Use of Alternate Fuels for Aviation: - Concerns of GT Industry

Med Colket
United Technologies Research Center

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Outline

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Primary interests in alternate fuels

Motivation for AF Combustion Rules and Tools program

Other potential benefits

Status of R&T program

Future opportunities for collaboration with universities

OEM's Interests In Alternative Fuels & Reducing Emissions in Aviation

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- Design fuel-efficient engines
  - Example: P&W's PurePower™ engine family reduces fuel burn by more than 12% and dramatically cuts emissions
  - Will new fuels impact new engine designs?

- Validate alternative fuels
  - Support customer initiatives
    - Airlines
    - DoD
  - Evaluate impact on the engine
  - Provide a timely and cost-effective path for approval and field use
  - Lower particulate emissions

New Engines Have Historically Been Certified To Existing Fuel

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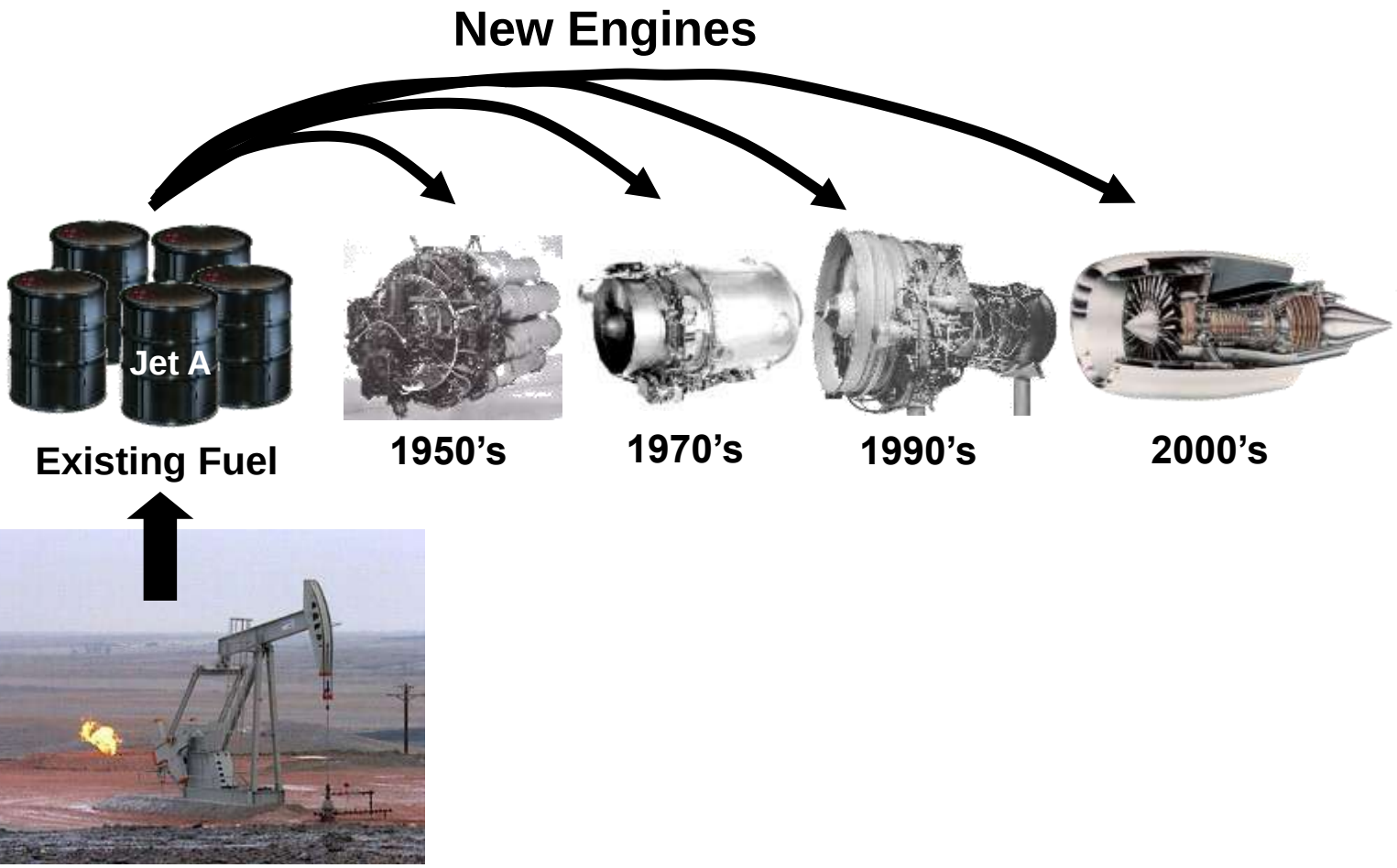

How Work Backwards to Prove a New Fuel Is Acceptable for Existing Fleet of Engines?

