

FINAL TECHNICAL REPORT  
NASA MICROGRAVITY COMBUSTION RESEARCH PROGRAM  
NASA LEWIS RESEARCH CENTER

RESEARCH CONTRACT: "An Experimental and Theoretical Study of Radiative Extinction of Diffusion Flames".

CONTRACT MONITOR: K. Sacksteder (Technical Officer)

PRINCIPAL INVESTIGATOR(S): A. Atreya  
I.S. Wichman\*

\* This final report details only the work of investigator and his students.

PERIOD COVERED: Duration of contract, 1991-1994.

GRANT NUMBER: NAG3-1271

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The essence of our research on this contract is contained in the attached Ph.D. thesis. Our work was primarily theoretical and numerical. We investigated firstly the simplified modeling of heat losses in diffusion flames, then we "ramped up" the level of complexity in each successive study until the final chapter discussed the general problem of soot/flame interaction.

With regard to the specific objective of studying radiative extinction, we conclude that in the steady case a self-extinguishing zero-g flame is unlikely to occur. The soot volume fractions are too small: it seems unlikely that the steady flame will generate sufficiently copious soot or other particulates to self-extinguish. On the other hand, our work does provide rational means for assessing the mixture of chemical energy release and radiative heat release. It also provides clues for suitably "tailoring" this balance. Thus, heat fluxes to surrounding surfaces can be substantially increased by exploiting and modify its sooting capability.

We believe that this work is the first serious attempt to synthesize soot radiating losses into combustion calculations. With all due respect to G. Faeth, J. Gore, Moss and colleagues, Ezekoye et al. and others, our work does not begin in midstream; rather, we work our way in from the shore, all the while carefully plumbing the limits of each successive step of our exploratory study. Although much of the work is numerical, we do a significant amount of theoretical calculation. Our later work-some of which is not included in chapter 6 of the thesis - involves a detailed nondimensionalization and order-of-magnitude analysis of the full equations. This is revealing, for it indicates how certain physical processes balance one another in different segments of the field.

In sum, we have done what most technical investigators seldom do. Instead of "reductio" we have attempted "synthèse": we have tried to reassemble the separate parts that so many investigators have been examining over the past quarter-century. Not via brute force, but by careful examination of each step of the process.

Herewith a summary of the attached work:

- 1) Progress reports from 1991-1995
- 2) Ph.D. thesis of Dr. Anjan Ray (completed July, 1996\*)
- 3) Combustion and Flame article "On the Influence of..." by I.S. Wichman, C&F, 97, 393-417 (1994).
- 4) Manuscript "Asymptotic Calculations for ..." by I.S. Wichman and A. Ray submitted July, 1996 to Combustion Science and Technology.
- 5) Manuscript "Influence of a Simple..." by A. Ray and I.S. Wichman submitted to Combustion & Flame on July 29, 1996.
- 6) Proceedings of the Central States (1996) entitled "The Influence of Soot Radiation on..." by A. Ray and I.S. Wichman.

\*P.S.: Dr. Ray secured a faculty position at IIT-Delhi, India's most prestigious Technical University.

NOTE: Chapters 4,5 and 6 of A. Ray's thesis are also being prepared as publications. We shall soon complete Chapter 5 as a publication submission. Dr. Ray will submit Chapter 6 from India this Fall.

NOTE: Presentations were also made at the 1994 and 1995 Eastern States meetings I do not have copies of these extended abstracts.

NASA PROVISIONS FOR RESEARCH GRANTS AND  
COOPERATIVE AGREEMENTS

APPLICABILITY OF PROVISIONS  
(AUGUST 1990)

(a) Whenever the words "grant" or "Grantee" appear in these provisions, they shall be deemed to include, as appropriate, the words "cooperative agreement" and "recipient of cooperative agreement" respectively.

(b) The Provisions set forth by the NASA Form (NF) 1463A apply to this award as those Provisions existed at the time of award, unless a revised NF 1463 is incorporated by a bilateral modification, except as noted in (c)(1). Any Special Conditions incorporated in an award or subsequent supplement take precedence over the NF 1463A, except as noted in (c)(2).

(c) (1) The grantee, at its option and at any time, may elect to prospectively apply the Provisions, in their entirety, of any newly revised NF 1463A to all NASA research grants and cooperative agreements with the grantee institution. The election is irrevocable for the designated version of the NF 1463A to which it applies, but may be replaced by a new election, designating the most recent version of the form. In no event does the election apply to any award which contains a NF 1463A dated later than the designated version.

