AD-A273 429

CUMENTATION PAGE

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
		FINAL/01 MAY 91 TO 30 APR 93

4. TITLE AND SUBTITLE

STABILITY OF PREMIXED LAMINAR FLAMES IN A
STAGNATION POINT FLOW TO GENERAL DISTURBANCES (U)

5. FUNDING NUMBERS

2304/A4
AFOSR-91-0180

6. AUTHOR(S)

Professor Thomas Jackson

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS

Old Dominion University
Dept of Mathematics & Statistics
Norfolk VA 23529

DTIC
SELEC
DEC 07 1993
B

AFOSR-TR-

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING MONITORING AGENCY NAME(S) AND ADDRESS(ES)

AFOSR/NM
110 DUNCAN AVE, SUITE B115
BOLLING AFB DC 20332-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

AFOSR-91-0180

11. SUPPLEMENTARY NOTES

93-29701

12a. DISTRIBUTION AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION IS UNLIMITED

UL

13. ABSTRACT *(Maximum 200 words)*

The researchers completed a stability analysis of the stagnation point flow to a general class of disturbances expressed an infinite series. They have shown that when truncated at some large N, a finite number of boundary value systems result for the determination of the growth rate and the flame shape that depends on N, on the cross stream wavenumber ond on all the relevant physiochemical parameters. The stability results thus obtained reduce to those of Kim and Matalon (1990) when N=0 and extend them to include corrugations in the direction of stretch with wave number proportional to N. The results are discussed in terms of the Lewis number which is related to the mixture composition, and the rate of strain experiences by the flame. This work was recently presented in the Fourth Internationsl Conference on Numerical Combustion held in St Petersburg, FL and has recently been published in <u>Combustion Science Technology</u>.

14. SUBJECT TERMS

15. NUMBER OF PAGES

7

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR(SAME AS REPORT)

93 12 6 024

FINAL REPORT ON AFOSR CONTRACT NO. 91-0180:

STABILITY OF PREMIXED LAMINAR FLAMES
IN A STAGNATION POINT FLOW
TO GENERAL DISTURBANCES

T.L. Jackson

Department of Mathematics and Statistics
Old Dominion University
Norfolk, Virginia 23529

1. PROJECT SUMMARY

The structure of premixed flames in the presence of stretch is a problem of fundamental importance in the understanding of laminar flames and is also relevant to the modeling of turbulent flames. A special configuration which has attracted considerable attention in both analytical and experimental work is the stagnation point flow. It has been observed that, at a sufficiently high strain rate, a flat flame can be stabilized at a well defined distance from the stagnation point. Various flame front instabilities are also possible at lower values of the rate of strain depending upon such factors as geometry, thermal expansion and mixture composition.

This proposal was directed towards the stability of a pre-mixed flame in a stagnation point flow. Although there is no essential difficulty in formulating the linearized disturbance equations, the resulting problem is not separable and therefore a normal mode analysis is not applicable. An exception is the special case of self similar disturbances, namely disturbances with periodic waviness in the cross stream direction only. This case has been analyzed by Kim and Matalon (1990) who have consequently determined neutral stability curves in terms of wavenumber, Lewis number and strain rate.

We have completed a stability analysis of the stagnation point flow to a general class of disturbances expressed as an infinite series. We have shown that when truncated at some large N, a finite number of boundary value systems result for the determination of the growth rate and the flame shape that depends on N, on the cross stream wavenumber and on all the relevant physiochemical parameters. The stability results thus obtained reduce to those of Kim and Matalon (1990) when $N = 0$ and extend them to include corrugations in the direction of stretch with wavenumber proportional to N. The results are discussed in terms of the Lewis number which is related to the mixture composition, and the rate of strain experienced by the flame. This work was recently presented at the Fourth International Conference on Numerical Combustion held at St. Petersburg, Florida and has recently been published in Combustion Science and Technology. Discussed below are some possible future research directions which are now possible to investigate as a direct result of the progress made under this research proposal.

