Twin Annular Premixing Swirler (TAPS) Combustor

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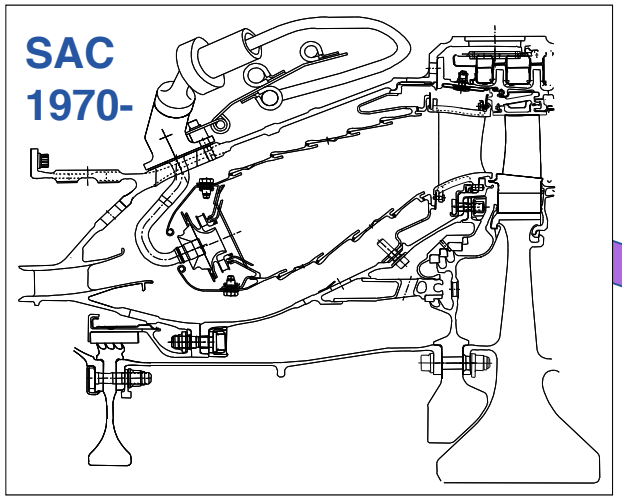
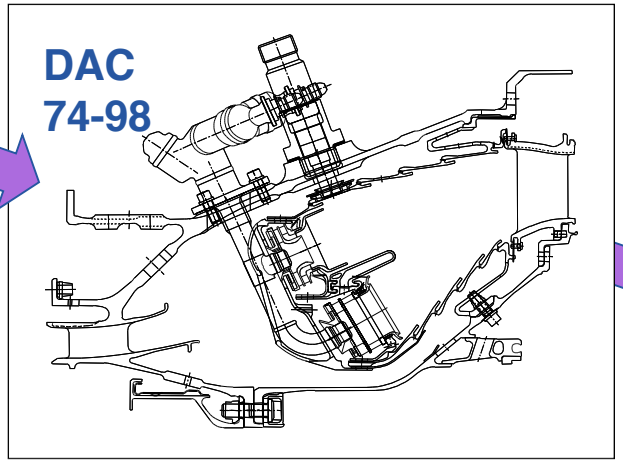
TAPS – Incentive to Reduce Emissions

- ICAO Emissions Standards focus on NOx reduction
  - -NOx stringency increased at CAEP/2 (20%), CAEP/4 (16%), and CAEP/6 (12%)
- Traffic Growth
  - -Even with CAEP/6 standard taking effect in 2008, worldwide airport NOx emissions are expected to double before 2020 (CAEP FESG)
- Local policies require limited emissions growth
- Current technologies can't offset traffic growth
  - -NOx progress with conventional rich-dome combustors has leveled off at ~60% of CAEP/2
  - -A combination of approaches will be needed, including a "NOx Technology Leap"

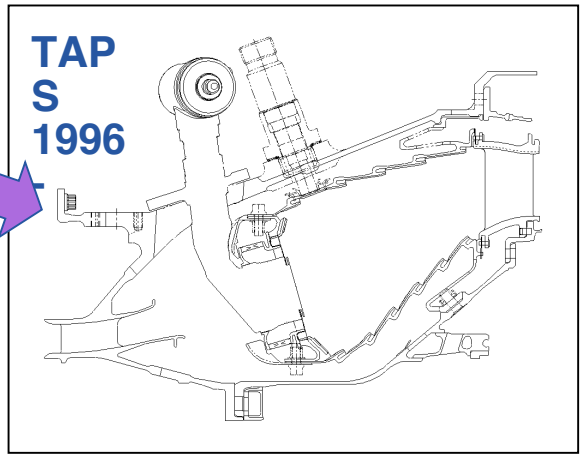
TAPS – Technology Evolution



- ***S**ingle **A**nnular **C**ombustor*
- *Rich burning*
- *Proven Performance*
- *Currently used by most operators*



- ***D**ouble **A**nnular **C**ombustor*
- *Radial Staging - lean at high power*
- *Design challenges:*
  -Low-power exit profile and emissions
  -Fuel burn & durability
  -Cost and weight relative to SAC



- ***T**win **A**nnular **P**remixing **S**wirler*
  - Premixing reduces NOx
  - Improved control of fuel spray reduces HC
- *Staging Within Swirler*
  - Uniform exit temperature profile at all operating conditions

