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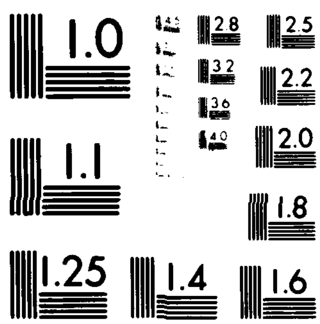

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

RADIATION/CATALYTIC AUGMENTED COMBUSTION

MOSHE LAVID
CORPORATE RESEARCH-TECHNOLOGY FEASIBILITY CENTER
EXXON RESEARCH AND ENGINEERING COMPANY
LINDEN, NEW JERSEY 07036

SEPTEMBER 1980

INTERIM REPORT [redacted]
CONTRACT NUMBER F49620-77-C-0085

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
BLDG. 410
BOLLING AIR FORCE BASE
WASHINGTON, D.C. 20332

THIS REPORT HAS BEEN RELEASED BY H. C. Hayworth

H. C. HAYWORTH
MANAGER,
CONTRACT RESEARCH DIVISION

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ABSTRACT

This research encompasses two promising techniques for extending aircraft operational range. They are radiative and catalytic augmentation techniques to enhance combustion initiation and reaction kinetics which restrict combustor operation via limits on flammability, flame propagation, ignition and stability. Both techniques have demonstrated the capability to enhance combustion processes and to broaden normally encountered stability limits. The radiative technique under laboratory static conditions has successfully ignited fuel-air mixtures, and has enhanced combustion processes, utilizing pulsed and continuous VUV light sources. Similarly, the catalytic technique has provided efficient combustion under normally difficult fuel lean, low temperature, conditions. A complementary effort involves the development of analytical capability required for modeling the radiative and catalytic techniques.

This document reviews the progress of research since the second annual report (May 31, 1979 thru May 31, 1980). The work was performed at Exxon Research and Engineering Company, Linden, New Jersey with Dr. Moshe Lavid as Principal Investigator. Within Exxon, the work is carried out in the Corporate Research-Technology Feasibility Center, Contract Research Division, Combustion Research Area.

Radiative ignition and combustion enhancement tests have been performed on propane-air mixtures under various static conditions. Successful radiative ignitions were obtained with pulsed and continuous VUV/UV light sources. The ignition with the continuous light source is reported for the first time. Combustion enhancement experiments were conducted with continuous irradiation. Encouraging enhancement results of higher flame propagation velocities and larger extinction times and extinction distances are also reported for the first time.

Catalytic combustion, in this program, is primarily aimed at improving flame stabilization and reducing pressure loss in aircraft afterburner systems. To this end, a conceptual design of a catalytic flameholder has evolved from an initial configuration of straight uniform cells to graded cells and finally to converging cells. The converging cells, in addition to offering an increase in resistance to blow-out and an increase in throughput, as the graded cells, exhibits also smooth convergence and upstream (where combustion is most unstable) heat radiation.

STATEMENT OF WORK

The work statement covering the contract period June 1977 thru November 1980 is presented below. A revised program milestone chart is provided in Figure 1:

The contractor shall furnish scientific effort during the funding period, together with all related services, facilities, supplies and materials, needed to conduct the following research.

a. Identify, acquire and evaluate appropriate vacuum ultraviolet and ultraviolet light sources. Purchase of available and specially modified sources will be pursued under subcontract. Source requirements will be specified based on photochemical combustion requirements previously determined under AFOSR contract F44620-70-C-0051 and AFAPL contract F33615-73-C-2063.

b. Select and characterize radiant sources for program use. Spectrographic measurements will be employed to determine wavelength dependence of source energy output as a function of energy input and pulse duration. Pulsed sources will be evaluated in the 145-245 nm range and continuous sources will be evaluated in the 200-360 nm range. Combustion initiation tests using static mixtures will also be performed to further characterize the source radiant beam.

c. Initiate experimental tests to identify and investigate the details of radiant beam-reactant mixture interaction. Explore the effects of inerts, fuel-free air zones, and depth of radiation penetration on the photo-combustion processes using gaseous, stationary reactant mixtures. Also design and initiate plug flow combustor experiments to provide for characterization of radiative effects in flowing reactive mixtures.

d. Carry out a comprehensive technical analysis to complement the experimental program. The detailed aspects of radiation-combustion interaction which lead to ignition and combustion enhancement will be considered. A consistent experimental and theoretical description of combustion augmentation will be developed.

e. Extend experimental tests on gaseous, stationary reactant mixtures to include investigation of the effect of radiant energy on the ignition and flame propagation of spark ignited mixtures. Attempt to obtain ignition using a focused, continuous light source.

f. Employ plug flow combustor experiments to investigate ignition and flame attachment in flowing reactive mixtures subjected to pulsed vacuum ultraviolet sources. Also study flame stabilization by continuous ultraviolet irradiation.

g. Design and initiate cannular combustion experiments to provide for characterization of radiative effects in non-premixed flowing reactive mixtures.

h. Utilize the experimental data and computer model to develop a consistent description of radiative augmentation processes. Undertake model revisions and refinements as necessary.

i. Perform cannular combustor experiments to investigate ignition and flame attachment in flowing, liquid-fuel, unpremixed, reactant systems subjected to pulsed vacuum ultraviolet and continuous ultraviolet irradiation.

j. Identify and evaluate alternate combustion augmentation techniques for application in practical combustion hardware. Carry out simple, preliminary experimental tests of the most promising techniques as appropriate.

k. Expand the radiative enhancement model to include methane-fueled system kinetics. Perform additional analysis to parametrically characterize radiative enhancement and to assess application feasibility.

l. Develop a comprehensive test plan for larger scale engine tests of the radiative augmentation techniques, including a parametric test matrix.

m. Develop a simple model of the catalytic flame stabilization process including salient features of the aerothermochemistry of the catalytic combustion mechanism and conventional flame-holding mechanism. Utilize the model to perform parametric analyses to assist the experimental program and to initially analyze experimental data.