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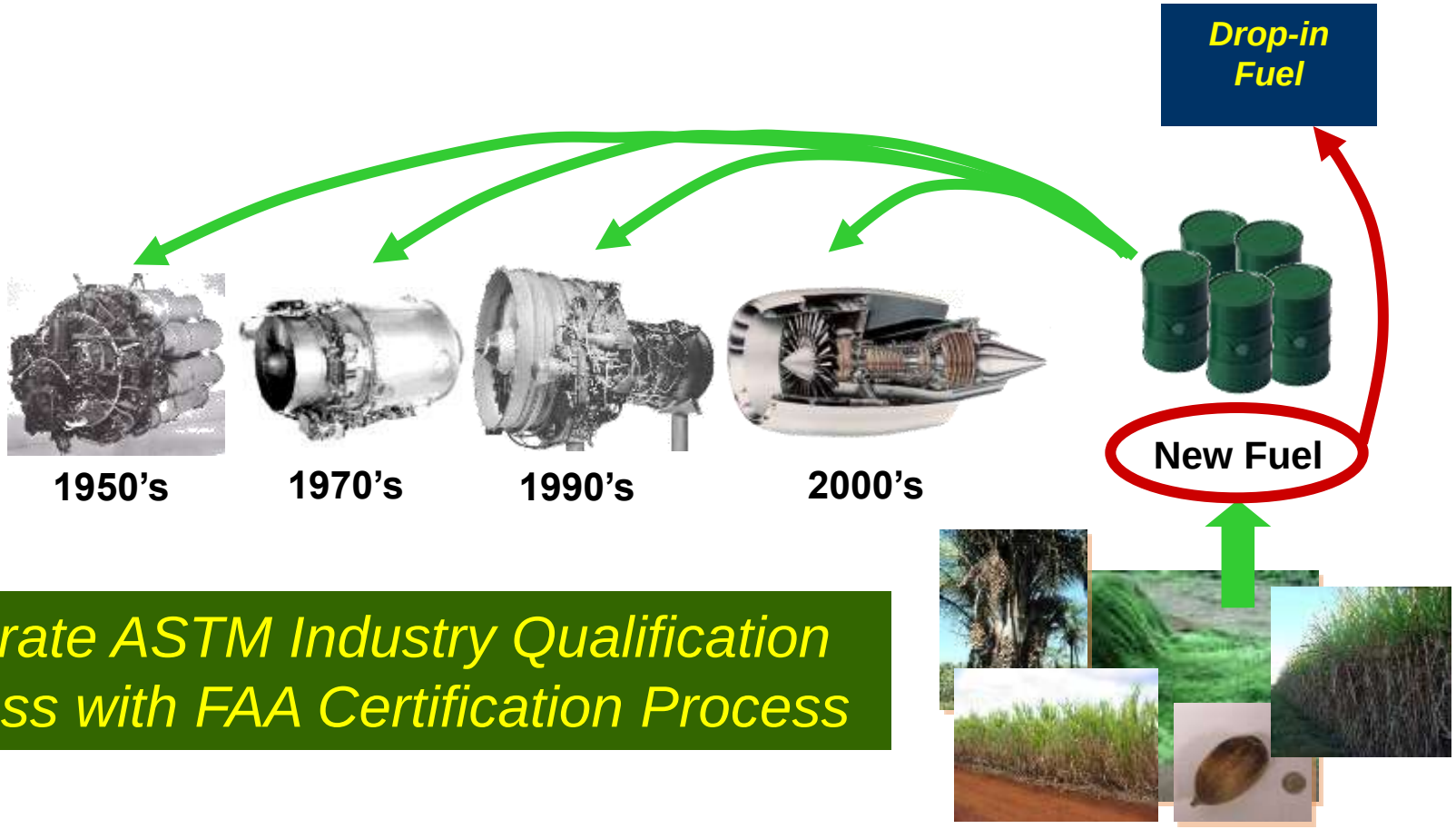