(2) A grantee's election, per se, to adopt a revised NF 1463A shall have no effect on any Special Conditions included in the most recent award instrument. However, if a new provision, added to a specific award instrument as a Special Condition, was also added to all grants and cooperative agreements pending its inclusion (either verbatim or in substance) in a future NF 1463A revision, similar and/or duplicative provisions of a newly designated NF 1463A takes precedence over any such Special Conditions.

(3) The election shall be made by sending an "Election to Accept New Provisions Certification" to NASA, Procurement Policy Division (Code HP), Washington, DC 20546. The certification, to be valid, must indicate an effective date; be signed by an individual authorized to commit the grantee; and contain the following statement: "Pursuant to the provision entitled 'Applicability of Provisions' in the NASA Research Grant and Cooperative Agreement Provisions, the [insert the name of the campus, institution or system to which the certification applies] hereby elects to apply the provisions of NASA Form 1463A... [designate current version by inserting date printed on bottom of the form]... prospectively to all research grants and cooperative agreements.

TECHNICAL REPORTS  
AND PUBLICATIONS  
(APRIL 1990)

(a) Publication to accomplish widest practicable and appropriate dissemination of research results is encouraged at any time during the course of the investigation. Examples of appropriate media for such dissemination are the learned journals, the proceedings of professional groups, conference presentations, and NASA scientific and technical publications. NASA Grantees may submit the results of their work for publication by

whichever media they feel most appropriate. Publications and reports prepared under a grant shall contain a statement which acknowledges NASA's support and identifies the grant by number. Submissions for NASA scientific and technical publications shall be accompanied by manuscripts provided initially in draft. Upon agency review and approval, a reproducible copy shall be submitted in the style and format specified by NASA.

(b) Copies of preprints or manuscripts of each publication shall be provided to NASA for information at the time of submission for publication. Prior approval for publication is not required unless security classification is involved or the grant contains special conditions pertinent to publication of results.

(c) Brief, informal Semiannual Status Reports, which shall include concise statements of the research accomplished during the report period, including full bibliographic references to, or abstracts of, publications, shall be submitted. This is a minimum reporting requirement, and Grantees are urged to submit interim reports to publish in the open literature or to present conference papers whenever the research has reached a point where it is logical to summarize the results, a research phase has been completed, or significant new findings are made.

(d) A final technical report will be submitted upon termination of support under a specific grant, whether or not support is continued under another grant number. The final report may be a comprehensive report of all research findings, suitable for printing as a permanent contribution to knowledge. It may be a brief summary of the entire project. In either case, cumulated bibliographic references to, or abstracts of, all publications issued during the course of the research shall be included.

(e) Status and final technical reports shall have a title page that displays the title of the grant, the type of report, the name of the Principal Investigator, the period covered by the report, the name and address of the Grantee's institution, and the grant number.

(f) Five copies of all preprints, reprints, manuscripts, status and interim reports, and the final technical report shall be submitted to NASA. Three of these copies shall be sent to the NASA Technical Officer designated on the cover page of the grant. The remaining two copies, one of which shall be of a quality suitable for microreproduction, shall be sent to:

NASA Scientific & Technical Information Facility  
P.O. Box 8757  
Baltimore/Washington International Airport  
Maryland 21240

EXTENSIONS  
(APRIL 1990)

(a) It is NASA policy to provide maximum possible continuity in funding grant-supported research, and grants may be extended for additional periods of time. Any extension requiring additional funding must be supported by a proposal submitted at least 4 months in advance of the expiration date of the grant.

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November 12, 1991

Dr. Kurt Saksteder  
Microgravity Combustion Research  
Mail Stop 506-217  
NASA Lewis Research Center  
Cleveland, OH 44135

Dear Kurt:

Here is our "progress report":

We have begun designing the test apparatus. The main difficulty is the establishment of a steady state within the drop period, so that extinction can be accurately studied. The "thermal inertia" of the potential test materials must be examined. This we have done by solving the transient conduction equation for our porous ceramic in both slab and spherical geometries. We require large  $\alpha - \lambda/\rho c$ , which is accomplished with small  $\rho c$ . We are finding that approximately 0.25 sec. is required to establish steady conditions in the porous solid.

I hope it suffices. We are planning to visit NASA in early December. See you then.

Sincerely,

*Indrek S. Wichman / jg*

Indrek S. Wichman