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41 items enclosed

OSHTKACP TP-1998-138

MEMORANDUM FOR PRS (Contractor Publication)

FROM: PROI (TI) (STINFO)

6 July 1998

SUBJECT: Authorization for Release of Technical Information, Control Number: **AFRL-PR-ED-TP-1998-138**
William H. Cahoun Jr (SPARTA), "Evaluation of Afterburning Cessation Mechanisms in Fuel Rich Rocket Exhaust"

AIAA (Vu-Graphs)

(Statement A)

EVALUATION OF AFTERBURNING CESSATION MECHANISMS IN FUEL RICH ROCKET EXHAUST PLUMES

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34 AIAA/ASME/SAE/ASEE JOINT PROPULSION CONFERENCE
JULY 13-15, 1998

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BACKGROUND

CHARACTERISTIC OF MANY ROCKET PROPULSION SYSTEMS:

- RUN FUEL RICH FOR PERFORMANCE REASONS
- EXHIBIT STRONG AFTERBURNING OF EXHAUST WITH THE ATMOSPHERE
- HIGH RADIATIVE EMISSIONS

AFTERBURNING AND AFTERBURNING CESSATION IMPORTANT TO:

- MISSILE BASE COMPONENT DESIGN (RADIATIVE HEAT TRANSFER)
- MISSILE TYPING, TRACKING AND INTERCEPT SYSTEMS

CHARACTERIZATION OF AFTERBURNING CESSATION EVENT

TWO BASIC TYPES OF CESSATION EVENT:

1) GRADUAL TOTAL INTENSITY DROP-OFF

- SHUTDOWN OCCURS OVER WIDE ALTITUDE RANGE

2) RAPID TOTAL INTENSITY DROP-OFF

- SHUTDOWN OCCURS OVER NARROW ALTITUDE RANGE

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POSSIBLE MECHANISMS RESPONSIBLE FOR AFTERBURNING CESSATION

- <u>SHEAR LAYER RELAMINARIZATION (VELOCITY MATCHING)</u>:
  - AFTERBURNING INHIBITED BY LACK OF TURBULENT MIXING
- <u>DAMKOHLER NUMBER EFFECT</u>:
  - DAMKOHLER NUMBER IS RATIO OF MIXING AND CHEMICAL TIME SCALES
  - LARGE SCALE TURBULENT MIXING COOLS PLUME FASTER THAN AFTERBURNING HEATS THE PLUME (LOW DAMKOHLER NUMBER)
- <u>CLASSICAL FLAME EXTINCTION MECHANISM</u>:
  - HIGH TURBULENT MIXING RATES AT THE SMALL SCALES CAUSES LOCAL FLAME EXTINCTION AND EVENTUAL AFTERBURNING CESSATION

OBJECTIVES

1) ASSESS THE RELEVANCE OF AFTERBURNING CESSATION MECHANISMS IN FUEL RICH PLUMES

2) MAKE MODELING ENHANCEMENT RECOMMENDATIONS FOR ENGINEERING LEVEL PREDICTIVE CODES

ACCOMPLISHED OBJECTIVES THROUGH A COMPUTATIONAL PARAMETRIC STUDY OF A GENERIC AMINE BOOSTER.

COMPUTATIONAL METHODOLOGY

- **SIMULATIONS ACCOMPLISHED USING THE "GASP" CODE:**
  - GENERAL AERODYNAMIC SOLVER FOR COMPRESSIBLE REACTING FLOWS
  - INCLUDES MODERN, WIDELY ACCEPTED TURBULENCE MODELS
  - DRAWBACK: NEGLECTS THE EFFECT OF TURBULENCE-CHEMISTRY INTERACTIONS

- **MISSILE MODELING:**
  - SIMULATE THE ENTIRE MISSILE BODY, BASE AND PLUME
  - ASSUME ONLY AXISYMMETRIC BODY CONFIGURATION

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PARAMETRIC STUDY SIMULATION MATRIX

Case	Turbulence	Chemistry
A	yes	finite rate
B	yes	frozen
C	no	finite rate
D	yes, enhanced	finite rate