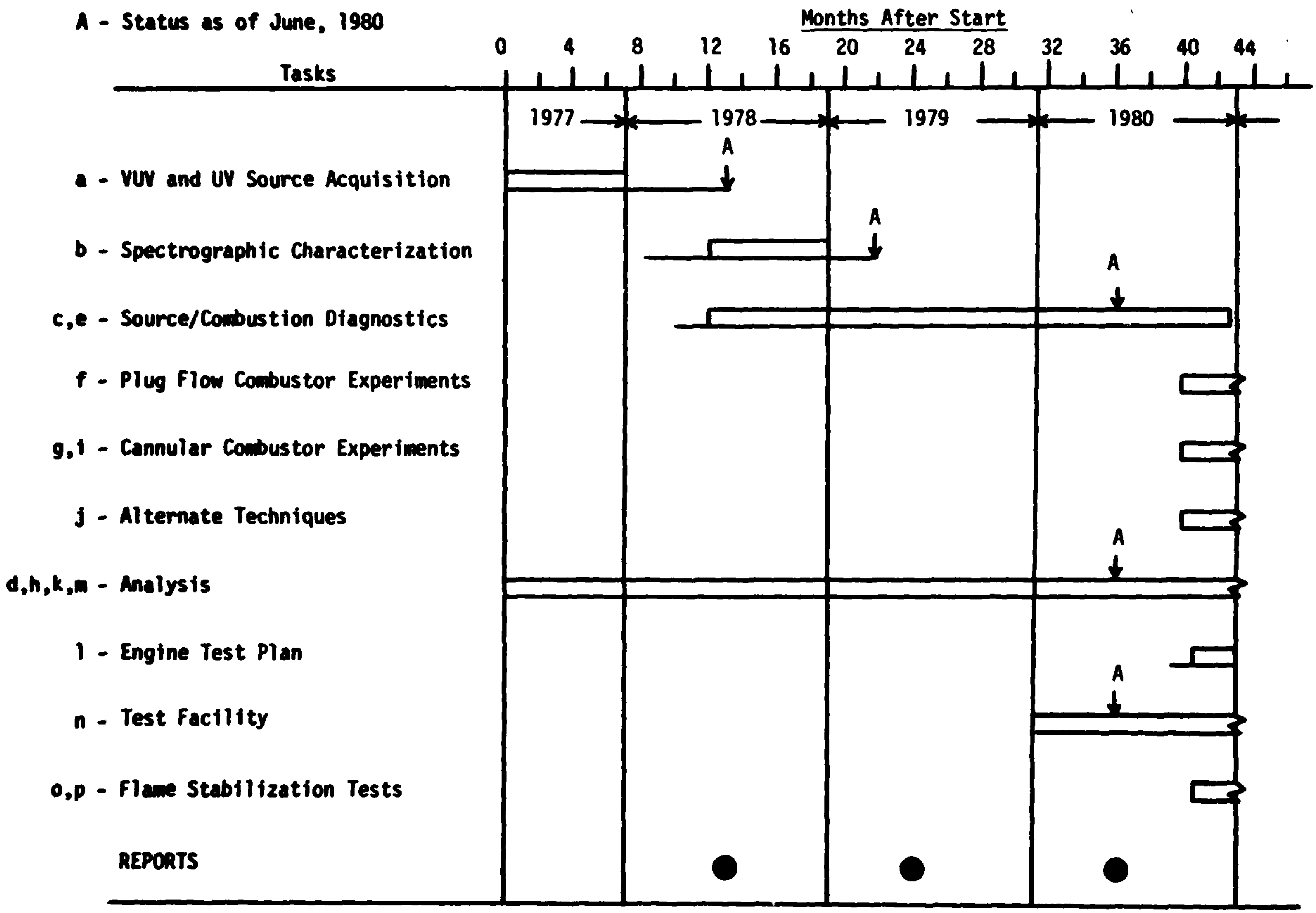
n. Design, fabricate and commission (shake down) an experimental flame-stabilization test facility which provides atmospheric reactant flow conditions at gas velocities up to 200 m/s and gas temperatures up to 1000 K.

o. Perform initial experimental flame-stabilization tests on a standard V-gutter, non-catalytic monoliths and catalytic monoliths under both non-reacting and reacting flow conditions. These tests will use one specific fuel and two commercially available catalyst types. Experimental variables will include inlet mixture ratio, temperature, and velocity.

p. Evaluate important combustion mechanisms using a specially fabricated stabilizer, with a sintered metal disk on the downstream side through which hot gases or products of partial fuel oxidation can be passed. Experimental variables will include fuel type, temperature and velocity.

