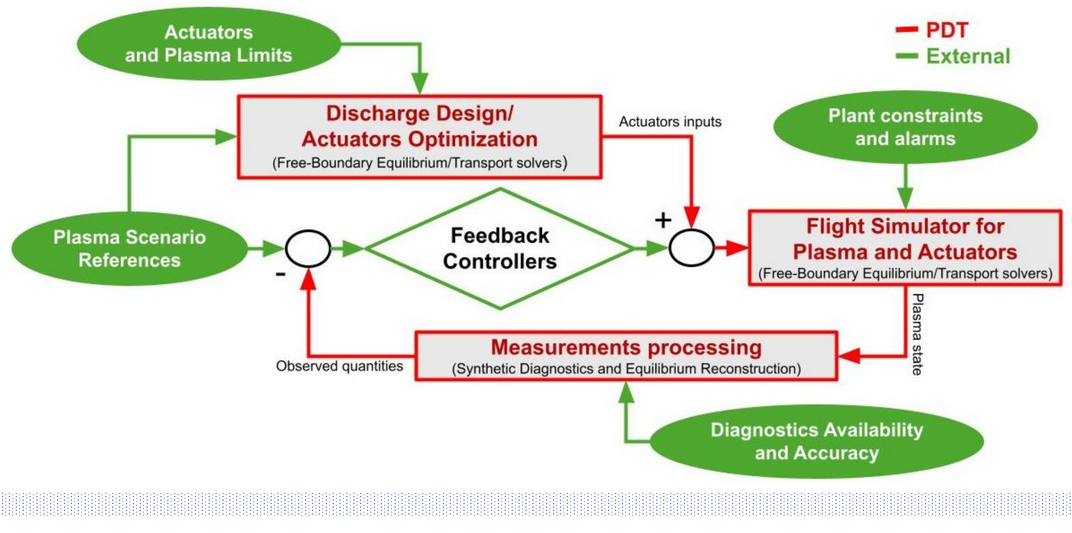
Codes

		Input	Output	Code
Free-Boundary Equilibrium	Inverse	- Plasma Shape - Profiles	PFC Currents Equilibrium	FBT/NICE/ FIESTA
	Reconstruction	- Measurements - Profiles	Plasma equilibrium	LIUQE/ NICE
	Forward	- PFC currents/voltage - Profiles	Plasma equilibrium	FGE/NICE
Transport		- Equilibrium - PFC currents	Profiles	RAPTOR/ METIS
Breakdown		- PFC currents - Neutral source	- Plasma shape - Global param	DYON

1. Pulse Design Tools extensions

Aim: **Enhance PDT simulations by integrating advanced physics modules for discharge optimization**

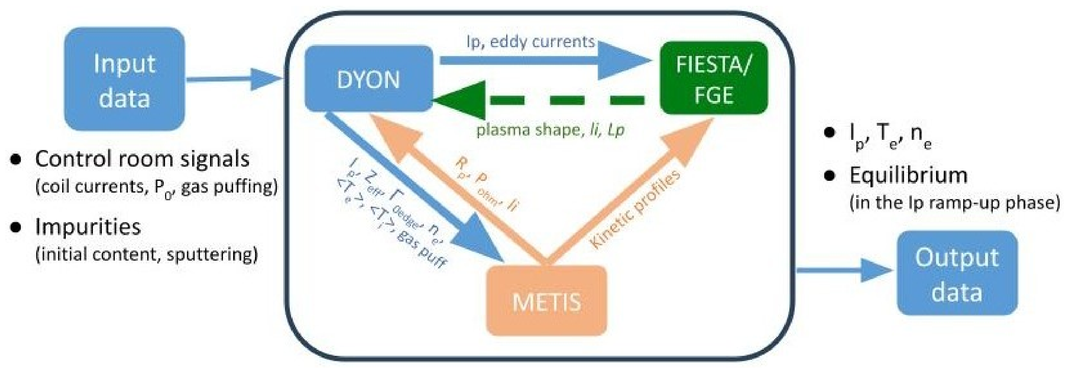
- Free-Boundary and transport coupling (COMPASS-U, TCV):
  - Inverse mode coupling: FBT-METIS.
  - Forward mode coupling FGE–METIS/RAPTOR-Controller.
- ECRH modeling in NEST (WEST PDT):
  - ECRH integration (TORBEAM) for power and current deposition.
  - Improve WEST ECRH scenario development and validation.



