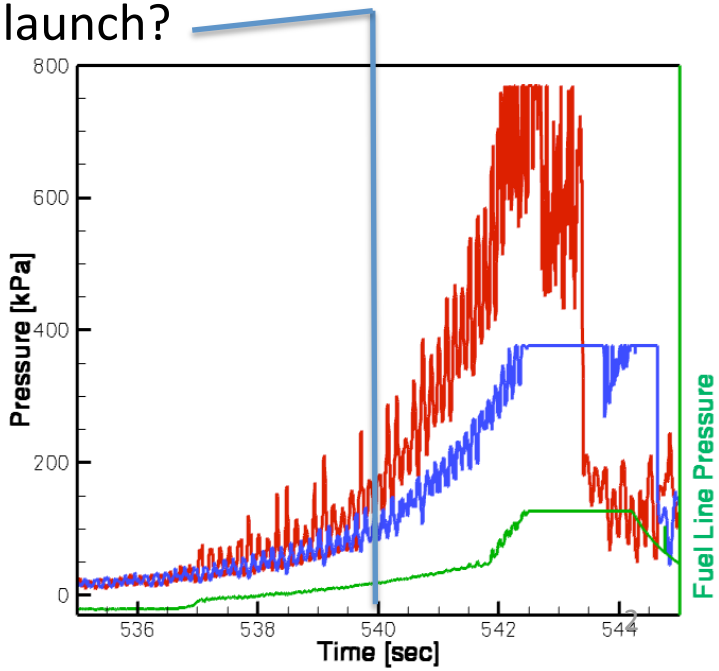
PSAAP Project

QMU @ Stanford

Component Analysis and relation to Full System Simulations

What do we want to predict?

- Objective: prediction of the unstart limit expressed as probability of unstart (or alternatively as margin to unstart)
- Quantity of Interest: the max pressure in the combustor is the output metric we use to "detect" unstart.
- "the main questions can be formulated as":
  - Was hyshot operating safely 540sec after launch?
  - What is the fuel flow rate (kg/s of H2) that guarantees a given margin from unstart @540sec?



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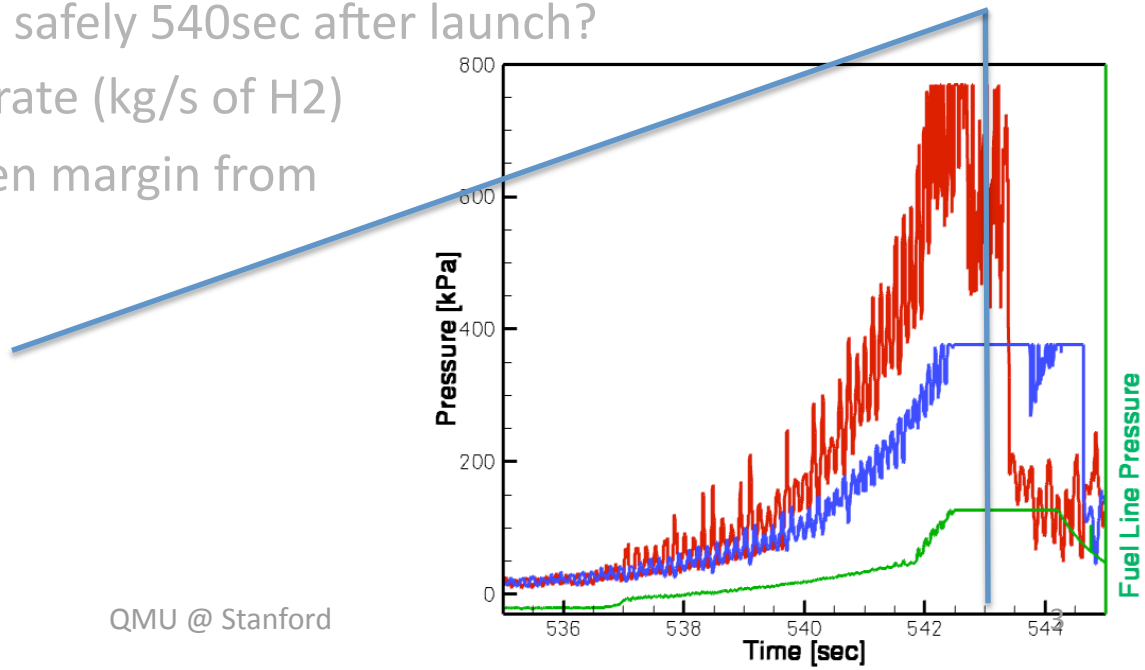
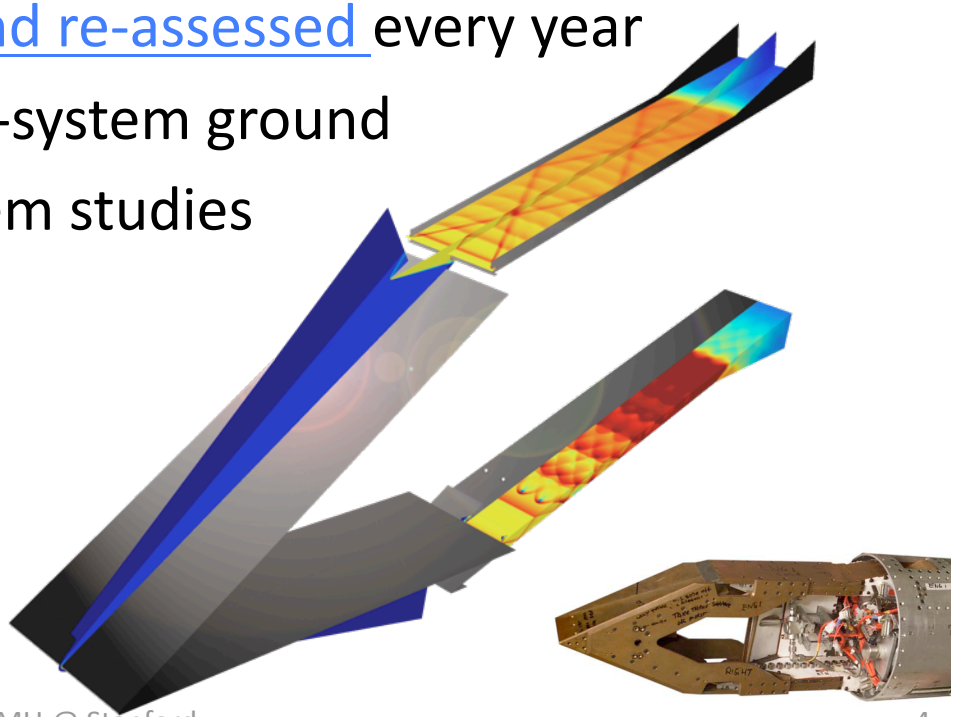
  - How about 543sec?