FIGURE 1

PROGRAM MILESTONE REVISED (6/1/80)



STATUS OF RESEARCH EFFORT

This section describes the program research accomplishments and covers the work completed through May 1980. Evaluation, selection and acquisition of three suitable vacuum ultraviolet and ultraviolet lamps have been completed. Spectrographic diagnostic tests for two of the light sources have been performed and analyzed. The newly obtained spectral information has been incorporated into the analytical radiative model. This radiative initiation model has been revised to include the effects of light source characteristics, photodissociation, kinetics (including electronically excited state species), and adiabatic temperature rise. The model has shown good phenomenological agreement with experimental results. Extensive static experiments have been conducted to demonstrate radiative ignition and combustion enhancement. Minimum ignition energies have been measured for various gaseous fuels as a function of equivalence ratio using a pulsed light source (ILC). For the first time radiative ignition was demonstrated with a continuous light source (EIMAC). Using the same continuous light source very encouraging enhancement results have been observed and measured. In the catalytic program, a new model for catalytic flameholding devices has been developed. It still has to be reviewed and then revised. The conceptual design of the catalytic flameholder has evolved from the initial configuration of uniform cells to graded cells and finally to converging cells.

(Task a) Light Source Acquisition

Three light source systems described in the first Interim Report (1) were acquired. The first system was received from ILC. It included ten pulsed VUV lamps with a power supply suitable for ignition experiments. The second system was shipped from Optical Radiation Corporation (ORC). It included a 1 kW continuous UV lamp suitable for combustion enhancement tests. The third system was bought from EIMAC (a Division of Varian). It consisted of a 0.5 kW continuous VUV/UV lamp with sapphire window and focusing reflector installed in a special housing. This lamp was found to be suitable for ignition as well as combustion enhancement tests. Two more lamps were ordered after the first one cracked during an ignition experiment. One lamp has arrived after a nine month delay and the second lamp, with a UV grade polished sapphire window, is expected to arrive soon. The possibility of using a VUV laser as a fourth light source has been explored in collaboration with Los Alamos Scientific Laboratory/Applied Photochemistry Division. The Lumonics TE-861 rare gas halide laser system was identified as the most suitable for our experimental needs. The logistics for conducting the radiative experiments with LASL lasers is being pursued.

(Task b) Spectrographic Characterization

Spectrographic diagnostic tests have been performed to characterize the EIMAC and ILC sources. Radiant output intensity and total energy measurements have been made as a function of spectral wavelength (140-380 nm), pulse time, and input energy or power. This data, which provides comprehensive description of light source behavior has been analyzed and reported in the second Interim Report (2).

Data on the continuous EIMAC source indicated that very little line radiation is present in the spectrum which shows a continuous drop in intensity with decreasing wavelength except for a small peak at about 165 nm. For power levels less than about 400 watts, radiant power output in the vacuum ultraviolet varies linearly with input power.

It was found that the spectral distribution of intensity for the pulsed vacuum ultraviolet light sources supplied by ILC has pronounced peaks in the 145 to 175 nm wavelength region. This is a region of photon energy which is extremely effective in initiating combustion reactions. Thus, the spectral data clearly supports the unique ability of these light sources in radiative ignition applications. The detailed spectral information is critical in correctly modeling the influence of VUV photons on the chemical kinetics of interest. Equally important is the pulse shape (intensity vs. time) behavior of the photon flux. Although it was found that the pulse shape varies with wavelength, it was concluded that an adequate time integrated value (energy deposition vs. time) could be obtained by assuming a pulse shape which corresponds to a classical critically damped discharge.

(Tasks c and e) Source/Combustion Diagnostics

The experimental combustion work has been divided into ignition and enhancement. Ignition has been attempted by using a pulsed light source (ILC) and a continuous light source (EIMAC). Combustion enhancement has been investigated using both continuous light sources (ORC and EIMAC).

