ULTRA-LOW EMISSIONS GAS TURBINE COMBUSTION SYSTEM PROGRAM

Progress Report

for Period July 1, 1993 - February 28, 1994

Mahesh Talwar

Santa Barbara County
Air Pollution Control District
Goleta, California 93117

February 1994

Prepared for

THE UNITED STATES DEPARTMENT OF ENERGY
AWARD NUMBER DE-FG02-93CE41026

MASTER

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

ABSTRACT

The Santa Barbara County Air Pollution Control District (SBCAPCD) has arranged a consortium to develop ultra-low emissions combustor technology applicable to gas turbines. The goal of the program is to develop and demonstrate a safe, efficient, and cost-effective method to meet a 9 ppmv NOx emission limit for gas turbines. Currently this emission limit can only be met with the selective catalytic reduction (SCR) technology (a post combustion cleanup process that is capital intensive and maintenance intensive).

In coordination with a comprehensive technical advisory committee, SBCAPCD has evaluated different potential low emissions technologies and decided upon a lean premix approach to retrofit existing turbines and to integrate with new engines. This technology will provide a low cost alternative to the expensive controls and will substantially reduce NOx emissions from gas turbines.

The design, fabrication and testing of the ultra-low NOx combustor system is currently being performed by Allison Gas Turbine Division, General Motors Corporation. This project continues to be overseen by a technical advisory committee to ensure timely and cost-effective product delivery.

Santa Barbara County
Air Pollution Control District

MEETING MINUTES

A project status meeting on the low emission turbine combustor development program was held on January 6, 1994 at the Santa Barbara County Air Pollution Control District offices at 26 Castilian Drive in Goleta, California. Participants were as follows:

Mahesh Talwar
Jeff Carmody
Al Ronyecz
Mohan Razdan
Hugh Davis
William Parks
Steve Waslo
Don Anson
Bob Garten
Tom Morjig
Robert Buettner
Jim Rohr
Lt. Ron Zawadzki
CMSgt Wayne Fowler
Nancy Wellhausen
Kevin Gerrity
Paul Bautista
Dave Hatfield

Santa Barbara County APCD
Santa Barbara County APCD
Santa Barbara County APCD
Allison Engine Company
Allison Engine Company
US Dept of Energy
US Dept of Energy
Battelle
Catalytica Inc.
Catalytica Inc.
Vandenberg Air Force Base
Vandenberg Air Force Base
Vandenberg Air Force Base
Vandenberg Air Force Base
EMC
Southern California Gas Co.
GRI
California Energy Commission

A summary of items discussed are as follows:

Discussion Item	Agency	Remarks
Technical and program presentation of 9ppm and 25ppm projects	AEC	Both 9ppm and 25ppm project design and testing are on schedule and within budget.
Catalytica Inc. catalytic controlled combustor concept	Catalytica, DOE, AEC	Catalytica presented conceptual design of catalytically controlled combustor for Allison 501KB turbines. No funding presently exists for design or field demonstration of hardware. AEC and DOE will meet at the end of January to discuss available sources of funding.
Feasibility of Vandenberg Air Force Base (VAFB) South Vandenberg Power Plant (SVPP) serving as a field demonstration site for the 25ppm and 9ppm combustor hardware.	SBAPCD, AEC, VAFB	District permit limits are presently set at 25ppm for NOx making this site potentially feasible for the 9ppm combustor. VAFB engineering staff will evaluate the economics and logistics before granting permission for the power plant to serve as a field demo site.
Feasibility of converting the VAFB SVPP into a cogeneration plant	VAFB, So Cal Gas, CEC	VAFB, So Cal Gas, and CEC will explore the possibility of converting the SVPP into a cogeneration plant with the waste heat being used to offset boiler generated heat or used in conjunction with a desalination plant. More continuous operation of the turbines could enhance the SVPP as a combustor field demo site.
Dispersed power generation combustor retrofit program	So Cal Gas, CEC	So Cal Gas indicated there is funding available to explore design and demonstration of low emitting combustors on small turbine units (30-250 kw). CEC indicated funding may be available through the CEC Energy Technology Advancement Program.
Formation of a technical advisory committee	SBAPCD	SBAPCD announcement of the formation of a TAC consisting of the following organizations: SBAPCD, DOE, CEC, EPRI, So Cal Gas, VAFB, Chevron, GRI, EPA, and CARB.
Schedule of next status meeting	SBAPCD	The next status meeting was scheduled for April 12, 1994 at the Indianapolis office of Allison Engine Company. Participants were requested to check calendars and contact Mahesh if conflicts exist.