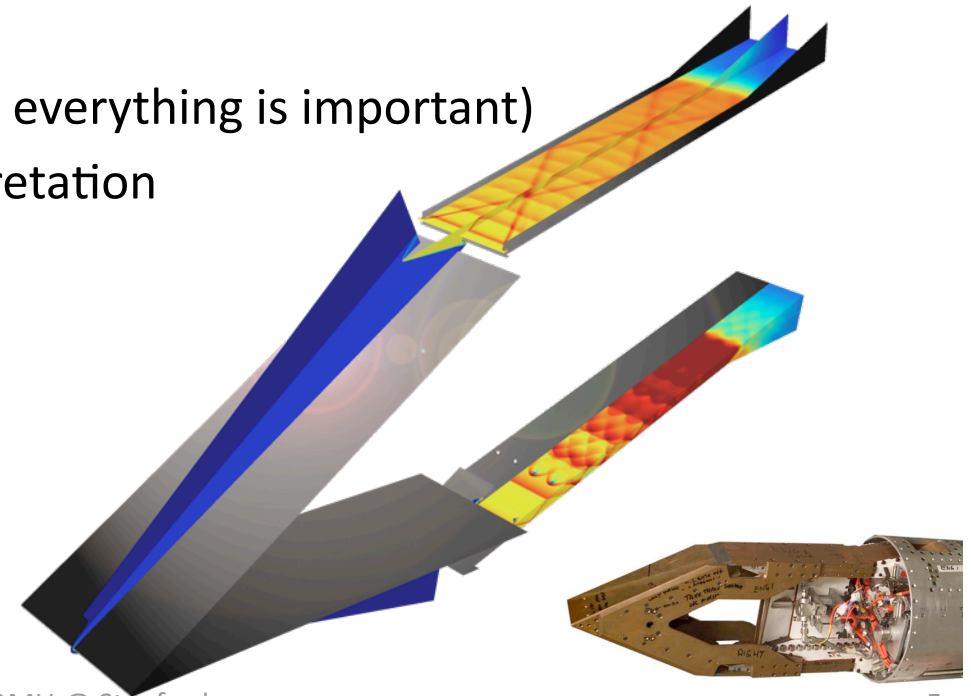
How do we want to predict it?

- Approach: build a V&V-ed full-system simulation capability based on Joe + heat release model (ROM) and simulate a range of realistic operating conditions.
- ROM Definition: is based on component analysis and expert opinion and is informed and re-assessed every year
- Validation: is based on full-system ground tests (DLR) and unit problem studies



Why do we need QMU?

- Full System calculations (even extremely accurate ones) provide only one realization
- Out objective is to evaluate engineering safety factors
- QMU provides:
  - Focus on critical conditions
  - Dimensional reduction (not everything is important)
  - Metrics for physical interpretation



Organization

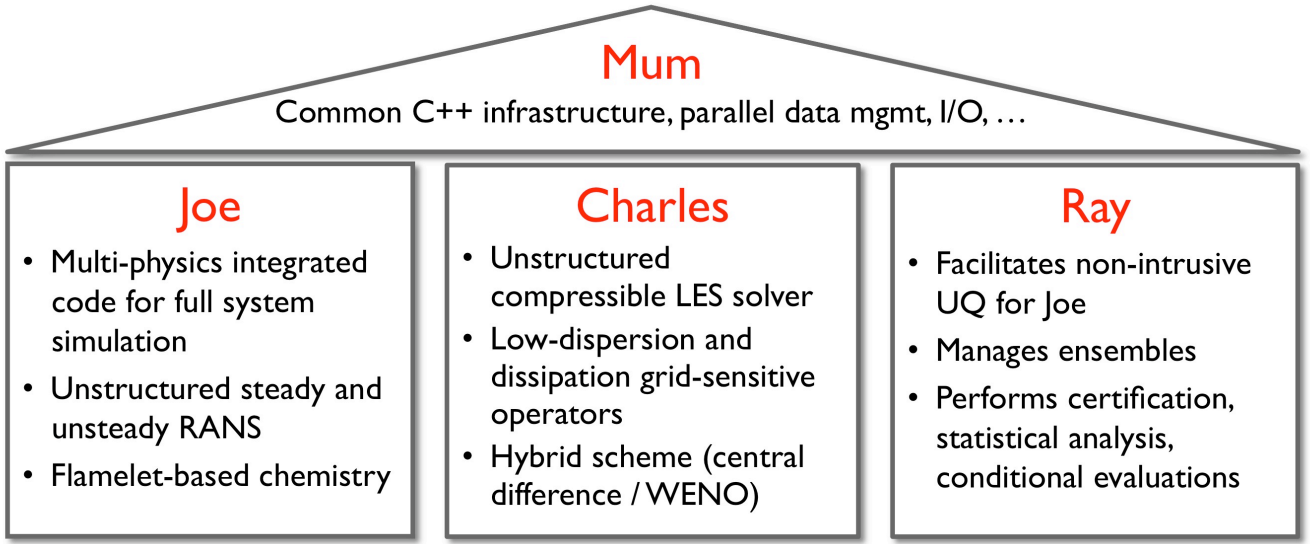
- Center-wide Activities
  - Full system Simulation & Analysis
  - Computational Infrastructure Development & Support

- Multiple teams working on various component with clearly defined role and objectives
  1. Heat Release Modeling
  2. Shock Dynamics Modeling
  3. Fuel Injection Modeling
  4. HyShot Flight Characterization
  5. Thermal Management Modeling

Center-Wide Activities

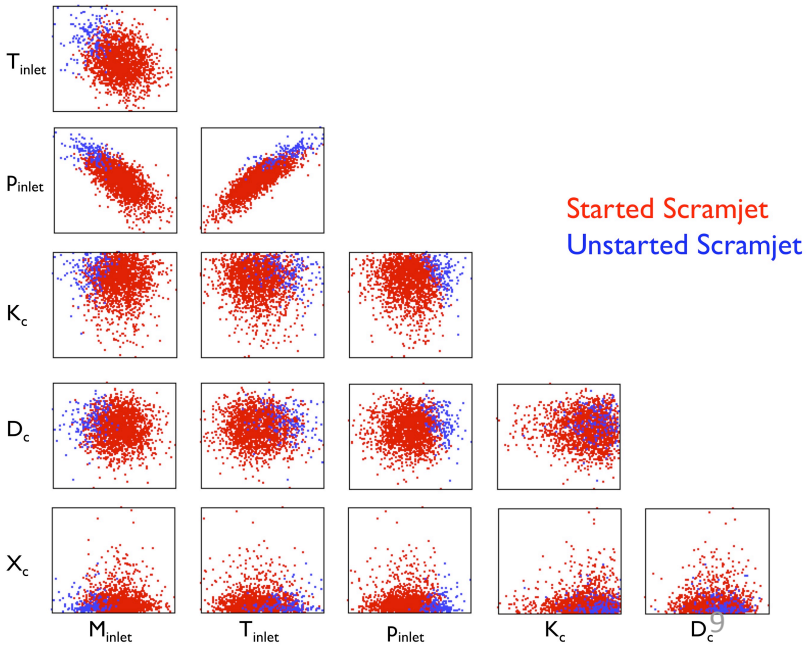
Computational Infrastructure

- Objective: Develop/verify/support the simulations tools used to perform RANS/LES and ROM computations
  - Task 1: provide comprehensive physical modeling capabilities
  - Task 2: establish verification suite and tutorials