Integrate ASTM Industry Qualification Process with FAA Certification Process

Fuel must be acceptable for other ground-based operations

Engine Manufacturers' Requirements

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- High Energy Content

- Drop In-technology Invisible to the Engine
  - Requires no redesign, component development program, or re-certification

- Does No Harm

Basically, It's All Jet A

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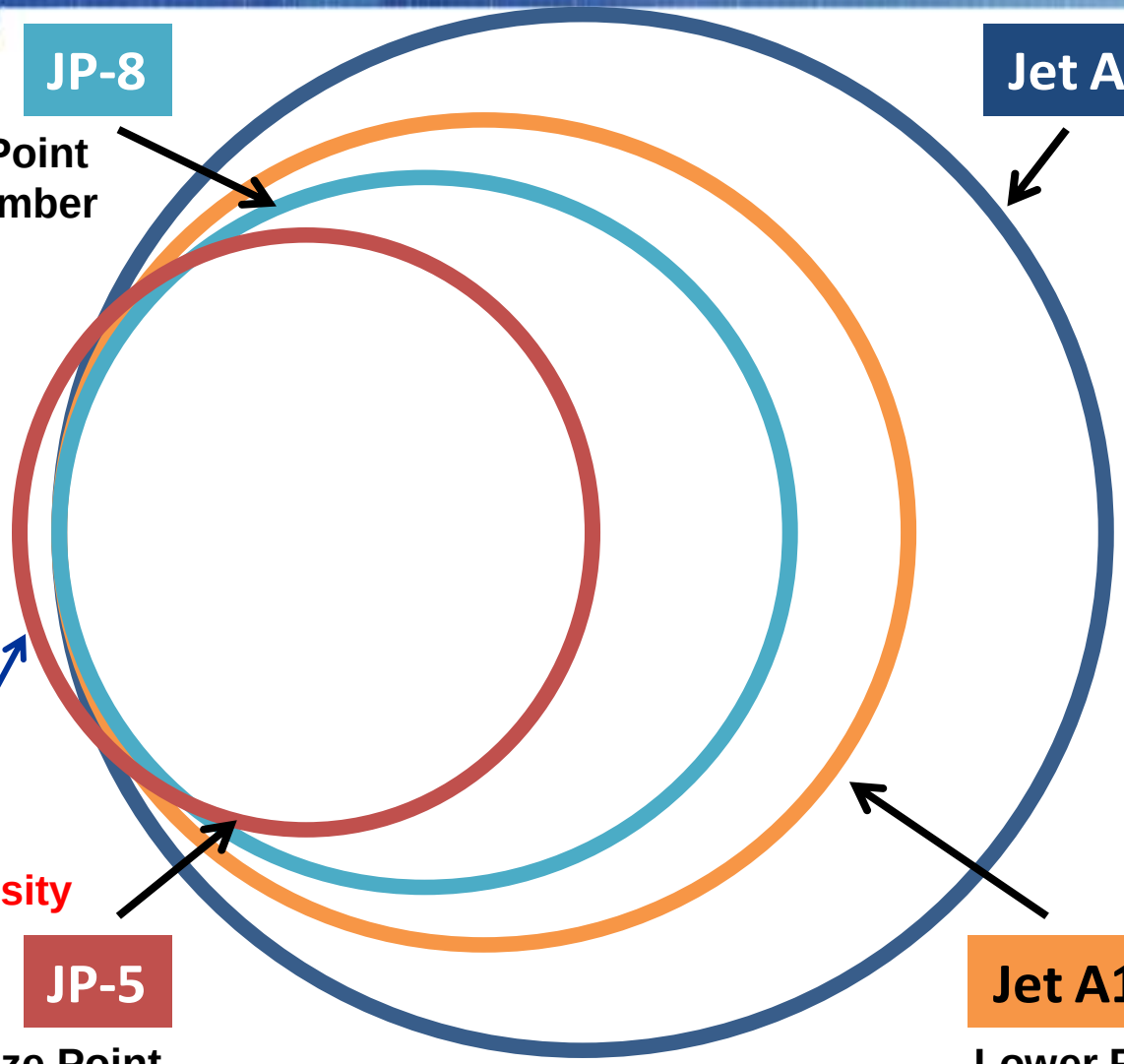