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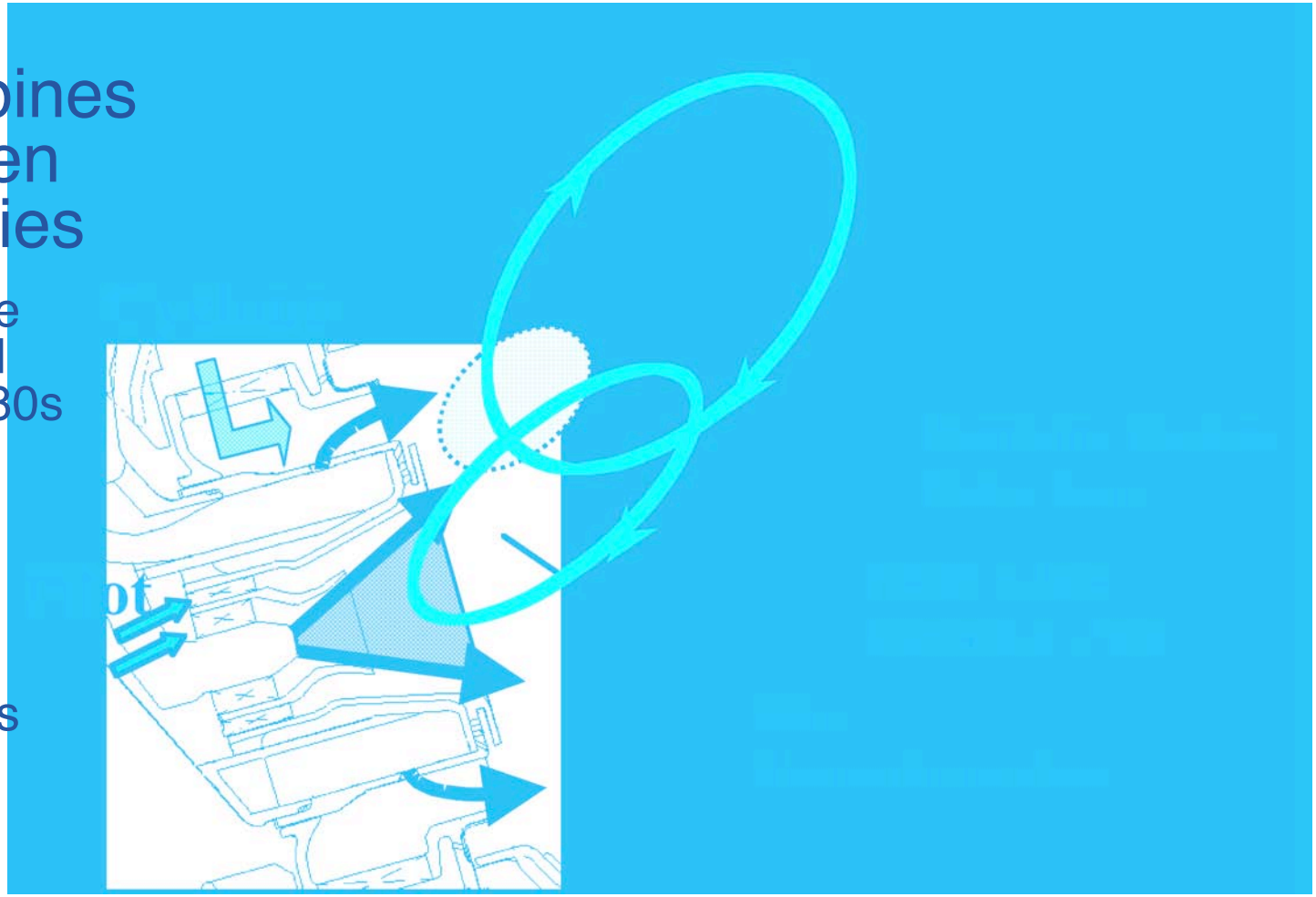
TAPS – Aero Functionality