Full System Simulation & Analysis

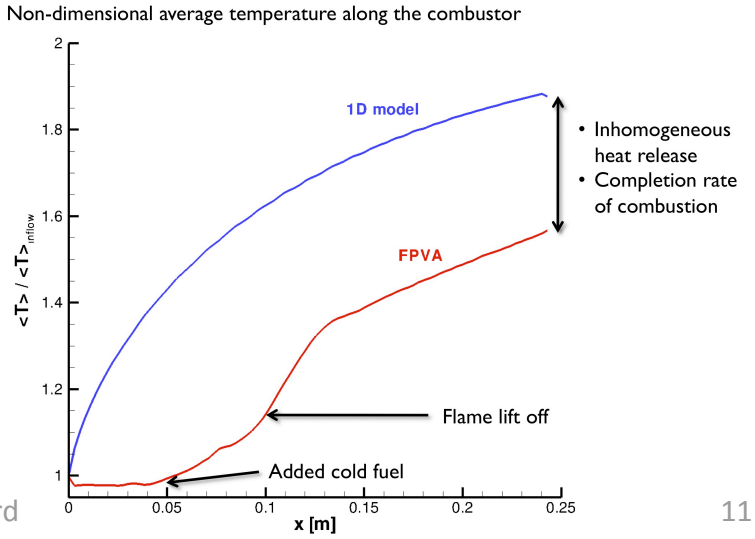
- Objective: Formulate the full-system ROM, identify all the input uncertainties, gather data from other teams, perform full system simulations and subsequent analysis.
  - Task 1: Perform ensemble simulations (UQ)
  - Task 2: Data analysis (QMU): identification of conditional probabilities & main/secondary effects.
- Questions: is there a reduced set of inputs (and input values) that determines unstart with high probability? What is the chain of events -*the physics*- that leads to unstart?



Physics Teams

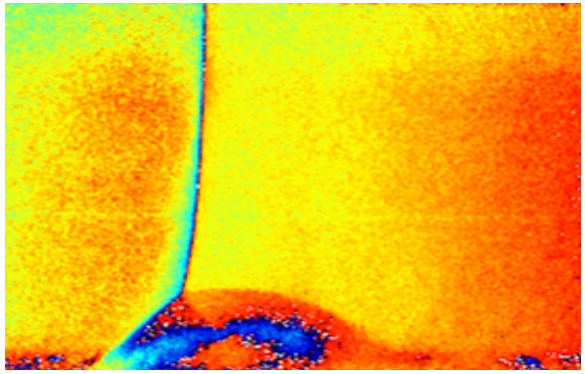
Heat Release Modeling

- Objective: Combustion/Mixing modeling - identification of the main factors controlling the mixing and combustion of the fuel.
  - Task 1: reveal the physics of ignition and heat release
  - Task 2: provide inputs for the Heat Release Model in the full-system ROM (characterize and possibly reduce the epistemic uncertainty)
- Questions: what are the controlling parameters? and how the heat is distributed in the engine? what is the effect of changes in the fuel flow rate on the heat release?
- Approach: Perform LES/RANS focused on DLR/UTRC ground test and Mungal/Gamba/Hanson experiment



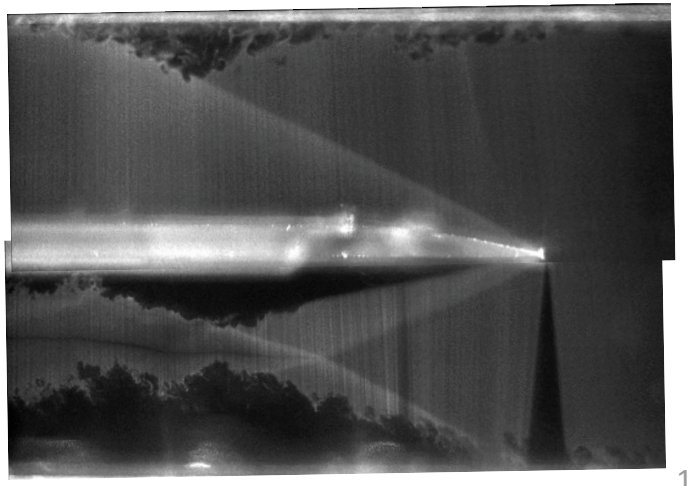
Shock Dynamics Modeling

- Objective: Shock/Turbulence interaction modeling - identification of the main factors controlling the shock dynamics in the chamber
  - Task 1: reveal the physics of thermal choking and unstart inception
  - Task 2: provide inputs for the turbulence modeling in the full-system ROM (characterize and possibly reduce the epistemic uncertainty)
- Questions: what affects the shock strength and the interaction with the boundary layers? what determines the speed of the shocks? is the flow massively separated?
- Approach: Perform LES/RANS focused on the experiments of Eaton, Clemens, Hanson and others



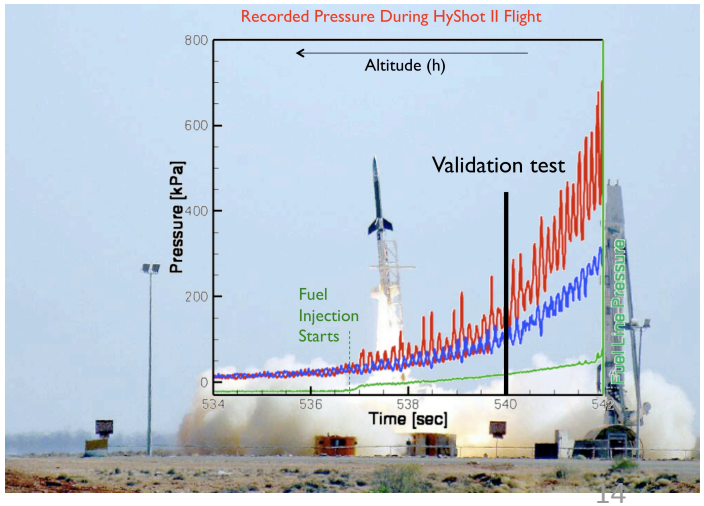
Fuel Injection Modeling

- Objective: Fuel injection modeling - identify the fuel flow conditions and related uncertainty in the HyShot flight
  - Task 1: identify the physics of mass-injection-driven unstart
  - Task 2: provide inputs to the full-system ROM (define the aleatory uncertainty)
- Questions: what is the sensitivity to the flow rate? is the flow chocked at high injection rate? Are injection flow-rate fluctuations important?
- Approach: Perform LES/RANS focused on the experiments of Cappelli



HyShot Flight Characterization

- Objective: Flight modeling - identify the conditions and related uncertainty in the HyShot flight
  - Task 1: characterize the vehicle flight conditions, provide inputs to the full-system ROM (define the aleatory uncertainty)
- Questions: is the flow unsteady? what is the uncertainty in the flight conditions? is the uncertainty constant over a range of conditions?
- Approach: perform Bayesian inversion from the measured flight data and also back-up the DLR conditions as a verification test