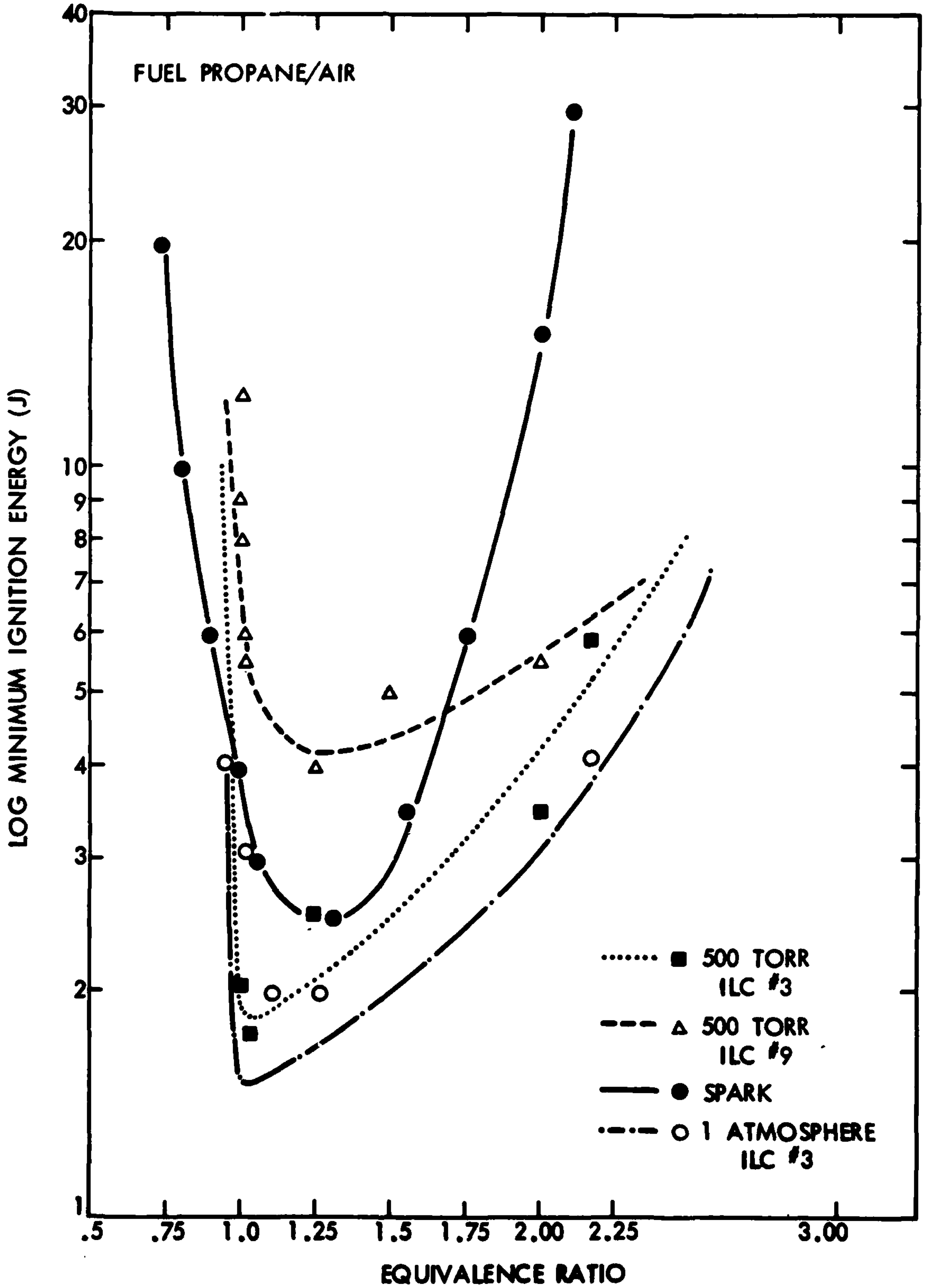
Ignition: Various gaseous fuel/air and fuel/oxygen mixtures have been successfully ignited by using only a light source (no thermal effects). A few of the reactive mixtures ignited by the pulsed ILC light source are hydrogen/oxygen, methane/air and propane/air. The experimental variables besides the reacting mixtures were equivalence ratio, combustion chamber pressure and power of the light. The gases were admitted to the combustion chamber at predetermined equivalence ratios and pressures and then the light source was turned on. If the mixture did not ignite the power supplied to the light was increased until by trial and error the critical power for ignition was found.

Following this procedure a series of radiative ignition tests were performed with stoichiometric hydrogen-oxygen mixtures using ILC VUV pulsed lamps. These results were reported in the previous Interim Report (2). We concluded that the pulsed VUV source can be considered as a point source, and thus extensive beam spreading occurs resulting in a significant increase in the source energy required for ignition. A parallel beam and particularly a focused beam source would benefit substantially the radiative augmented technique.

Extensive propane-air radiative ignition tests, using ILC pulsed light sources, were also conducted under static conditions. Successful ignitions were obtained and minimum ignition energies were determined for various equivalence ratios at atmospheric and subatmospheric pressures. Figure 2 depicts typical results of minimum ignition energy versus equivalence ratio for a propane-air mixture.

FIGURE 2

MINIMUM SPARK AND RADIATIVE INITION ENERGIES VS. EQUIVALENCE RATIO AT (SUB)ATMOSPHERIC PRESSURE



All measurements were made at room temperature (about 20°C), under two chamber pressures: 1 atmosphere and 500 torr and with two ILC light sources designated as #3 and #9. A minimum spark ignition energy reproduced from Reference 3 was drawn on the figure for comparison. It is noted that the minimum radiative ignition energy curves are similar in shape to the spark ignition curve, namely, a minima of the ignition energy occurs at some equivalence ratio. Increasing or decreasing the equivalence ratio from the value corresponding to the minima results in an increase in light as well as spark ignition energies until the equivalence ratios are outside the flammability limits and all attempts to ignite fail. It is important to note that light minimum ignition energy occurs at a leaner equivalence ratio than that of spark ignition, and that light minimum ignition energies are less sensitive to pressure variations than spark ignition.

The significance of the successful pulsed light source ignition experiments is two-fold: it reconfirms the concept of radiative ignition, and it demonstrates technical achievement in the design of an advanced optical radiative igniter, which was the result of a collaboration with ILC.

For the first time, radiative ignition was demonstrated with a continuous light source (EIMAC). The premixed gases were propane-oxygen at stoichiometric ratio and at atmospheric pressure. The lamp cracked during the experiment and a new one was ordered. Upon receiving the new lamp we will try to reproduce and reconfirm the radiative ignition with continuous irradiation. This first reported successful ignition with a continuous light source implies the potential possibility of using the light as an optical-radiative flame stabilizer with zero pressure drop instead of the conventional flameholders.