A summary of items discussed are as follows:

Discussion Item	Agency	Remarks
Technical and program presentation of 9ppm and 25ppm projects	AEC	Both 9ppm and 25ppm project design and testing are on schedule and within budget.
Catalytica Inc. catalytic controlled combustor concept	Catalytica, DOE, AEC	Catalytica presented conceptual design of catalytically controlled combustor for Allison 501KB turbines. No funding presently exists for design or field demonstration of hardware. AEC and DOE will meet at the end of January to discuss available sources of funding.
Feasibility of Vandenberg Air Force Base (VAFB) South Vandenberg Power Plant (SVPP) serving as a field demonstration site for the 25ppm and 9ppm combustor hardware.	SBAPCD, AEC, VAFB	District permit limits are presently set at 25ppm for NO _x making this site potentially feasible for the 9ppm combustor. VAFB engineering staff will evaluate the economics and logistics before granting permission for the power plant to serve as a field demo site.
Feasibility of converting the VAFB SVPP into a cogeneration plant	VAFB, So Cal Gas, CEC	VAFB, So Cal Gas, and CEC will explore the possibility of converting the SVPP into a cogeneration plant with the waste heat being used to offset boiler generated heat or used in conjunction with a desalination plant. More continuous operation of the turbines could enhance the SVPP as a combustor field demo site.
Dispersed power generation combustor retrofit program	So Cal Gas, CEC	So Cal Gas indicated there is funding available to explore design and demonstration of low emitting combustors on small turbine units (30-250 kw). CEC indicated funding may be available through the CEC Energy Technology Advancement Program.
Formation of a technical advisory committee	SBAPCD	SBAPCD announcement of the formation of a TAC consisting of the following organizations: SBAPCD, DOE, CEC, EPRI, So Cal Gas, VAFB, Chevron, GRI, EPA, and CARB.
Schedule of next status meeting	SBAPCD	The next status meeting was scheduled for April 12, 1994 at the Indianapolis office of Allison Engine Company. Participants were requested to check calendars and contact Mahesh if conflicts exist.

EXTERNAL DRY LOW NO_x ULTRA LEAN PRE-MIXED "GREEN THUMB" COMBUSTION SYSTEM

- EMISSION GOALS: 9 PPM NO_x
50 PPM CO
20 PPM UHC
- EXTERNAL COMBUSTION SYSTEM
- ULTRA LEAN PRE-MIXED

- MULTI-INJECTION SEQUENTIAL FUEL STAGING
 - CERAMIC WALLS
 - FUNDED BY DOE/SBAPCD/ALLISON
- STATUS: UNDER DEVELOPMENT
– 1996 FIELD EVALUATION

DOE/SBAPCD/SoCal Gas 9 PPM DRY LOW NO_x PROJECT APPROACH

- **ULTRA LEAN PRE-MIXED COMBUSTION SYSTEM**
 - equivalence ratios < 0.5
- **"GREEN THUMB" SINGLE CAN COMBUSTOR**
- **MULTI-INJECTION SEQUENTIAL FUEL STAGING**
- **DIFFUSER BLEED/VARIABLE GEOMETRY**
 - improve engine turndown
- **COMPLAINT METAL CERAMIC/CERAMIC HOT WALLS**
 - minimize CO/UHC emissions
 - improve flammability