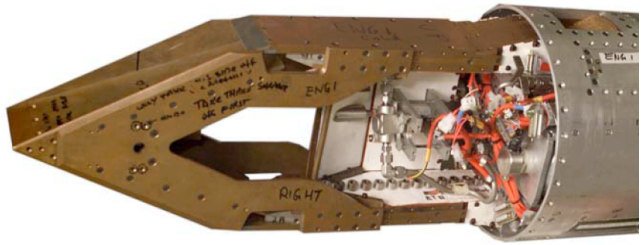


Thermal Management Modeling

- Objective: Heat transfer modeling - characterize the heat losses in the engine and identify the wall thermal conditions in the engine during flight.
  - Task 1: provide inputs/boundary conditions to the full-system ROM (define the aleatory uncertainty)
- Questions: is solid conduction and radiation important? Is the wall temperature constant?
- Approach: model radiation/conduction

  using RANS/MC methods, and validate

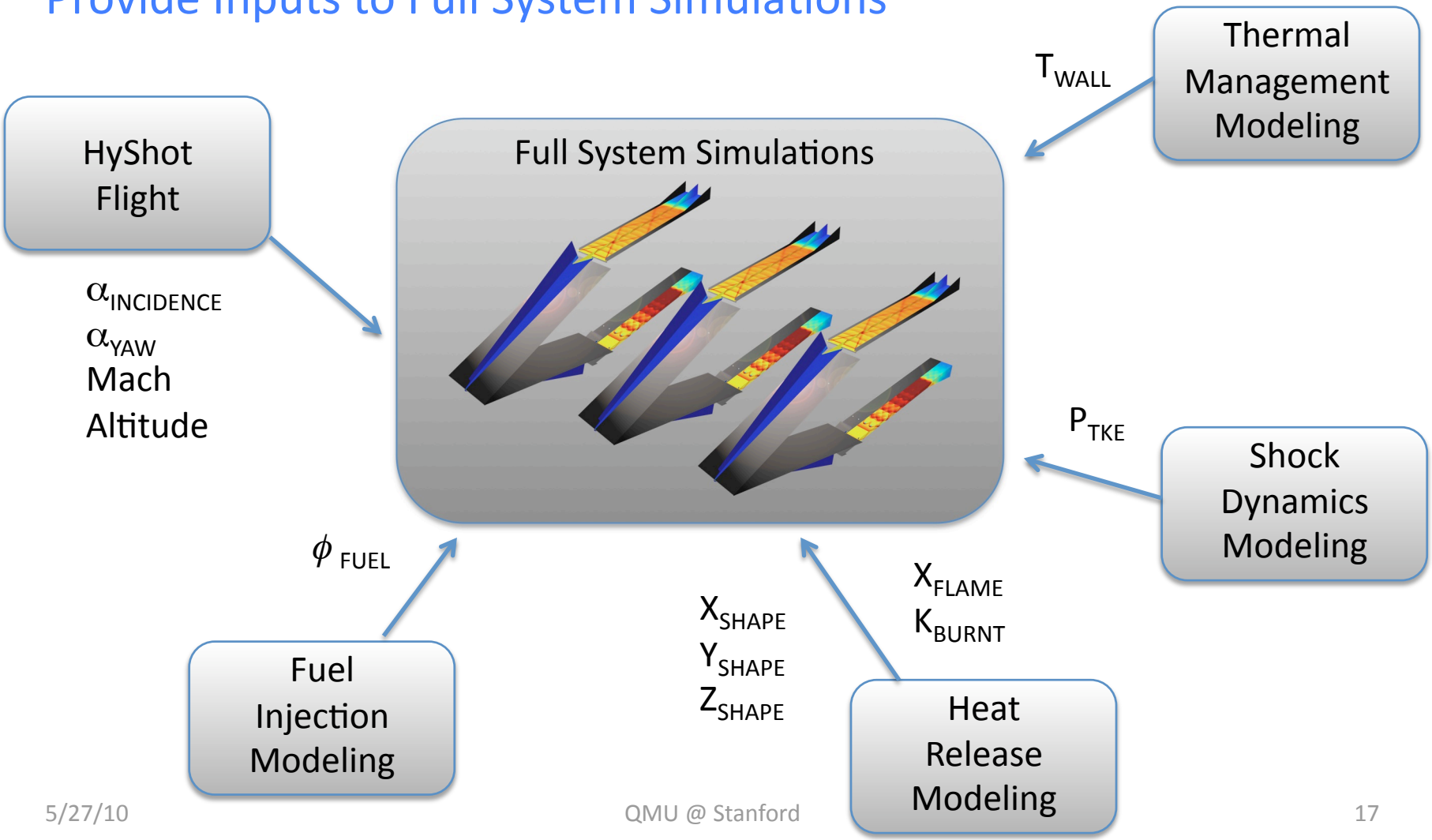
  against DLR experiment



QMU-driven Research

Team Interactions

Provide Inputs to Full System Simulations



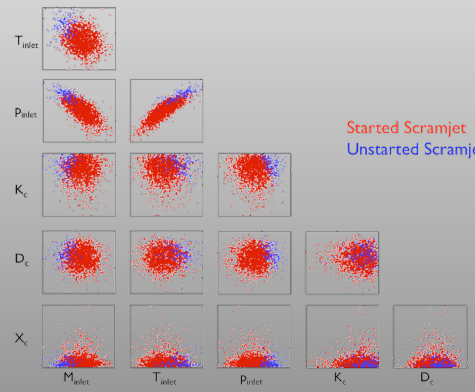
Team Interactions

Receive Data from Full System Analysis

HyShot Flight

α_{YAW} NOT Important

Full System Analysis



Thermal Management Modeling

P_{TKE} DOMINATES when Inflow Mach # is low

Shock Dynamics Modeling

Fuel Injection Modeling

Uncertainty in Y_{SHAPE} VERY IMPORTANT

Heat Release Modeling

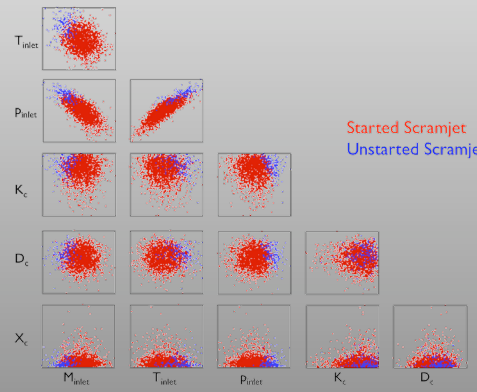
Team Interactions

Receive Data from Full System Analysis

HyShot Flight

α_{YAW} NOT Important

Full System Analysis



Thermal Management Modeling

Interactions are critical and require coupled simulations

Shock Dynamics Modeling

Heat Release Modeling

Fuel Injection Modeling

State of Affairs

- Full System Simulations
  - 2D, (U)Euler, 1D Heat Release
  - 6 inputs: 3 flight conditions, 3 heat release parameters
  - Ensemble of 3,000 simulations
- Full System Analysis
  - Ongoing
  - Correlation maps produced
  - Estimate of probability of unstart