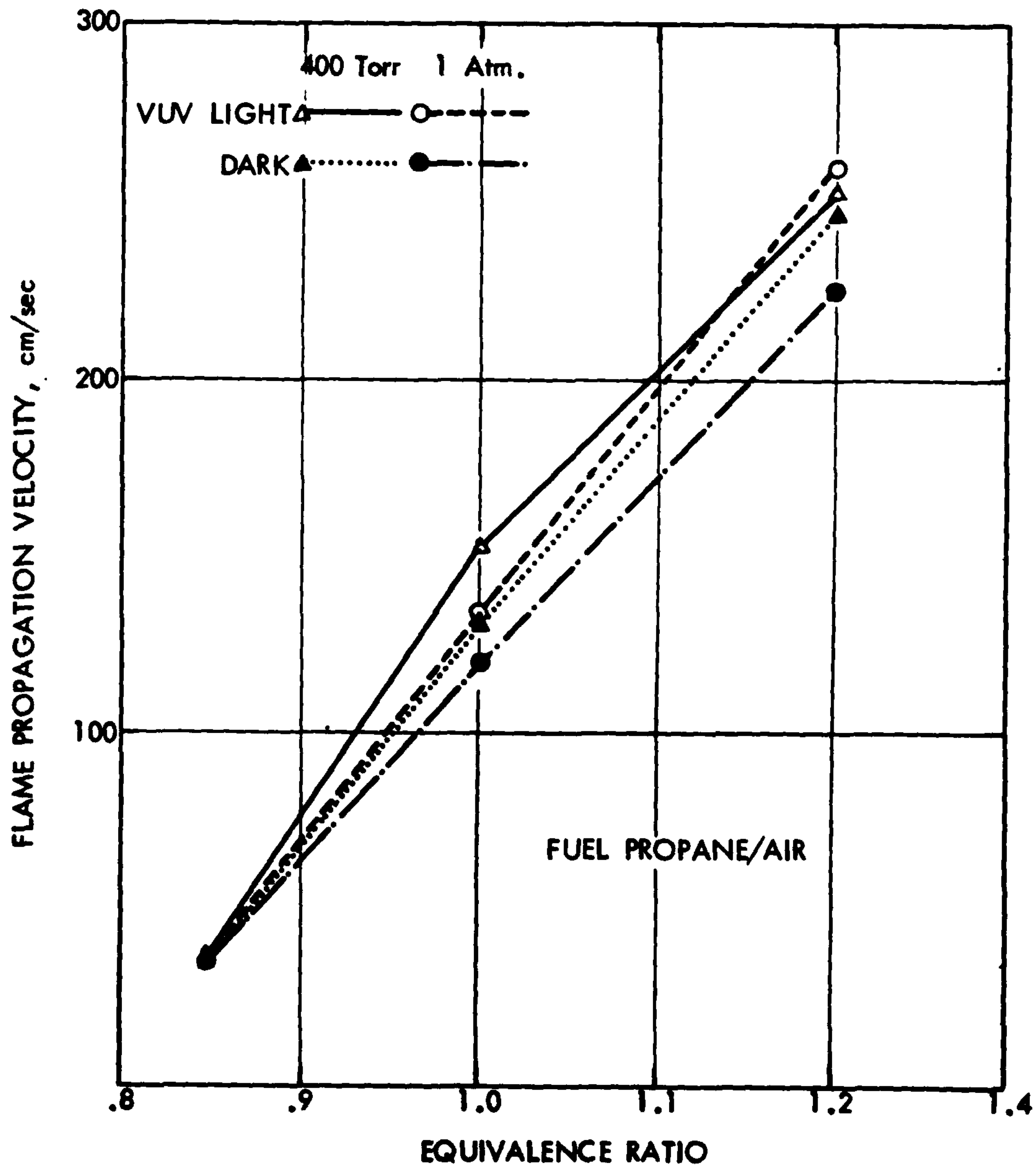
Combustion enhancement: Combustion enhancement experiments were conducted with propane/air mixtures at various equivalence ratios and pressures. The average flame propagation velocity is used to evaluate combustion enhancement. It is defined as the average velocity at which the luminous flame front travels throughout the combustion tube (it is not the burning velocity). The calculated flame propagation velocities were compared under light and no light conditions for otherwise identical conditions. Figure 3 depicts such one comparison. The light source is EIMAC irradiating from the left-hand side of the combustion chamber while the spark igniter is discharged from the right-hand side causing the flame to propagate from right to left, into the light source.

The enhancement in terms of average flame propagation velocity is very small at lean mixtures and becomes more substantial at stoichiometric and rich mixtures (up to 15-20%) at atmospheric pressure. At subatmospheric pressure significant enhancement of 10% was obtained at an equivalence ratio of unity and it decreased at lean and rich mixtures to only 2-3%.

Other measurements used to evaluate combustion enhancement for marginal flames were extinction distance and extinction time. The former is the propagation distance of the flame along the tube until extinction, and the latter is the time recorded from ignition until extinction. The experiments were conducted with the light source and the spark electrodes both on the left-hand side of the combustion chamber. Table I summarizes

FIGURE 3

FLAME PROPAGATION VELOCITY VS. EQUIVALENCE RATIO
AT (SUB)ATMOSPHERIC PRESSURE AND
UNDER VUV LIGHT/DARK CONDITIONS



the results. It is shown that for marginal flames (near the lean flammability limit) the extinction time and extinction distance are increased under continuous irradiation of the EIMAC light source. The former is increased by up to 80% and the latter is increased by 15-25%. No enhancement has been detected when the ORC continuous light source has been used.

These very encouraging experimental results of combustion enhancement in terms of higher flame propagation velocities and larger extinction times and extinction distances can be construed as an extension of the general flammability limits by the use of a VUV continuous light source.

(Tasks d and k) Radiative Analytical Effort

The modeling effort on radiative initiation and enhancement of hydrogen-oxygen-nitrogen mixtures has progressed. The model includes the effect of light source characteristics; photodissociation of light absorbing species; reactant mixture kinetics, including electronically excited state species; and adiabatic temperature rise due to reaction heat release.