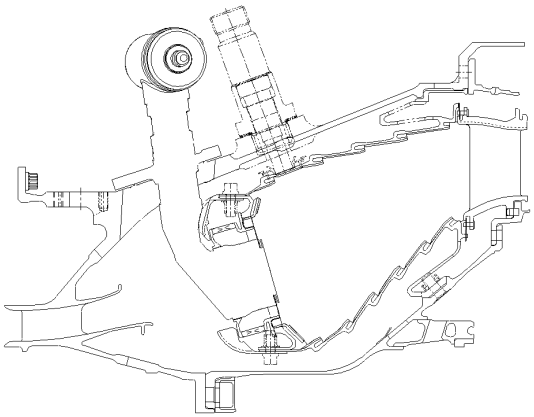
TAPS combines two proven technologies

- Premixing cyclone first developed and patented in the 1980s

- Conventional pilot configuration used in GE engines since 1970s



TAPS – CFM56 Test Hardware



TAPS combustor for demonstration in a CFM56-7B engine

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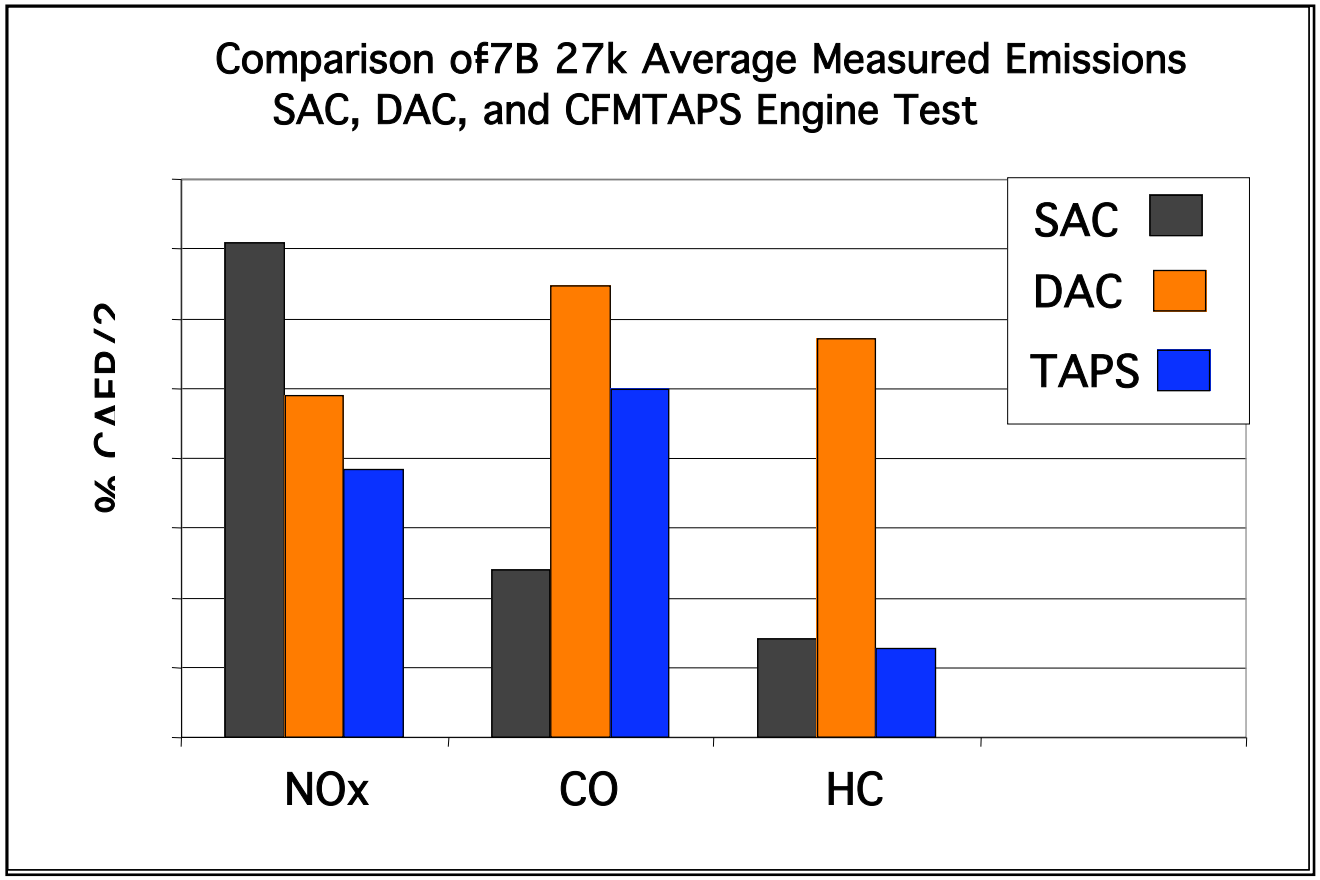
TAPS – Gaseous Emissions Reductions at the Airport