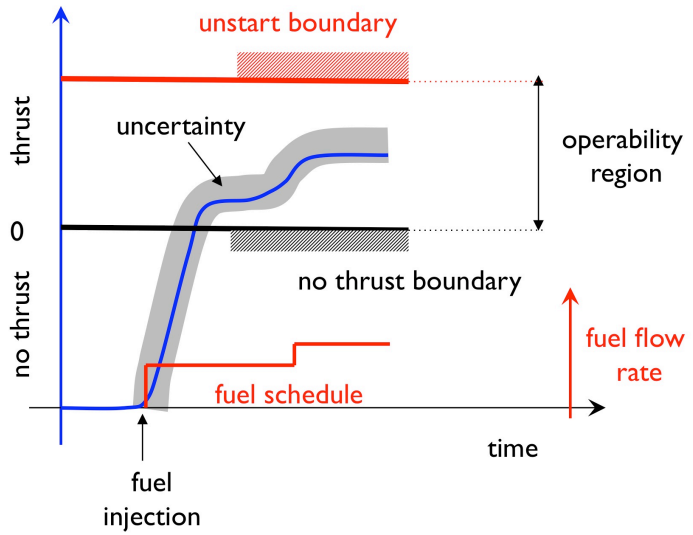
Next Steps

- Full System Simulations
  - 2D → 3D
  - (U)Euler → (U)RANS
  - 1D → 3D Heat Release
  - 6 inputs → 12 inputs
  - Ensemble size ?
- Need discussion & justification
  - In DoE terms : a process → QMU

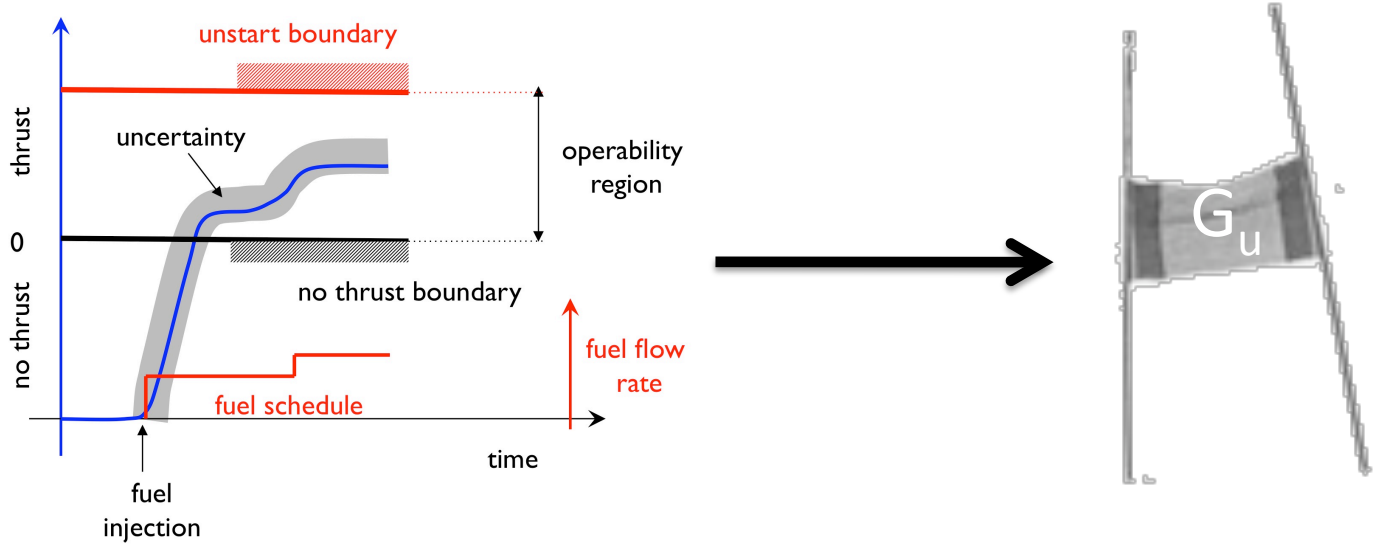
The need for QMU

- The probability of unstart is a "raw" number
  - It is impossible to validate
  - Assumes high confidence in the predictive capabilities of the computational tools and the input uncertainties
  - Provides no information about the physics of unstart
  - Provides no feedback to component analysis