The initiation model has shown good phenomenological agreement with experimental results. Now that additional experimental data are available, it is important to examine more closely the quantitative as well as qualitative agreement between predicted and observed energies required to initiate combustion of various hydrogen-oxygen mixtures. To facilitate this comparison, the emission characteristics of the ultraviolet light sources used, which are now available, will be incorporated into the model. Subsequently, oxygen atom concentration required for combustion initiation, the effect of the presence of other species (e.g., water), and optimal pulse characteristics will be investigated. In addition, it may prove feasible and desirable to include in the model the kinetics, possibly in simplified form, needed to treat other fuel/oxidant mixtures. Finally, the computer program will be modified to provide indication of those reactions which are dominant at specifiable times.

The results of the initiation model have been used to investigate the phase plane diagram for given hydrogen-oxygen mixtures. The reaction paths for various pulse intensities have indicated combustion initiation by the attainment of critical temperature and oxygen-atom concentration in a time less than an assumed characteristic heat loss time. An explicit heat loss mechanism will be added to the model to allow further study of the phase plane and the dependence of the separatrix (between stable and combustion regions) upon the assumed heat loss mechanism and associated parameters. Preliminary results suggest that the phase plane configuration depends more strongly on the underlying kinetics than on the precise form assumed for the heat loss. Initially, a simple linear heat loss term will be used.

Work has already begun on expanding the initiation model to include species diffusion and associated boundary conditions. The function and Jacobian subroutines have been modified to include the

TABLE I

EXTINCTION TIMES AND DISTANCES
FOR MARGINAL PROPANE-AIR FLAMES

Equivalence Ratio	Pressure	Dark/Light	Extinction Time (frames)*	Change %	Extinction Distance (cm)	Change %
.82	1 atm	Dark	20.0		13.9	
		Light	36.3	+81	17.4	+25
.82	400 torr	Dark	18.0		17.3	
		Light	30.0	+67	21.0	+21
.78	607 torr	Dark	41.5		24.2	
		Light	50.0	+20	28.0	+15

* 64 frames = 1 sec

appropriate terms. Upon integrating the resulting equations the results are compared to those of the simpler model to examine the effect of diffusion and wall recombination upon combustion initiation. The first integration approach is the numerical method of lines with the spatial variable discretized either by finite difference or collocation with splines techniques. This work can then provide the basis for the possible subsequent inclusion of the more detailed hydrodynamics required to investigate combustion enhancement.

(Task m) Catalytic Analytical Effort

A model of new catalytic flameholding devices has been developed. This model is based on the usual wake recirculation formulation, as influenced by the work of Zukoski and Marble (4,5) on critical ignition times. The split of flow through and around the catalytic monolith is determined by pressure drop considerations. The flow into the recirculation zone is thus the sum of the flow through the monolith and that resulting from turbulent inclusion. The distance needed for a flame to develop is predicted as a product of mean convective velocity and reaction time obtained from the analysis of Kundu et al. (6) and compared to a recirculation zone length calculated on the basis of flow parameters. The comparison of these lengths allows the determination of blow-out or flameholding.

In this way, the existing model allows:

(1) Description of the influence of overall geometry, blockage ratio, and substrate configuration on aerodynamic and thermodynamic variables, especially pressure drop.

(2) Determination of the degree of approach flow penetration through the catalytic section, recirculation zone size and shape, and shear layer characteristics.

(3) Description of the concept's ability to widen stability and ignition limits and to widen the cross-sectional area occupied by the stabilization devices.

This model requires a careful review in the following areas:

(1) Flow split

(2) Characterization of catalytic flameholder effluent

(3) Wake recirculation formulation

(4) Flameholding/blow-off determination

Any of these areas which we believe are not adequately treated in the current model will be revised to produce a sufficiently detailed, realistic, and balanced model.

After such a review has been completed, modifications required to bring the existing computer program into conformity with the revised model will be made. Model predictions will then be compared to experimental data as they become available. Where lack of agreement is noted, we shall endeavor to identify its causes and revise the model until good agreement is obtained in the regimes of interest. The resulting analytical tool will be used as an adjunct to the experimental effort to broaden our understanding of the underlying aerothermochemical interactions and as an aid in performance optimization.

(Task n) Test Facility

Flow experiments in both catalytic and radiative augmented combustion will be conducted in the Combustion Science Research Facility. This facility was designed for combustion experiments requiring high fuel and air flow rates, at pressures up to 5 atm. It can accommodate various combustor modules which can be readily interchanged. The Continuous Flow Combustor module was selected for the augmentation tests. It is basically a plug flow combustor 4 inch in diameter and 48 inch long, fabricated of Inconel 600. It has numerous ports for viewing or accommodating optical diagnostics, for sampling, and for measuring temperatures and pressures. The combustor is very flexible, and can be adapted to various kinds of experiments. Its capabilities and limitations are determined by the support systems of the general Combustion Facility. The air supply system consists of a storage tank, 18 feet in diameter, with capacity of 20,000 SCF, which is supplied by an air compressor rated to provide 200 SCFM at 125 psi. This translates to combustor velocities of about 10 m/s and 60 m/s at one atmosphere and 300°K and 1900°K, respectively. The air preheat capability is about 900°K at 150 SCFM. The fuel system can provide gaseous, liquid, residual, or slurry fuels at rates up to 10 gal/hr.

The facility is equipped for accurate determination of combustion product gas composition, combustion efficiency, combustor temperature, pressure, fuel flow, and air flow. The gas analysis train includes instrumentation for determination of CO, CO_2, NO, NO_x, O_2, and total hydrocarbon. Additional instrumentation, wet chemical analysis, or gas chromatographic capability can be provided to determine SO_2, HCN, NH_3, H_2, or hydrocarbon identification. Recently, the facility has been also equipped with three advanced optical systems for better diagnostics of the flow-field, species concentration and droplet size distribution. The systems are: (1) Schlieren by Space Optics Research, (2) Laser Doppler Velocimetry by TSI and (3) Malvern. Outputs from all existing instrumentation is logged into the site's pilot plant computer system and on-line analysis is performed to report (via teletype) to the operator the status of the experimental information being acquired.