- Emissions measured in CFM56-7 engine tests (2001)
- Nearly 50% NOx reduction
- No increase in HC
- CO emissions meet current standards for higher pressure ratio engines



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TAPS – Other Emissions

- No measurable smoke in engine tests – solid particulate matter (PM) expected to be extremely low around airports
- High altitude NOx and PM (contributors to climate effects?) are expected to be significantly reduced

TAPS – Reliability

- Reliability of fuel staging controls and fuel nozzles has been proven over 35+ years
  - 1970's - CF6-6, -50, -80 hydraulic staging
  - 1980's - CFM56-5A FADEC staging for LBO
  - 1990's - GE90 and CFM56-5B DAC-I lean staged combustors
- 10 years lean staged combustor experience with CFM56 DAC II
  - Demonstrated acceptable lean staged combustor reliability
  - Demonstrated staged fuel injector durability

TAPS – Operability

- Control strategies are based on CFM56 DAC experience

•230 hours performance & operability testing on CFM56 TAPS engine combustion system (2001):

- Ground starts
- Max rate accelerations and decelerations
- Lean Blow-out margin
- Water & Hail Ingestion

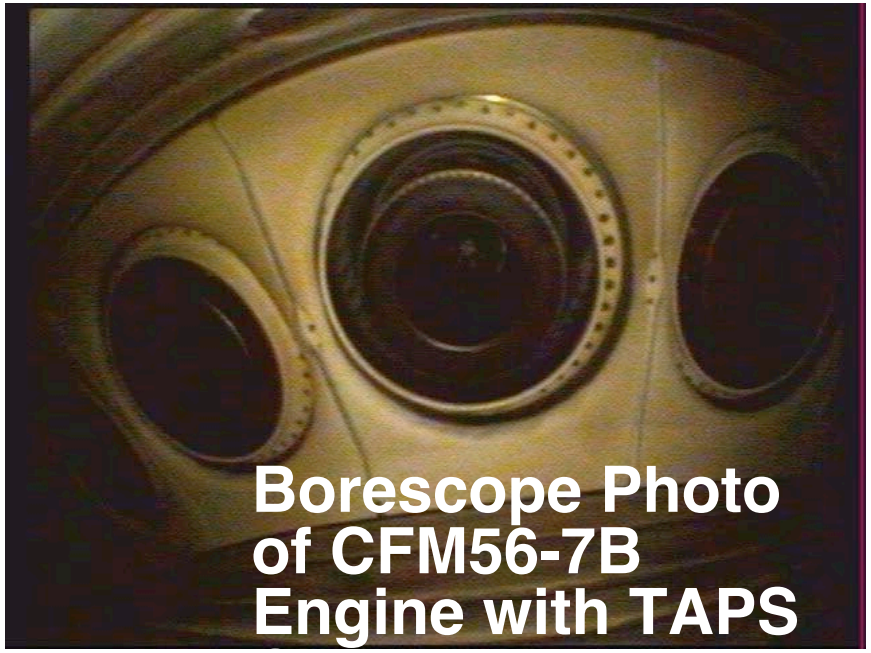
• Extensive annular rig test demonstrated full range of altitude start capability

TAPS – Durability Results (2002)

- CFM56 hardware condition excellent after 736 hrs of engine durability testing:
  - 3982 modified blade cycles
  - 2000 fuel nozzle purge cycles

- Lower & more uniform flame temperatures for reducing NOx emissions also improve combustor durability:
  - Reduced flame radiation
  - Reduced hot streaks