The QMU process

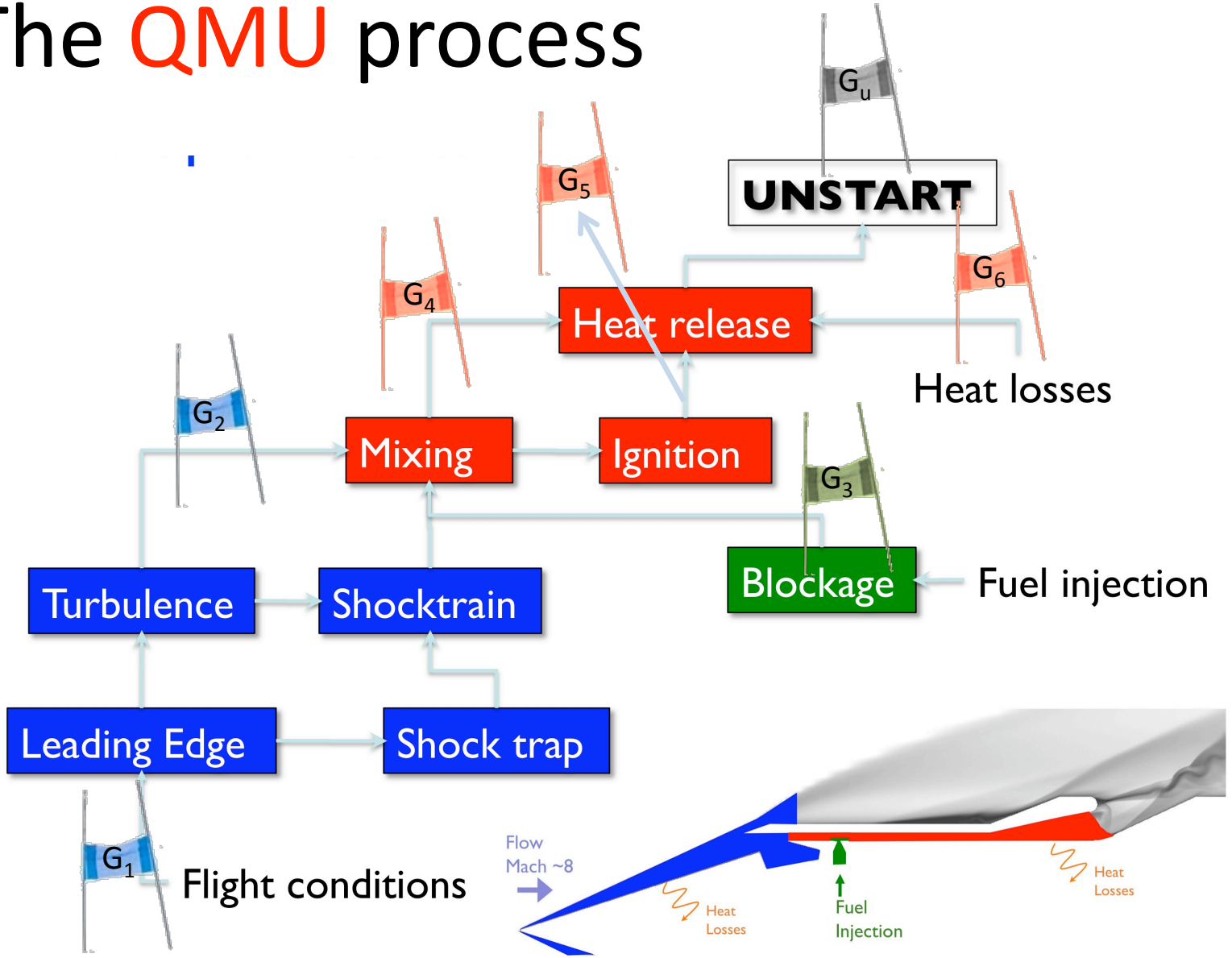


The QMU process



- We need a "fine-grain" process

The QMU process

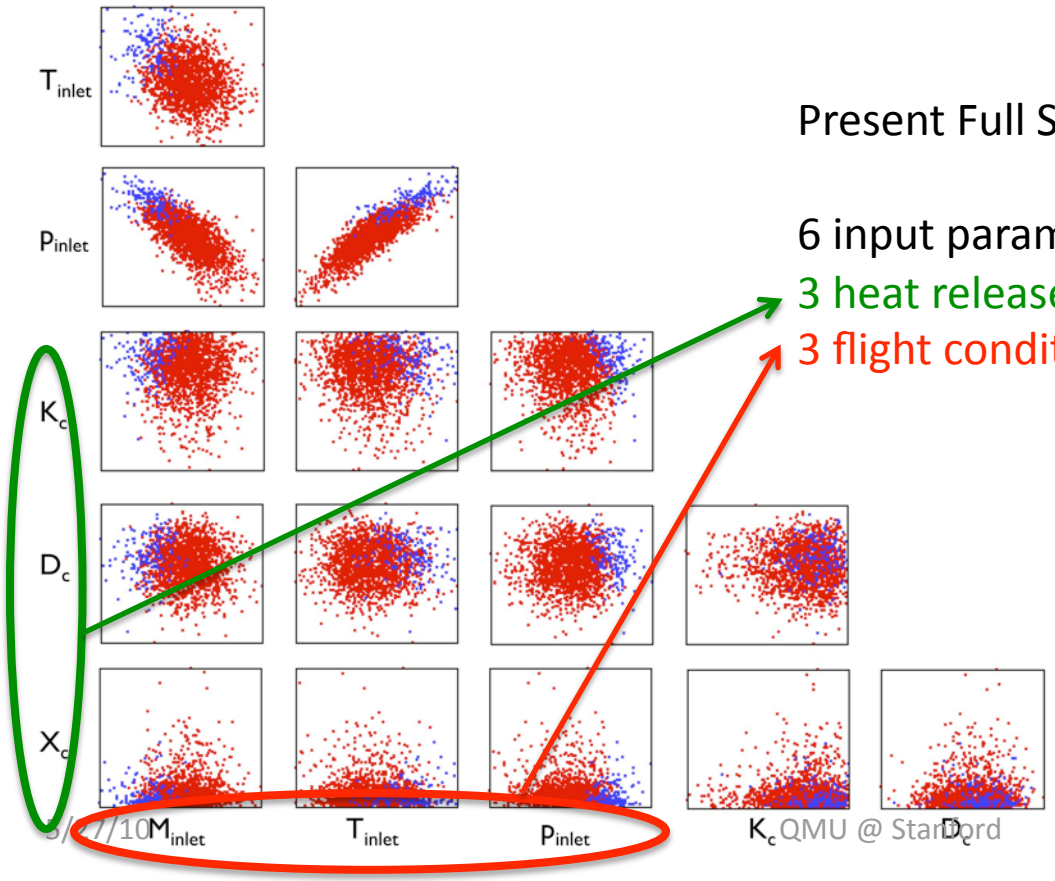


The QMU process

- Unstart scenario as a chain of events
  - Identify multiple output metrics
  - Assess the probability of unstart conditioned on the success (or lack of) in "upstream" metrics
    - G1: Nose – Stagnation Temperature
    - G2: Combustor Inlet – Centerline Properties & BL Thickness
    - G3: Fuel Injection – Jet momentum ratio
    - G4: Mixing – Mixedness
    - G5: Ignition – Ignition delay time
    - G6: Heat losses – Wall flux

The QMU process - Example

- G5: Ignition delay time



Present Full System Simulations

6 input parameters
3 heat release calibration parameters
3 flight conditions

3000 realizations

The QMU process - Example

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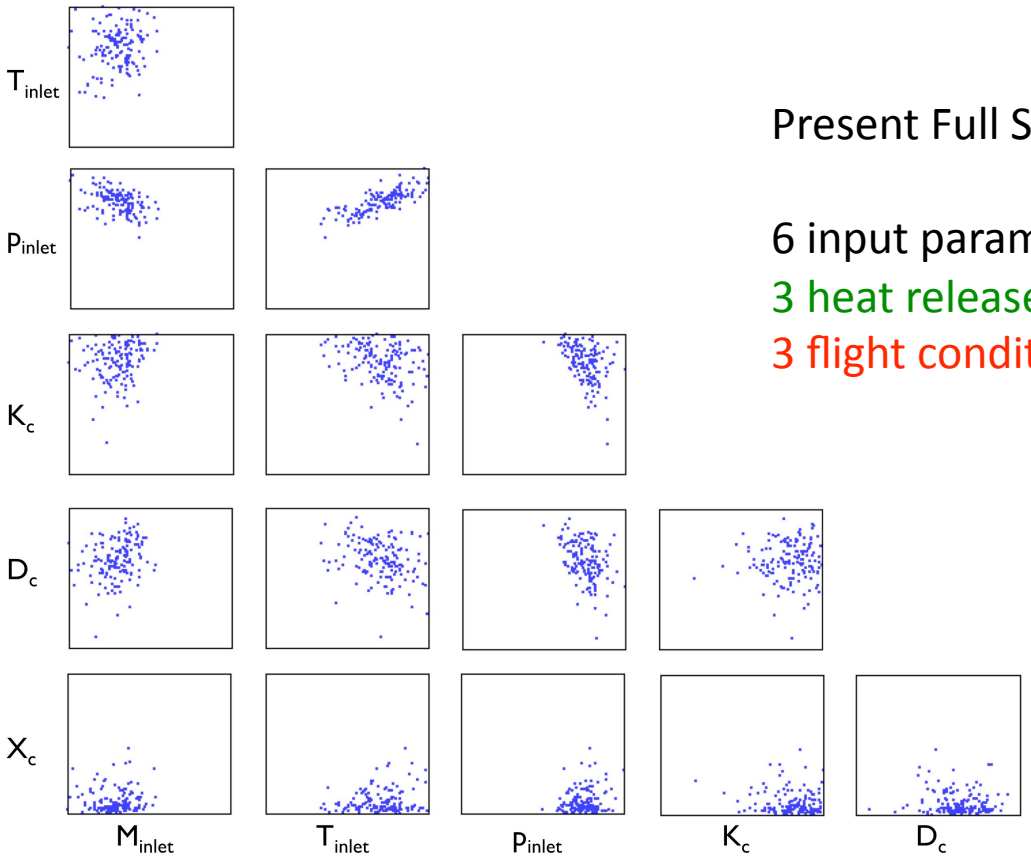