PARALLEL FUEL STAGING/VG PROVIDES SELECTIVE CONTROL OF COMBUSTION STOICHIOMETRY OVER THE ENGINE OPERATING CYCLE

DOE/SBAPCD/SoCal Gas 9 PPM DRY LOW NO_x PROJECT STATUS

- **PROJECT STARTED JULY 1993**
- **SYSTEM DESIGN UNDERWAY**
 - fuel staging
 - variable geometry
 - diffuser bleed
- **AERODYNAMIC DESIGN UNDERWAY**
 - lpm modules
 - bench testing
- **HIGH-PRESSURE SECTOR RIG DESIGNED**

FUTURE WORK IDENTIFIED IN LAST MEETING

- Current LPM module concept
 - ◆ Further refinement and optimization of LPM design
 - ◆ Fabricate initial LPM design

- Evaluate other LPM concepts
 - ◆ 2D and 3D modelling and analysis

- Bench Test LPM design at ERC
 - ◆ Fuel/Air mixing characteristics
 - ◆ LBO and Flame Visualization
 - ◆ Combustor Exit Measurements
 - ◆ LDA and LIF Measurements

OPTIMIZATION OF MIXING PASSAGE FOR LPM

- Removal of forward facing step reduced pressure drop with minimal sacrifice in mixing efficiency

MMP1 Premixer Design

ASP SWIRLER CAN PROVIDE COMBUSTION STABILITY WITHOUT FLASHBACK

Allison Industrial Gas Turbine Engines

ADVANCED PROTOTYPE CASTING IS USED IN FABRICATION OF ASP SWIRLER ASSEMBLIES

Allison Industrial Gas Turbine Engines

BENCH TESTING OF SINGLE PASSAGE: MP01

- Best mixing obtained to date with this concept: $\pm 3\%$ variation

- Several lengths tested
- Mixing efficiency insensitive to length beyond 4 inches

Seven modules in rig emulates portion of engine

Seven modules in rig emulates portion of engine

Current status of combustion sector rig:

- Layout drawings and details in checking
- Inlet and exhaust spools ordered
- Instrumentation and controls ordered:
 - BOT thermocouple rakes
 - Gas sample probes
 - Sample probe translators and actuators
 - Heated sample lines
 - Fuel controls hardware
 - External piping, valves, fittings
- Test spool, liner, etc. to be ordered as drawings are completed

Combustor sector rig heat transfer studies

Liner material	Hot wall temp (°F)	Cold wall temp (°F)	Coolant flux (pps/in)	Status
Compliant Metal				
Ceramic	1975	1670	0.002	Quote requested
Nicalon reinforced Alumina	1920	1680	0.000	Being considered
Effusion cooled, TBC coated	1640	1600	0.017	Will be used initially

*Data is for combustor sector rig. Increased external convection reduces temperatures in engine.

Analytical study of combustor flow fields

- Solutions obtained with 3-dimensional CFD codes
- Stable, efficient combustion zones predicted
- Cases studied include engine with 7, 13, or 19 lit modules and test rig with 1 or 7 lit modules

Predicted velocities and temperatures in rig with $\phi=0.5$

temp. F

Allison Industrial Gas Turbine Engines

Stoichiometry control

- Further investigation of staging possibilities (parallel, series)
 - Various control hardware considered
 - Methods investigated for minimizing discontinuities
-

Parallel staging incorporates 6 stages

Series Staging Keeps Walls Hot
(Potential benefits in minimizing CO/UHC)

Future Work

- Adapt current test rig for testing single module at engine conditions
- Fabricate combustion sector rig
- Continue analytical study of combustor blow out limits, temperature profiles, and combustion efficiency
- Make modifications to MMP1 and RSPN1 as warranted by bench test results