2. FUTURE DIRECTIONS

The flame front instabilities observed experimentally by Ishizuka and Law (1982) can not be adequately explained by using the planar geometry described above. They showed that the instabilities in the radial direction are suppressed as the strain rate is increased. Therefore, we will extend the stability analysis to axisymmetric stagnation point flows. The unsteady equations and jump conditions still hold, but for an

axisymmetric coordinate system. The leading order basic state, which corresponds to a steady plane flame located at $x_s = -d$, is given by (Eteng, Ludford and Matalon, 1986)

$$u_s = 2F(x), \quad v_s = -yF'(x), \quad w_s = 0, \tag{1}$$

where

$$F(x) = \begin{cases} -\varepsilon(x + a) & -\infty < x < -d \\[3mm] -\varepsilon(\dfrac{\varepsilon}{2}\dfrac{\sigma - 1}{\sigma}x + \sqrt{\sigma})x & -d < x < 0 \end{cases} \tag{2}$$

and

$$d = \frac{\sigma}{\varepsilon(1 + \sqrt{\sigma})}, \tag{3}$$

$$a = d - 1/2\varepsilon. \tag{4}$$

Here, y and v denote the radial coordinate and radial velocity component, respectively. The stability problem for the axisymmetric flow can be derived in an analogous fashion to the planar flow. This is an important problem as noted above in that it can be directly related to experiments and will provide helpful insight into the effect of stretch (or strain) on the instabilities of the flame.

The above problems only incorporate diffusional transport processes as a perturbation to the otherwise inviscid jump conditions. Thus, only the "Cellular Branch" (characterized by $\omega = 0$) can be described, which leads to cellular type patterns for the flame front instabilities. To describe the "Pulsating Branch" (characterized by $Re(\omega) = 0$ and $Im(\omega)$ non-zero), one needs to turn to the framework in which the flame thickness and diffusion time are the appropriate scales, and thus hydrodynamic and diffusional transport effects are of equal importance. In this framework, the inviscid solutions are to be considered as outer solutions, with an inner solution describing the reaction zone governed by boundary layer equations. The motivation for this problem is also given by the work of Ishizuka and Law (1982) who observed the pulsating (or vibrating) flame experimentally. We know of no theoretical study which investigates the "Pulsating Branch" for the stagnation point flow.

As the rate of strain is increased a flame, if it exists, is pushed into the viscous boundary layer at the plate. In this case, the Euler equations must be replaced with the unsteady boundary layer equations subject to appropriate boundary and jump conditions. In particular, the boundary conditions at the plate could be chosen to include such effects as (1) no slip conditions for the velocities or injection in the normal direction, (2) heat loss or heat gain through the plate (or insulated conditions), and/or (3) catalytic conditions at the plate. We shall examine the basic state, as well as its stability. We note here that in keeping with the work of Brattkus and Davis (1990) the expansion functions necessary to include general disturbances for the flame surface will be Hermite polynomials.

Additional research directions could possibly extend as much of the stability analysis so as to include such effects as (1) heat loss, (2) gravity, (3) radiation (an important question related to fire safety), (4) a porous plate or cylinder with injection, and (5) diffusion flames (as opposed to premixed flames) for the counterflow geometry, etc. This last area is extremely important in the understanding of turbulent combustion, where a turbulent diffusion flame is viewed as an ensemble of laminar diffusion flamelets (Peters, 1984). Stability studies may give insight into the origin of the onset of turbulence.

3. RELATED WORK

The overall theme of this proposal was the investigation of the structure and stability of a particular reacting flow. In keeping with this theme, work has been completed on other related problems, both in subsonic and well as supersonic flows. Below is a list, together with abstracts, of all work that acknowledges support under this AFOSR contract.

● Below is a list of manuscripts either published or submitted acknowledging AFOSR support:

"IGNITION AND STRUCTURE OF A LAMINAR DIFFUSION FLAME IN A COMPRESSIBLE MIXING LAYER WITH FINITE RATE CHEMISTRY", C.E. Grosch and T.L. Jackson, Phys. Fluids A, 3(12), pp. 3087-3097, 1991.

Abstract. *In this paper we consider the ignition and structure of a reacting compressible mixing layer lying between two streams of reactants with different freestream speeds and temperatures using finite rate chemistry. Numerical integration of the governing equations show that the struc- ture of the reacting flow can be quite complicated depending on the magnitude of the Zeldovich number. In particular, for sufficiently large Zeldovich number, the three regimes first described by Linan and Crespo (1976); ie., ignition, deflagration, and diffusion flame, occur in supersonic as well as in subsonic flows. An analysis of both the ignition and diffusion flame regimes is presented using a combination of large Zeldovich number asymptotics and numerics. This allows us to analyze the behavior of these regimes as a function of the parameters of the problem. For the ignition regime, a well defined ignition point will always exist provided the adiabatic flame temperature is greater than either freestream temperature. For the diffusion flame regime, the location of the flame changes significantly with changes in the equivalence ratio and the Schmidt numbers.*

"NONSEPARABLE EIGENMODES OF THE INCOMPRESSIBLE BOUNDARY LAYER", with C.E. Grosch and A.K. Kapila. in *Instability, Transition* and *Turbulence*, Hussaini, Kumar and Streett, eds., Springer-Verlag, pp. 127-136, 1992.