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The QMU process - Example

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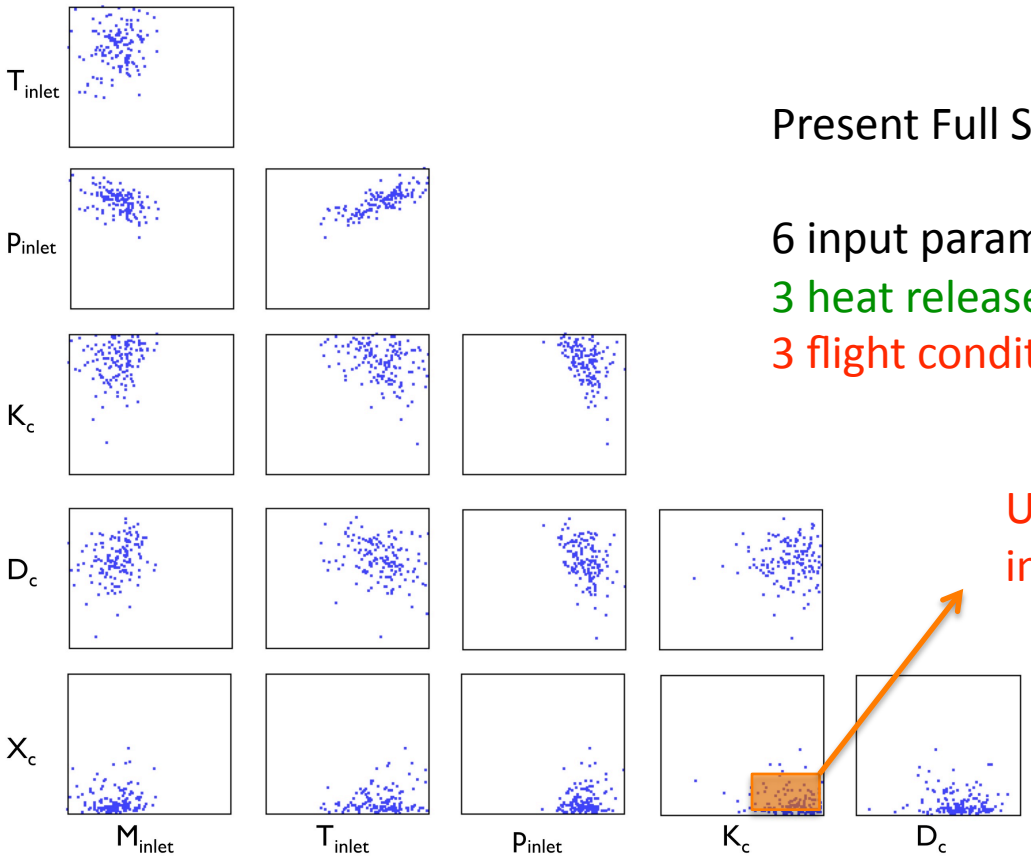

Present Full System Simulations

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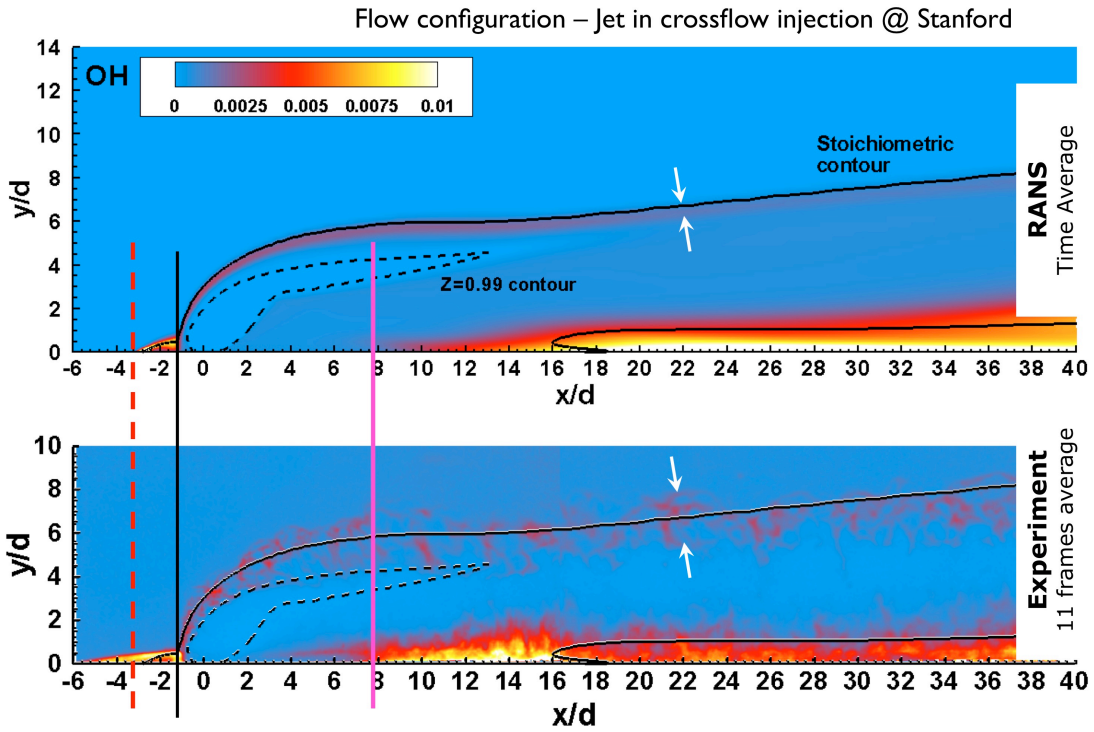
3 flight conditions