INLINE DRY LOW NO_x PRE-MIXED COMBUSTION LINER

- EMISSION GOALS: 25 PPM NO_x
50 PPM CO
20 PPM UHC
- FUNDED BY GRI/ALLISON
- LEAN PRE-MIXED COMBUSTION SYSTEM

- FUEL STAGED TO ALLOW TURNDOWN OPERATION
- EFFUSION COOLED/CERAMIC COATED WALLS
- ENGINE RETROFITABLE

STATUS: UNDER DEVELOPMENT
– 1995 FIELD EVALUATION

GRI 25 PPM DRY LOW NO_x PROJECT STATUS

- **DESIGN/FABRICATION**
 - several configurations designed and fabricated
- **BENCH TESTS**
 - mixing tests/in-situ measurements
- **RIG TESTS**
 - lowest emissions levels to date measured with config. 2A:
 - ➔ 14 ppm NO_x (15% O₂ corrected)
- **DESIGN CHANGES DEVELOPED TO FURTHER IMPROVE COMBUSTION STABILITY AND CO/UHC EMISSIONS**
- **FUEL STAGING AND DIFFUSER BLEED BEING EVALUATED**

CONFIGURATION 2A NO_x LEVELS ARE WELL BELOW GRI PROGRAM GOAL

GRI 25 PPM DRY LOW NO_x PROJECT APPROACH

- **ENGINE RETROFITABLE IN-LINE DESIGN**
- **LEAN PRE-MIXED COMBUSTION SYSTEM**
 - equivalence ratios < 0.65
- **FUEL STAGING/DIFFUSER BLEED**
 - improve engine turndown
- **CERAMIC COATED HOT WALLS**
 - minimize CO/UHC emissions
 - improve flame stability

MIXING CUP DESIGN HAS EVOLVED TO DELIVER IMPROVED MIXING

NO_x VS. CO TRADEOFF FROM RIG TESTING

DLN CONFIGURATION 2C

MAX POWER CONDITIONS

MIXING, WALL COOLING AND SWIRL HAVE A STRONG EFFECT ON NO_x VS. CO TRADEOFF

LEAN PRE-MIX COMBUSTION REDUCES MAXIMUM EXIT TEMPERATURES

IMPROVED RADIAL TEMPERATURE PROFILE CAN ENHANCE TURBINE DURABILITY

LEAN PRE-MIX COMBUSTION CAN IMPROVE LINER DURABILITY

SPLIT PILOT OPERATION IS BEING INVESTIGATED

- MAY ENABLE STARTS USING SPARK IGNITER
- RETAINS MOST OF THE ADVANTAGES OF CENTER PILOT
- MAY IMPROVE MIXED PILOT/PREMIxed OPERATION

OUTER PILOT ONLY

CENTER PILOT ONLY

75% CENTER PILOT, 25% OUTER PILOT

WALL QUENCHING REDUCTION THROUGH JETS BEING INVESTIGATED

- INITIAL INVESTIGATION SUGGESTS THAT MOST CO/UHC DUE TO WALL QUENCHING
- CONSIDERING USE OF SLOT SHAPED JETS TO MIX QUENCH LAYER / BULK FLOW

BC7N CHEMICAL KINETIC CALCULATION

STATUS

- **CONFIGURATIONS 2C AND 2D BEING TESTED**
- **RAPID PROTOTYPED DOME BEING FABRICATED**
- **WAITING ON TECHNETICS FOR QUOTE ON
COMPLIANT METAL CERAMIC LINER**
- **CENTER PILOT AND SPLIT PILOT HARDWARE READY**
- **WALL QUENCHING / INTERMEDIATE JET STUDY UNDERWAY**
- **CONFIGURATION 2A.2 BEING FABRICATED**

SPLIT PILOT OPERATION IS BEING INVESTIGATED

- MAY ENABLE STARTS USING SPARK IGNITER
- RETAINS MOST OF THE ADVANTAGES OF CENTER PILOT
- MAY IMPROVE MIXED PILOT/PREMIxed OPERATION

OUTER PILOT ONLY

CENTER PILOT ONLY

75% CENTER PILOT, 25% OUTER PILOT

DATE

FILMED

5/12/94

END