The general Combustion Science Research Facility has been constructed and its shakedown is near completion. The Continuous Flow Combustor module requires some revisions and is expected to be ready for initial flow tests by the end of the first quarter of 1981.

(Tasks o and p) Flame Stabilization Tests

The conceptual design of the catalytic flameholder has evolved from the initial configuration of straight uniform cells to graded cells and finally to converging cells. This concept evolution is depicted in

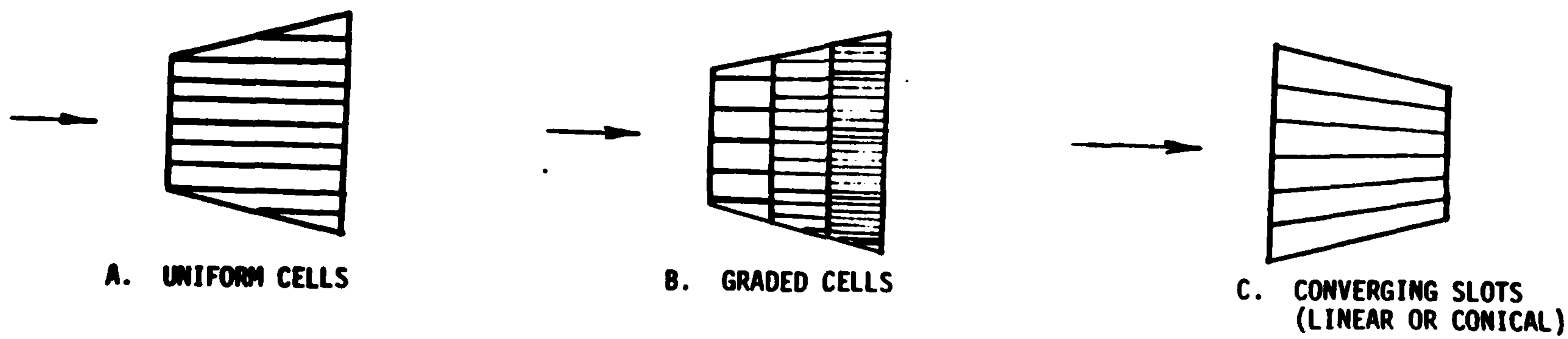
Figure 4. The idea of graded cells was promoted during the Third Workshop on Catalytic Combustion, and it offers an increase in resistance to blow-out and an increase in throughput. The converging cells (slots) design was suggested to us by W. B. Retallick at the Fourth Workshop on Catalytic Combustion. This design, in addition to offering the same advantages as the graded cells, exhibits also smooth convergence (no stepping down) and upstream heat radiation. The smooth convergency suggests better flow characteristics and easier fabrication. The upstream radiation enhances initial surface reaction close to the inlet where ignition occurs, and where combustion is most unstable.

All the configurations will be assessed and the most promising ones will be experimentally evaluated and compared to the baseline performance obtained by the conventional V-gutter flameholder.

FIGURE 4

CATALYTIC FLAMEHOLDER

CONCEPTUAL DESIGN



FEATURES FOR CONSIDERATION:

MATERIAL: CERAMIC VS. METAL

FLOW: GRADED VS. STRAIGHT FLOW PATH

COMBUSTION: COMPLETE VS. PARTIAL

CONSTRUCTION: COMPLEX VS. SIMPLE

REFERENCES

(1) Cerkanowicz, A. E., and Bartok, W., "Radiation Augmented Combustion," Interim Report AFOSR-TR-78-1508, July 1978.

(2) Cerkanowicz, A. E., "Radiation Augmented Combustion," Interim Report AFOSR-TR-79-1096, July 1979.

(3) Lewis, B., and VonElbe, G., "Combustion, Flames and Explosion of Gases," 2nd Ed., p. 334, Academic Press, 1967.

(4) Zukoski, E. E., and Marble, F. E., "The Role of Wake Transition in the Process of Flame Stabilization on Bluff Bodies," Combustion Researches and Reviews, pp. 167-180, Butterworths, 1955.

(5) Zukoski, E. E., and Marble, F. E., "Experiments Concerning the Mechanism of Flame Blowoff from Bluff Bodies," Proc. Gas Dynamics Symposium, pp. 205-210, Northwestern University, 1956.

(6) Kundu, K. M., Banerjee, D., and Bhaduri, D., Combustion Science and Technology, Vol. 17, p. 153, 1977.

PROFESSIONAL PERSONNEL ASSOCIATED WITH RESEARCH EFFORT

Dr. Moshe Lavid - Principal Investigator - PhD Mechanical Engineering, State University of New York at Stony Brook, 1974.

Dr. L. A. Ruth - Group Leader - PhD Chemical Engineering, City University of New York, 1973.

Dr. W. S. Blazowski - Combustion Consultant - PhD Mechanical Engineering, Stevens Institute of Technology, 1971.

Dr. A. E. Cerkanowicz - Combustion Consultant - PhD Thermodynamics, Stevens Institute of Technology, 1970.