Unstart is highly correlated to intense burning close to the injector

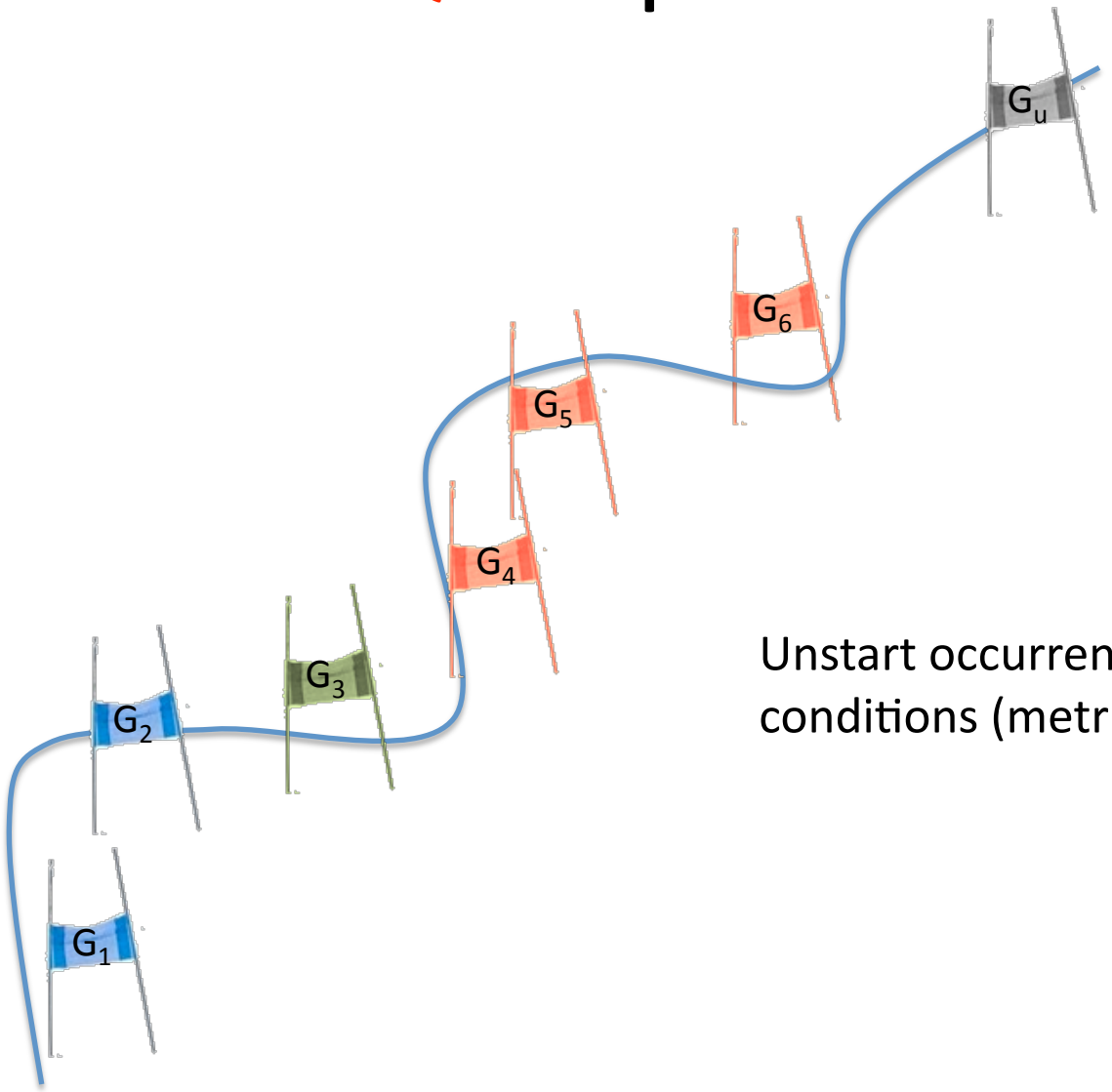
The QMU process - Example

- G5: Ignition delay time
  - Unstart is highly correlated to intense burning close to the injector
  - Current full-system simulations (ROM) are based on a heat-release model that does not capture the ignition delay
  - Need to improve the ROM through experiments and high-fidelity simulations

QMU "drives"

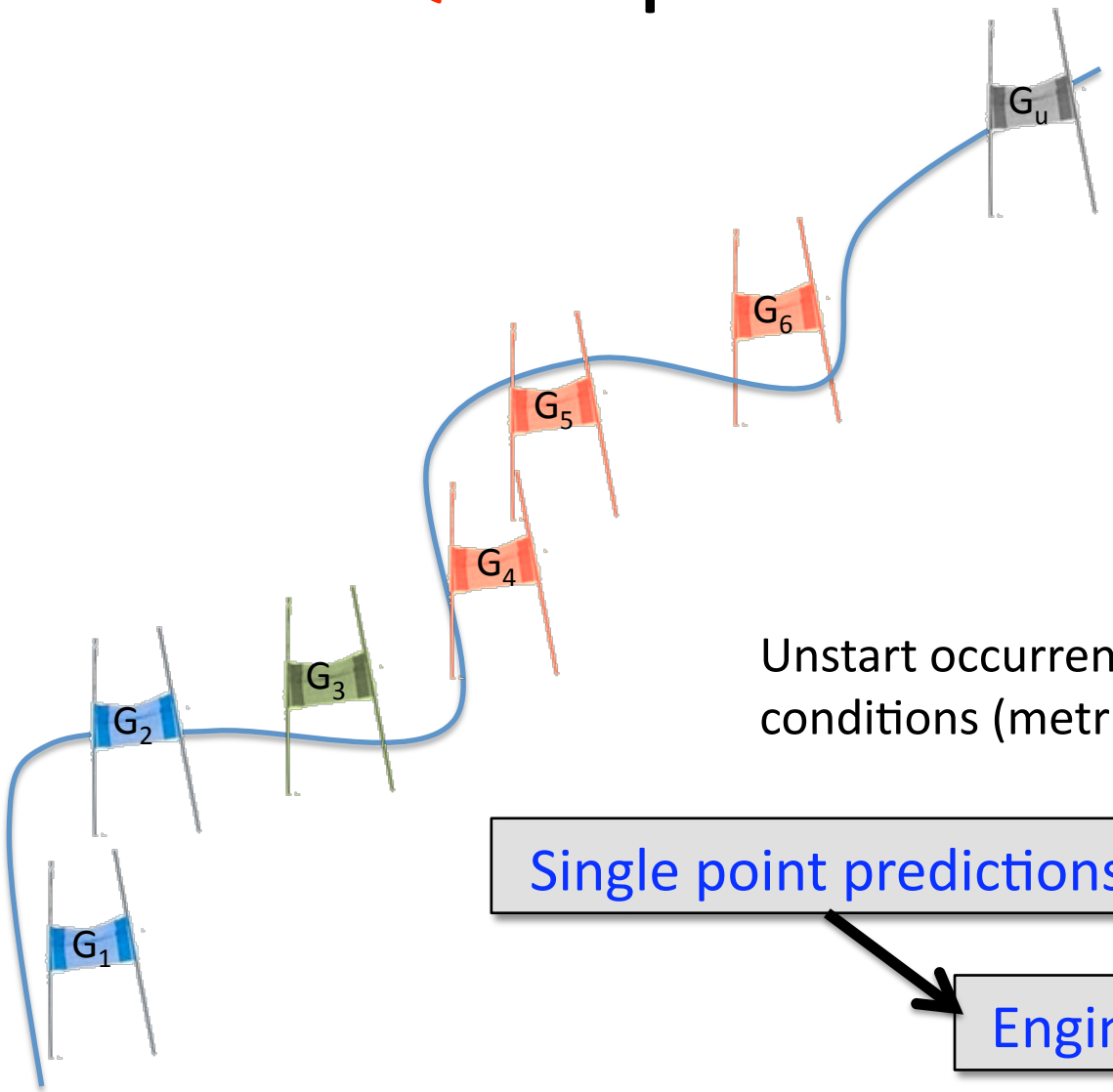


The QMU process



Unstart occurrence directly related to the conditions (metrics) in prior events

The QMU process



Unstart occurrence directly related to the conditions (metrics) in prior events

Single point predictions

Engineering safety factors

Action Items

- Technical Leads
  - Full System QMU (Iaccarino)
  - Computational Infrastructure (Ham)
  - Heat Release Modeling (Terrapon)
  - Shock dynamics Modeling (Sanjiva)
  - Fuel Injection Modeling (Cappelli)
  - Flight Characterization (Alonso)
  - Thermal Management (Boyd)
- Short Term (now to AST2010) – Each Group
  - Assessment of capabilities & progress
  - 5months Objectives and Plan
  - Presentation at the Friday's Meeting
- Longe(er) Term - Center
  - Identification of roadblocks
  - Restructure groups or efforts if necessary

Additional Questions

- General Questions
  - Geometry of the HyShot and DLR model; are there uncertainties remaining?
  - Time dependency in the flight trajectory (nutation etc.); is that comparable with the unstart time dynamics? How closely do we need to match the flight?
  - Is the air in equilibrium (DLR is vitiated?)?
  - What is the uncertainty in the experimental data both in JIC, flight and DLR (repeatability + errors)
  - Is the "mean" pressure the correct measure of unstart?
  - Others?