Abstract. *We report the results of a study of the response of the incompressible boundary layer to disturbances of fixed frequency which are generated within the boundary layer. We show that there exists an infinite set of eigenvalues and corresponding nonseparable eigenfunctions. Series expansions for the eigenfunctions were constructed and used to construct initial conditions for numerical computations. The results of the numerical calculations are used to examine the characteristics of these eigenmodes. Sample results are presented.*

"ROLE OF ACOUSTICS IN FLAME/VORTEX INTERACTIONS", T.L. Jackson, M.G. Macaraeg, and M.Y. Hussaini, J. Fluid Mechanics, 254, pp. 579-603, 1993.

Abstract. *The role of acoustics in flame-vortex interactions is examined via asymptotic analysis and numerical simulation. The model consists of a one-step, irreversible Arrhenius reaction between initially unmixed species occupying adjacent half-planes which are allowed to mix and react by convection and diffusion in the presence of an acoustic field or a time-varying pressure field of small amplitude. The main emphasis is on the influence of the acoustics on the ignition time and flame structure as a function of vortex Reynolds number and initial temperature differences of the reactants.*

"ABSOLUTE/CONVECTIVE INSTABILITIES AND THEIR ASSOCIATED WAVE PACKETS IN A COMPRESSIBLE REACTING MIXING LAYER", F.Q. Hu, T.L. Jackson, D.G. Lasseigne, and C.E. Grosch, Phys. Fluids A, 5(4), pp. 901-915, 1993.

Abstract. *In this paper the transition from convective to absolute instability in a reacting compressible mixing layer with finite rate chemistry is examined. The reaction is assumed to be one step, irreversible and of the Arrhenius type. It is shown that absolute instability can exist for moderate heat release without backflow. The effects of the temperature ratio, heat release parameter, Zeldovich number, equivalence ratio, and the Mach number on the transition value of the velocity ratio are given. The present results are compared to those obtained from the flame sheet model for the temperature using the Lock similarity solution for the velocity profile. Finally, the structure of the wave packets produced by an impulse in the absolutely unstable flow is examined.*

"INDUCED MACH WAVE-FLAME INTERACTIONS IN LAMINAR SUPERSONIC FUEL JETS", F.Q. Hu, T.L. Jackson, D.G. Lasseigne, and C.E. Grosch, Phys. Fluids A, 5(2), pp. 422-427, 1993.

Abstract. *A model problem is proposed to investigate the steady response of a reacting, compressible laminar jet to Mach waves generated by wavy walls in a channel of finite width. The model consists of a two-dimensional jet of fuel emerging into a stream of oxidizer which are allowed to mix and react in the presence of the Mach waves. The governing equations are taken to be the steady parabolized Navier-Stokes equations which are solved numerically. The kinetics is assumed to be a one-step, irreversible reaction of the Arrhenius type. Two important questions on the Mach wave-flame interactions are discussed: (i) how is the flame structure altered by the presence of the Mach waves, and (ii) can the presence of the Mach waves change the efficiency of the combustion processes?*

"INTERACTION OF TURBULENCE WITH A DETONATION WAVE", T.L. Jackson, M.Y. Hussaini, and H.S. Ribner, Phys. Fluids A, 5(3), pp. 745-749, 1993.

Abstract. *This paper addresses a specific reactive-flow configuration, namely, the interaction of a detonation wave with convected homogeneous isotropic weak turbulence (which can be constructed by a Fourier synthesis of small-amplitude shear waves). The effect of chemical heat release on the rms fluctuations downstream of the detonation is presented as a function of Mach number. In addition, for the particular case of the von Karman spectrum, the one-dimensional power spectra of these flow quantities are given.*

"TEMPERATURE AND SUCTION EFFECTS ON THE INSTABILITY OF AN INFINITE SWEPT ATTACHMENT LINE", D.G. Lasseigne, T.L. Jackson, and F.Q. Hu, Phys. Fluids A, 4(5), pp. 2008-2012, 1992.