ASTM D7566 Structure

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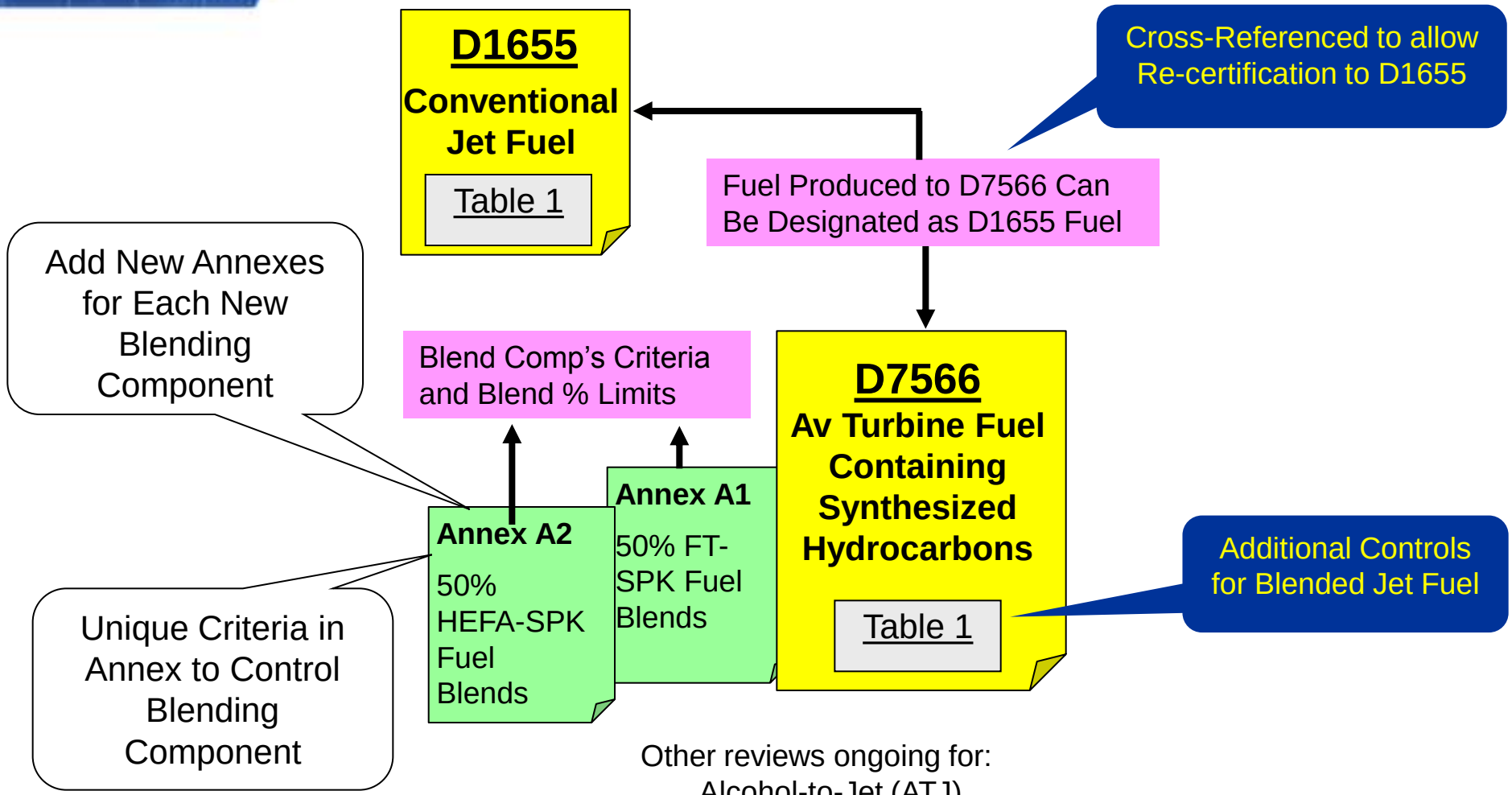

Other reviews ongoing for:

- Alcohol-to-Jet (ATJ)
- Hydro-treated Depolymerized Cellulosic Jet (HDCJ)
- Catalytic Hydrothermal Process (CH)
- Direct Sugar to Hydrocarbons (DSHC)

Test Program Comprised of Four-Tier Gated Process

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TIER 1

Specification Properties

TIER 2

Fit-For-Purpose Properties

TIER 3

Component/Rig/APU Testing

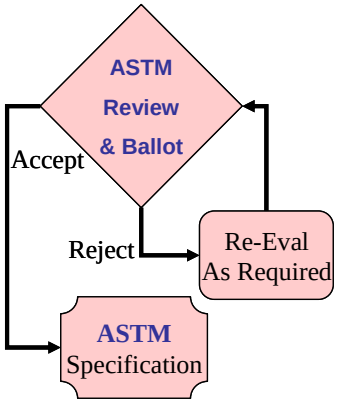
TIER 4

Engine Testing

ASTM Research Report

OEM/FAA Review & Approval

ASTM Balloting Process



ASTM Specification

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Tier 1
Fuel Specification Properties
Relating to Engine Safety, Performance and Durability
(ASTM D 1655/ Def Stan 91-91, Mil-DTL-83133, Mil-DTL-5624)

Component Test Required?

No

No Effect/Positive Effect

Yes

Tier 2
Fit-for-Purpose Properties

CHEMISTRY
- Hydrocarbon Chemistry (carbon number, type and distribution)
- Trace Materials

BULK PHYSICAL AND PERFORMANCE PROPERTIES
- Boiling Point Distribution
- True Vapor Pressure vs. Temperature
- Thermal Stability Breakpoint
- Lubricity
- Response to Lubricity Improver
- Viscosity vs. Temperature
- Specific Heat vs. Temperature
- Density vs. Temperature
- Surface Tension vs. Temperature
- Bulk Modulus vs. Temperature
- Thermal Conductivity vs. Temp.
- Water Solubility vs. Temperature
- Air Solubility (oxygen/nitrogen)

ELECTRICAL PROPERTIES
- Dielectric Constant vs. Density
- Electrical Conductivity and Response to Static Dissipator

GROUND HANDLING / SAFETY
- Effect on Clay Filtration
- Filtration (coalescers & monitors)
- Storage Stability
  - Peroxides
  - Potential Gum
- Toxicity
- Flammability Limits
- Autoignition Temperature
- Hot Surface Ignition Temperature

COMPATIBILITY
- With Other Approved Additives and Fuels
- With Engine and Airframe Seals, Coatings and Metallics

Tier 3
Component Tests *

TURBINE HOT SECTION
Oxidative or Corrosive Attack On Turbine Blade Metallurgy and Coatings
(Burner Rig Test)

FUEL SYSTEM
- APU Cold Filter
- Fuel Control
- Fuel Pump
- Fuel Nozzle

COMBUSTOR RIG TESTS
- Cold starting, sea level to 10,000 feet
- Lean Blowout
- Aerial Restarting
- Turbine inlet-temperature distribution
- Combustor Efficiency
- Flow path carboning/plating
- Emissions
- Auxiliary Power Unit altitude starting

Anomolies

Negative Effect

No Anomalies

Engine Test Required?

Yes

No

Tier 4
Engine Endurance Test *

Anomlies

No Effect

Unacceptable

Reject Fuel or Additive
File Report

OEM Approval
Incorporate into Fuel Specification with FAA Concensus

Tests Required for Each Tier are Well Defined

But each OEM needs confirmation!
For each new product
For each legacy engine

Typical Fuel Volumes Required

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TIER 1
Specification Properties

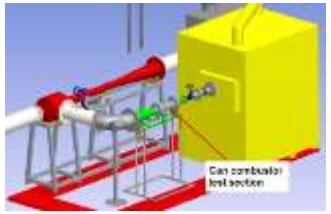
ASTM INTERNATIONAL Standards Worldwide

TIER 2

Fit-for-Purpose Properties

TIER 3

Component and Rig Tests



TIER 4

Engine Tests

Can rig tests be defined to increase confidence in engine tests?

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Failure in engine tests still possible - after producing and testing 225,000+ gal of fuel!

Hence AFRL Combustion Rules and Tools Program (for characterization of alternative fuels) – OEM/AFRL partnership to develop generic set of rig tests, acceptable to all OEMs.