2. Coupling between Breakdown and PDT

Aim: **Improve PDT simulations by refining breakdown phase and initial discharge conditions**

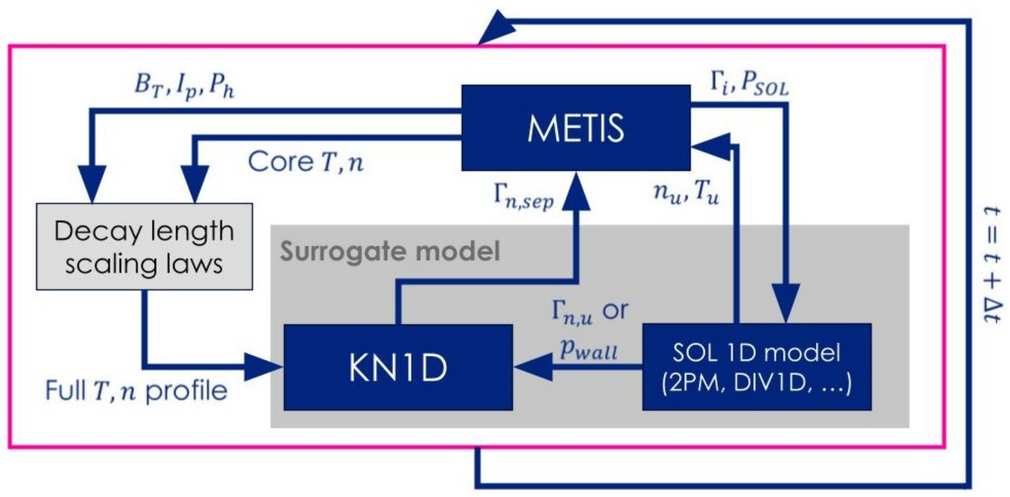
- Breakdown link with FGE: DYON-METIS-FGE workflow.
- Connect breakdown to flight simulators for variable initial conditions and full breakdown–discharge simulation.
- Workflow validation in COMPASS-U, MAST-U and TCV.



3. Surrogate model for plasma fueling

Aim: **Improve separatrix density predictions to inform pedestal and SOL parameters while reducing computation time**

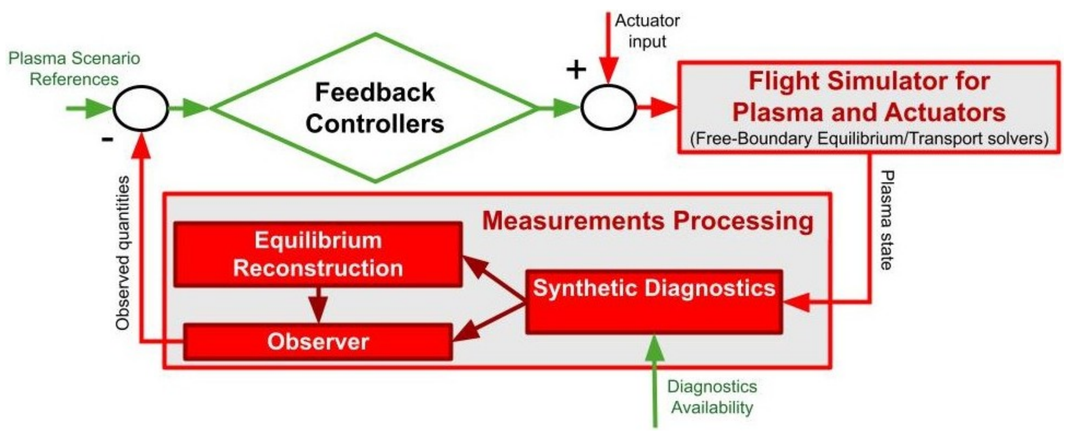
- KN1D + METIS + SOL scaling for self-consistent edge fueling.
- Train ML algorithm on simulated data for KN1D.
- Validate against high-fidelity neutral transport (EIRENE).



4. Synthetic Diagnostics and Reconstruction testing

Aim: **Enhance simulation realism by adding synthetic diagnostics to better match experimental conditions**

- Addition of synthetic diagnostics and equilibrium reconstruction in NEST (WEST):
  - Addition and test of Interferometry and Polarimetry (TIP).
  - Addition of plasma shape reconstruction.
  - Validation against WEST experiments.
- Equilibrium reconstruction in MEQ-METIS/RAPTOR:
  - Link equilibrium reconstruction (LIUQE) with controllers and simulator.
  - Validation against COMPASS-U and TCV.



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