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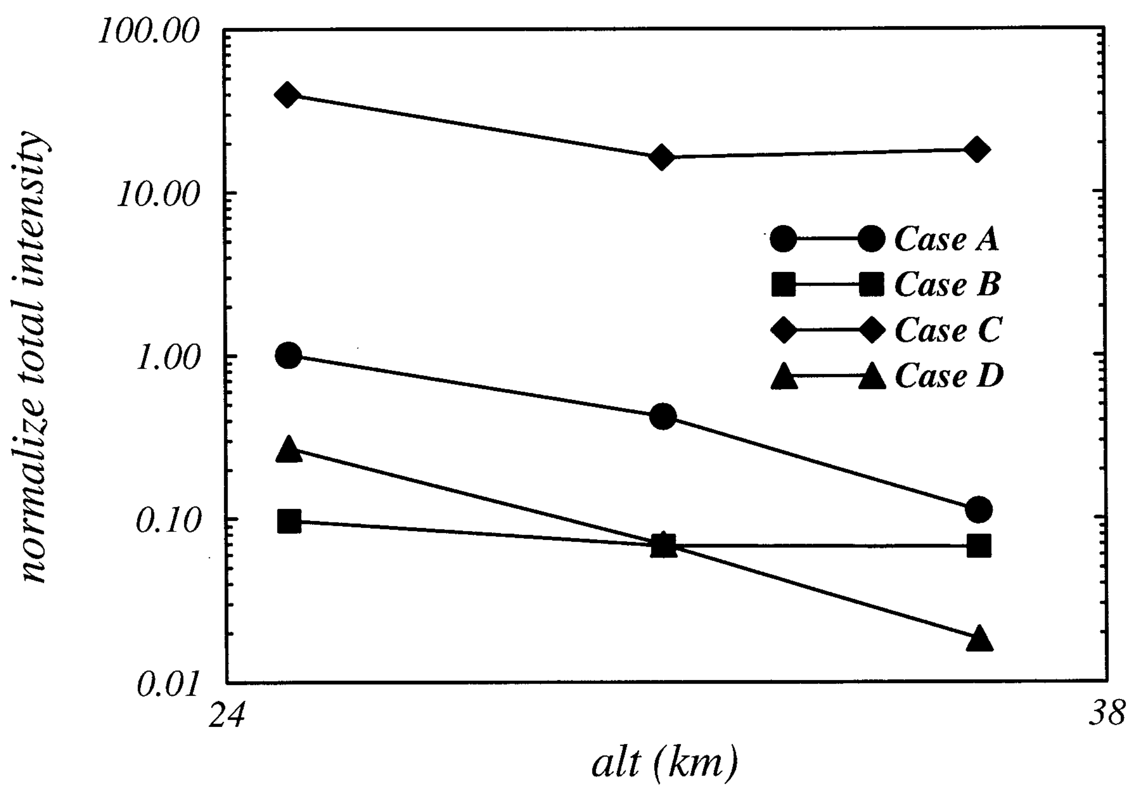
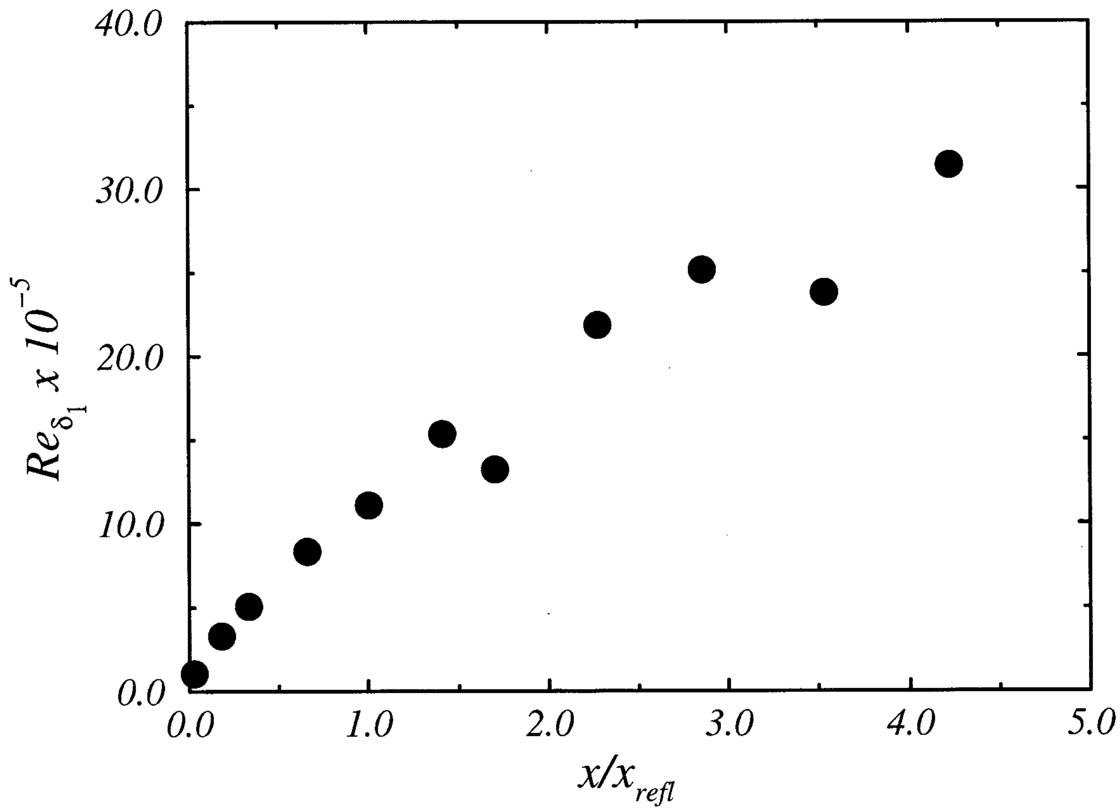
PREDICTED TOTAL RADIANT INTENSITY