Other Advantages

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- **Could broader specs widen pool of approved synthesized hydrocarbons (lower $$) without negative impact on engine performance?**
- **Could altered specs widen operational regimes of aircraft?**
- **Will future engine/combustor configurations impose new constraints on the new fuels**
  - **Or inhibit ability to employ advance technologies**
- **Can R&D program advance design approaches?**
  - **Empiricism => science based**

Status of Rules and Tools Program – GT OEMs w/AFRL

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- **Phase I – complete**
  - **2009-2010 – (AFRL-PR-WP-TR- 2010-2134)**
  - **Agreement amongst OEMs (GE, PW, RR/LW, Williams, Honeywell) to work jointly with AFRL**
  - **Report recommended creation of a set of generic test protocols and a plan to develop and execute the effort**
- **Phase IIA – Initiated, but terminating**
  - **2012-2013**
  - **One rig designed, analyzed and fabricated**
  - **Test procedures and diagnostics identified**
  - **Fuels selected; several acquired**
  - **Spray data collected (Purdue)**
  - **Model approaches identified**
  - **AFRL expecting to proceed with testing**

Rig Design

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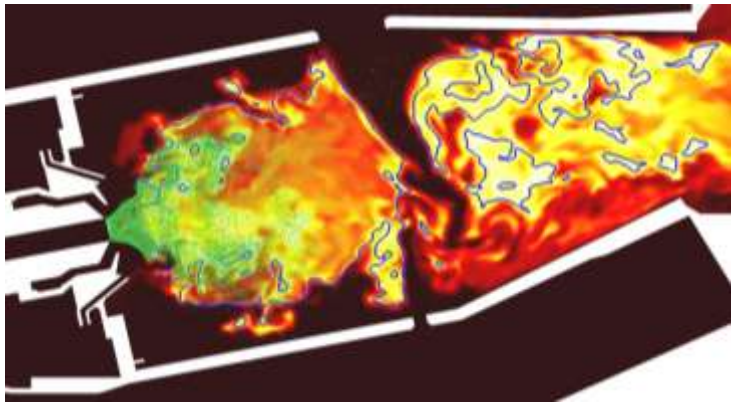
- **Four cup swirl stabilized rig – designed and fabricated**
- **Representative of fielded hardware**
- **Designed with an objective to be sensitive to fuel variations**
- **Alternate fuel nozzles/swirlers**
- **Heavily instrumented**



Example of Combustor Design
With droplets (green) and
temperature (red/yellow)
Courtesy of PW and Mike Mueller

Fuels

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Fuels selected to explore both physical and chemical effects

Three categories identified

- **A: Three standard (approved) petroleum-based fuels, one average, one each at extremes**
- **B: Two synthetic fuels: one approved, one not**
- **C: Five other synthetic fuels to explore other characteristics. Each meets specifications but has unusual physical or chemical characteristics**

Category A and B fuels identified and procured

Category C fuels specified

Spray

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Atomization/spray rig developed at Purdue – sub to super atmospheric conditions

Capability for testing a range of fuel nozzles with or without swirlers

Multiple diagnostics

- **Laser diffraction (drop size)**
- **PDPA (drop size and velocity)**
- **Optical patternator (mass distribution)**

Five fuels tested (Category A fuels, JP-10 with high viscosity, and a light calibrating fluid)

Modeling

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Preparation for CFD simulations

- **Grid constructed**
- **Methods for incorporating fuel-dependent spray (IC) developed**
- **Common CFD approach identified**
- **Fuel kinetics and surrogates identified**

Review/construction of Phenomenological Models

- **LBO**
- **Altitude relight**
- **Durability/radiation**

Opportunities for Collaborations

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Use University developed expertise and facilities:

Laboratory characterization of combustion 'properties' for each of the fuels

- **Flame speed, ignition delay, product distribution, flame extinction**

CFD simulations of rig using advanced modeling capabilities

But resources and timing TBD

Summary

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Industry maintains strong interest in alternative fuels

- **Primary concern is – do no harm**
- **Opportunities**
  - Lower emissions
  - Increased knowledge

AF Rules & Tools program (Phase 2A) initiated

- **But stalled**
- **Possible opportunities in future for collaboration**