Abstract. *It is known that the incompressible, infinite swept attachment line flow is unstable to streamwise disturbances which originate in the boundary layer when the crossflow exceeds a critical magnitude. Furthermore, a small degree of suction at the surface has a significant stabilizing influence while a small degree of blowing has a considerable destabilizing influence. This paper investigates the stabilizing and destabilizing effects of, respectively, cooling or heating the plate and the competing or enhancing effects of suction or blowing. A non-orthogonal flow with respect to the attachment line is also considered by adding a component of shear to the mean flow.*

"STABILITY OF A PREMIXED FLAME IN STAGNATION POINT FLOW AGAINST GENERAL DISTURBANCES", T.L. Jackson and M. Matalon, Combust. Sci. and Tech., 90, pp. 385-403, 1993.

Abstract. *In a previous analysis, the stability of a premixed flame in a stagnation point flow was discussed for a restricted class of disturbances that are self-similar to the basic undisturbed flow. Thus, flame fronts with corrugations only in the cross stream direction have been considered. In this paper, we consider a more general class of three-dimensional flame front perturbations, which permits corrugations in the streamwise direction as well. It is shown that, because of the stretch experienced by the flame, the hydrodynamic instability is limited only to disturbances of short wavelength. If, in addition, diffusion effects have a stabilizing influence, as would be the case for mixtures with Lewis number greater than one, a stretched flame could be absolutely stable. Instabilities occur when the Lewis number is below some critical value less than one. Neutral stability boundaries are presented in terms of the Lewis number, the strain rate and the appropriate wavenumbers. Beyond the stability threshold, the two-dimensional, self similar modes always grow first. However, if disturbances of long wavelength are excluded, it is possible for the three dimensional modes to be the least stable ones. Accordingly, the pattern that will be observed on the flame front, at the onset of the instability, will consist of either ridges in the direction of stretch, or the more common three dimensional cellular structure.*

"STRUCTURE AND STABILITY OF A LAMINAR DIFFUSION FLAME IN A COMPRESSIBLE, THREE-DIMENSIONAL MIXING LAYER", T.L. Jackson and C.E. Grosch, Theoretical and Computational Fluid Dynamics, Invited manuscript to appear in the special issue on Combustion, (in press).

Abstract. *In this paper we consider the structure and stability of a three dimensional, finite rate, reacting compressible mixing layer lying between two streams of reactants with different freestream speeds and temperatures. Using both numerical calculations and asymptotic analyses, the structure of the ignition and diffusion flame regimes was studied; in particular the effect of crossflow on the structure. The results of both approaches are in good agreement. In the stability analysis the general case of three dimensional disturbances was studied. It was shown that certain general results, in particular the circle theorem, could be easily extended to three dimensional disturbances in a compressible fluid with crossflow. The introduction of a chemical reaction, in the form of a flame sheet, was found to have complex effects on the flow stability. These include the appearance of additional neutral modes as compared to the nonreacting case and substantial changes in growth rates with heat release, the skew angle of the mean flow and the direction of propagation of the disturbance wave. These results are discussed in detail.*

"EVOLUTION OF DISTURBANCES IN STAGNATION POINT FLOW", W.O. Criminale, T.L. Jackson and D.G. Lasseigne, submitted to J. Fluid Mechanics.

Abstract. *The evolution of three-dimensional disturbances in an incompressible three-dimensional stagnation-point flow in an inviscid fluid is investigated. Since it is not possible to apply classical normal mode analysis to the disturbance equations for the fully three-dimensional stagnation-point flow to obtain solutions, an initial-value problem is solved instead. The evolution of the disturbances provide the necessary information to determine stability and indeed the complete transient as well. It is found that when considering the disturbance energy, the planar stagnation-point flow, which is independent of one of the transverse coordinates, represents a neutrally stable flow whereas the fully three-dimensional flow is either stable or unstable, depending on whether the flow is away from or towards the stagnation point in the transverse direction that is neglected in the planar stagnation point.*

● Below is a list of conferences that were attended, at which presentations were made, with AFOSR support:

44th Annual Meeting, Division of Fluid Dynamics, American Physical Society, Scottsdale, AR, Nov. 1991.

The Fourth International Conference on Numerical Combustion, St. Petersburg, Florida, December 1991. Also, organized a minisymposium titled, "Numerics and Asymptotics: Some Basic Models in High Speed Propulsion".

45th Annual Meeting, Division of Fluid Dynamics, American Physical Society, Tallahassee, FL, Nov. 1992.

DTIC QUALITY INSPECTED 3

Accession For
NTIS GRA&I ☑
DTIC TAB ☐
Unannounced ☐
Justification

By
Distribution/
Availability Codes
Avail and/or
Dist Special
A-1