- Reduced TAPS temp. variation improves turbine durability



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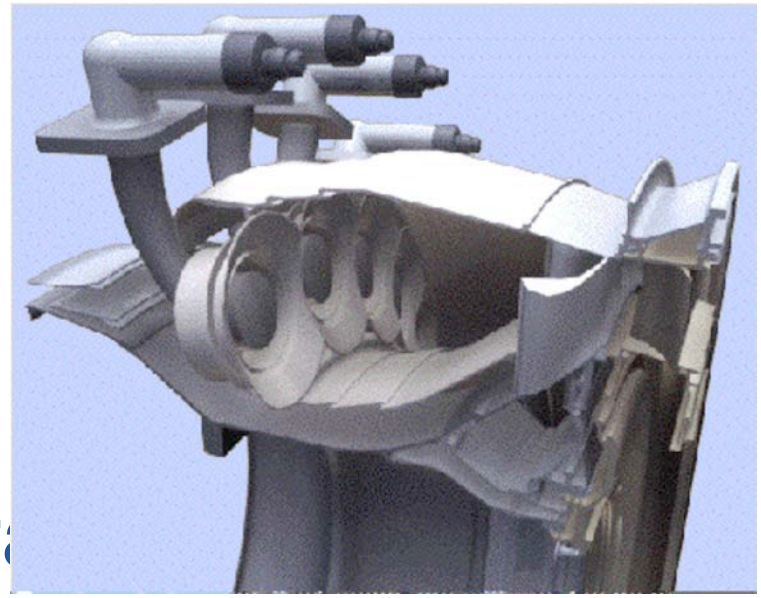
TAPS – Performance

- Combustion efficiency equivalent to SAC
- Pressure drop equivalent to SAC
- Combustor exit temperature profile similar to SAC at both high and low power

CFM56-7B Engine with TAPS Combustor in Performance Cell

TAPS – Transition to Product

- Initial planned application is the GEnx engine for Boeing 787 and Airbus A350 aircraft



  - Currently in final design phase
  - Certification in 2007

Application to next gener aircraft engines will follow

  - Timing depends on new engine programs

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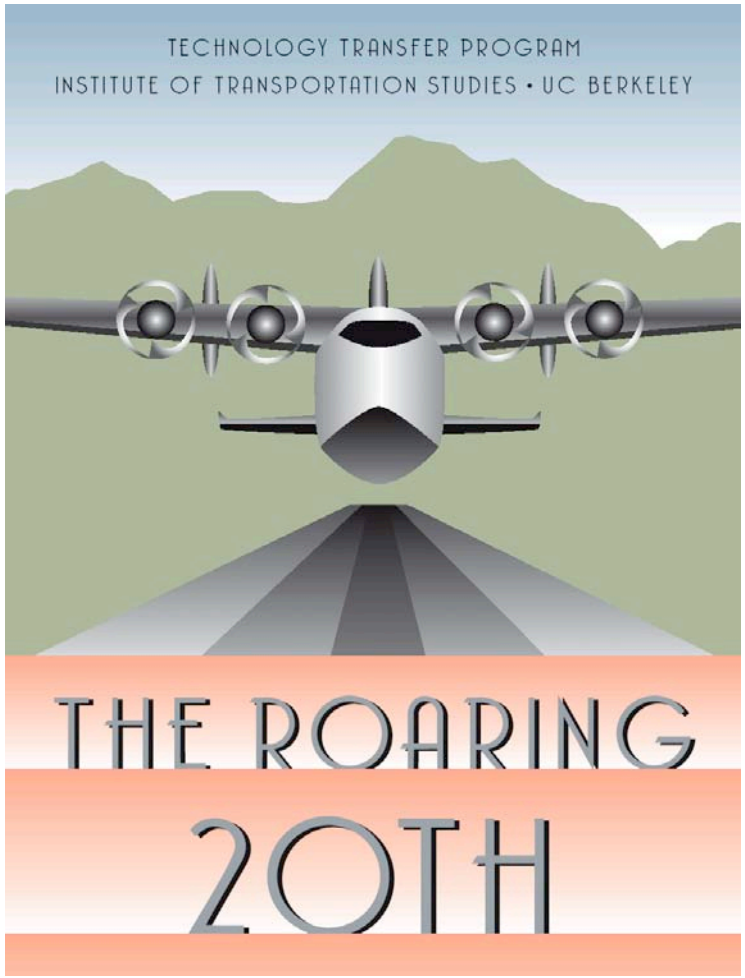
TAPS – Summary

- Mature technology base for product transition
  - Long term product engine experience with low emissions combustors
  - Ten years of TAPS-specific development (rig and engine test)
- TAPS will provide substantially reduced NOx and PM emissions at low altitude and cruise
- TAPS will enable improved durability with operability & performance equal to current conventional combustors
- TAPS technology will provide emissions reductions needed to comply with all foreseeable emissions rules and help enable expected growth of air travel
- TAPS will set the stage for the next phase of evolution in low emissions combustors

Thank You!



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