REYNOLDS NUMBER ALONG THE PLUME SHEAR LAYER AT 35 KM

$$Re = \overline{\rho}\Delta U \delta_1 / \overline{\mu}$$



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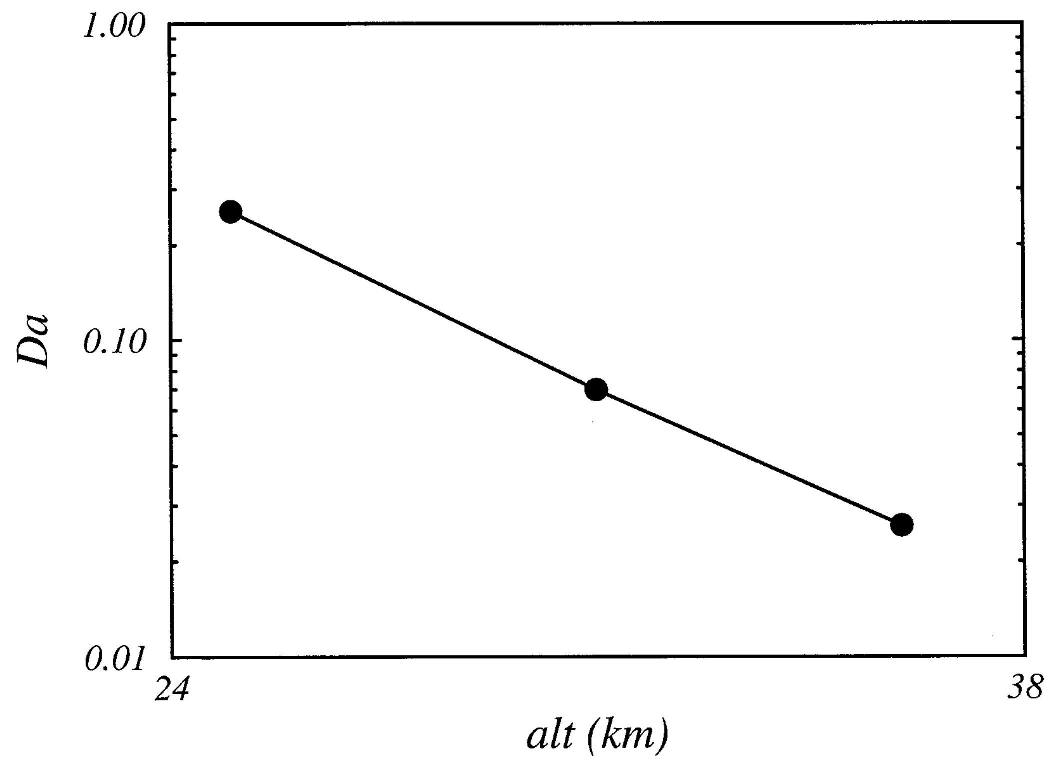
DAMKOHLER NUMBER VARIATION WITH ALTITUDE