INTERACTIONS/OUTSIDE INTEREST

A. Talks and Papers

Two internal (Exxon) presentations on the program were made to management and professionals on March 5, 1980 and April 16, 1980. Two presentations were also made at the last AFOSR Contractor's Meeting on "Air Breathing Combustion Dynamics and Kinetics," Alexandria, Virginia, January 1980. The first presentation was entitled "Catalytic Flame Stabilization," and the second one was entitled "Radiation Augmented Combustion."

Two more presentations were given at Sandia Laboratories, Albuquerque, New Mexico, February 8, 1980, and at the 4th Workshop on Catalytic Combustion, Cincinnati, Ohio, May 14-15, 1980. The former presentation was on "Photochemical Ignition and Combustion Enhancement," and the latter one was on "Catalytic Flame Stabilization."

One presentation entitled "Photochemical Initiation of Combustion" was made at Imperial College, London, April 21, 1980.

B. Interest Expressed by Other Scientists

Although a strong interest is expressed in our combustion augmented program, as can be seen by the many requests for additional technical information listed below, it seems that the only ongoing active work that is directly related to our radiative approach is the plasma jet work of Professor Felix Weinberg at Imperial College, London. Prof. Weinberg has carried out experiments and has reported encouraging combustion augmentation results by using chemical and fluid mechanical effects via his novel design of a plasma jet. The kinetics is modified by a supply of radicals from the plasma (especially H atoms) while the fluid mechanics is modified by the high velocity jet. The plasma jet demonstrated ignition of sub-lean mixtures, increased flame speeds and conversion rates. The current design is using a pulsed plasma jet, and there may be a need for developing a continuous plasma jet plug. Open communication has been established with Prof. Weinberg and he has been retained as a consultant to Exxon Research and Engineering and this program.

In the catalytic work, contact has been made with Dr. W. B. Retallick who has recently become a consulting engineer after being for several years a Vice President for R&D at Oxy Catalyst. Dr. Retallick has a strong interest in the development of the catalytic flameholder and believes that it can be utilized as a partial combustor, resulting in lower catalyst temperatures. Dr. Retallick has been retained as a consultant and he will provide the catalyst for the prototype flameholder.

During this reporting period requests for additional technical information were received from the following professionals:

Dr. W. B. Retallick, Consultant, West Chester, Pennsylvania

Dr. M. Gusinow, Sandia Laboratories, Livermore, California

Prof. M. J. Antal, Jr., Princeton University, Princeton, NJ

Prof. M. Summerfield, Princeton Combustion Laboratories, Princeton, NJ

Dr. Robert Hickling, GM Corporation Research Laboratories, Warren, Michigan

Dr. F. E. Fendell, TRW, Redondo Beach, California

Prof. A. K. Oppenheim, University of California, Berkeley, California

SUMMARY: POTENTIAL APPLICATION OF RESEARCH RESULTS

Both the radiative and catalytic techniques have demonstrated the capability to enhance combustion processes and to broaden normally encountered stability limits.

The work on radiative ignition and combustion enhancement is providing fundamental information on a unique combustion process. Concepts which represent a new departure and extension of conventional combustion practice can evolve from the experimental data being obtained. Aspects of the radiative ignition and enhancement concept have been demonstrated in our laboratory under static (no flow) conditions. Successful pulsed light source ignition experiments reconfirm the radiative augmented concept and demonstrate the technical feasibility of designing an advanced optical-radiative igniter. Successful ignition with a continuous light source implies the possibility of using the light as an optical radiative flame stabilizer with zero pressure drop instead of the conventional flameholders. Preliminary encouraging results of combustion enhancement in terms of higher flame propagation velocities and larger extinction times and distances demonstrate a potential opportunity to extend the combustor operating limits utilizing the radiative technique. It is construed that the enhanced flame propagation can be translated into higher combustion rate and extended flammability limits.

From the experimental results reported here we gain confidence that radiative augmented combustion is a potentially viable technique to extend current aircraft operating limits. Eventual application to gas turbine engine systems is envisioned both for improved combustor operation and flame holding. Some future areas of potential application are: High altitude combustor reignition following flame-out, drag-free flame stabilization in supersonic combustors, and added flexibility for conventional combustors to use future alternate fuels. To this end, radiative ignition and combustion enhancement experiments under flow conditions are required as well as continued VUV light source development in the direction of improved beam optics.

The catalytic flame stabilization concept is particularly important to aeropropulsion combustion: turbo propulsion mainburners, afterburners, duct burners and ramjet dump combustors. Potential benefits include improved ignitability, stability as well as efficiency, and combustion design flexibility for alternate fuel usage. In the afterburner application, the conventional bluff-body flameholder can be replaced by a porous catalytic device resulting in less pressure drop than a solid flameholder of equal cross-sectional area. It can broaden its stability range by allowing for operation at inlet velocities, temperatures and fuel mixtures where conventional flameholders begin to fail. In addition, it may have the advantage of being a passive autoignition device.

Finally, a potential opportunity exists for the development of an advanced combustor featuring the combined performance of catalytic stabilization and radiative enhanced combustion.

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This research encompasses two promising techniques for extending aircraft operational range. They are radiative and catalytic augmentation techniques to enhance combustion initiation, and reaction kinetics which restrict combustor operation via limits on flammability, flame propagation, ignition and stability. Both techniques have demonstrated the capability to enhance combustion processes and to broaden normally encount... bility limits. The radiative techniq... has successfully ignited fuel-air mixt...

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ABSTRACT (Contd.)

processes, utilizing pulsed and continuous VUV light sources. Similarly, the catalytic technique has provided efficient combustion under normally difficult fuel lean, low temperature conditions. A complementary effort involves the development of analytical capability required for modeling the radiative and catalytic techniques.

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