



Laser Induced Incandescence for Jet Engine Exhaust Particle Measurement and Engine Health Monitoring

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Cambridge Particle Meeting, 22nd May 2006

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Current Smoke Measurement Methods

- Certification procedures defined by International Civil Aviation Organisation (ICAO)
 - LTO cycle, measurement methods, data handling, etc
- Measurement methods recommended by SAE E-31 committee
 - OEMs, academics, regulators, consultants, etc
- Current smoke measurement method SAE filter paper
 - Dimensionless 'Smoke Number' related to plume visibility



Optical smoke meters also in use





Typical Flow in Large Modern Civil Engine













Limitations of Current Methods

- Challenge of representative sampling
 - Plume asymmetry and isokinetic flow conditions
- Intrusive
- Expensive hardware and test duration
 - Long sampling times
- Labour intensive
 - Off-line measurement of filter paper reflectance
- Water cooled probes required
- Poor resolution at low SNs from modern engines
- Large uncertainty: +/-3 SN





LII for Jet Engine Particle Measurement

- Method development since ~1996 on collaborative EU funded programmes
 - AEROJET I 1996
 - AEROJET II 1998
 - AEROTEST 2004 2007
 - Academic and industrial partners from: UK, Germany, France, Netherlands, Sweden, Greece
- Objective:
 - "Standardise and calibrate LII to the level required by ICAO for use as a non-intrusive method of engine emissions certification. Develop and validate LII as a method for gas turbine engine health monitoring"





LII Fundamentals

- Particles rapidly heated to incandescence temperature by laser pulse
- Resulting LII images captured on CCD camera
 - Signal proportional to soot volume fraction
- Particle size can be deduced from time decay of LII image intensity
- High laser fluence can lead to particle sublimation
- Calibration procedure requires knowledge of initial soot temperature, laser energy and soot optical properties to convert LII measurements to an absolute scale





Method of Implementation







LII Equipment







Sample Results

Experimental





0

1

0

1

0

1

z (mm)

z (mm)

-5

-5

-5

-1 4 mJ

-1 8 mJ

0

0

y (mm)

0

y (mm)

0

y (mm)

5

5

5

5



Rolls-Royce data-strictly private



-1

0

0

-1

0

-1

-1 8 m

-1

0

-1

4 m.

0

x (mm)

0

x (mm)

0

x (mm)

1

1

1

-1

z (mm)

z (mm)

z (mm)

z (mm)

Comparison of LII and SAE Smoke Number



Combustor Inlet Temperature

AEROTES



Engine Health Monitoring

- Unique images observed under some operating conditions
 - Transients unburned fuel 'spikes'



Oil seeded flow – simulated oil leak







Technical Challenges and Next Steps

- Finalise standard method for LII calibration to soot volume fraction
- Determination of soot mass emission rate
- LII signal from carbonaceous particles only how to account for particulate VOC?
- Equipment installation in production engine test bed at R-R Derby