$$Da = \tau_{mix}/\tau_{chem}$$



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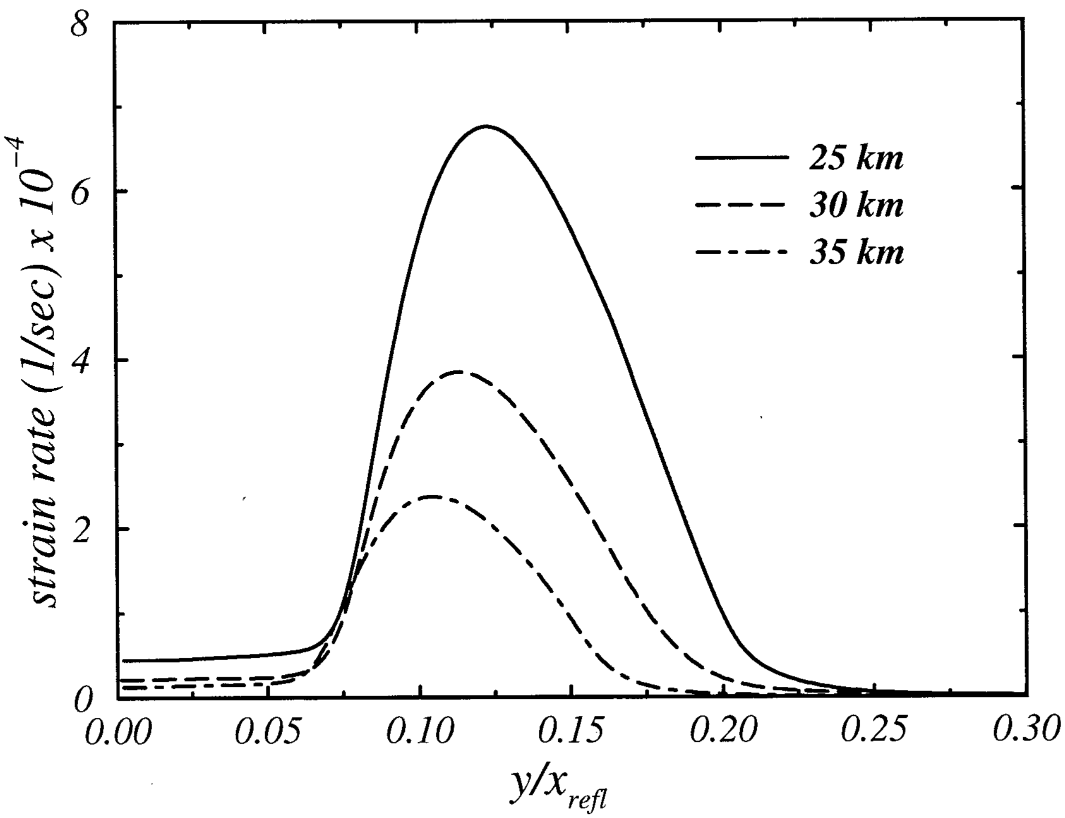
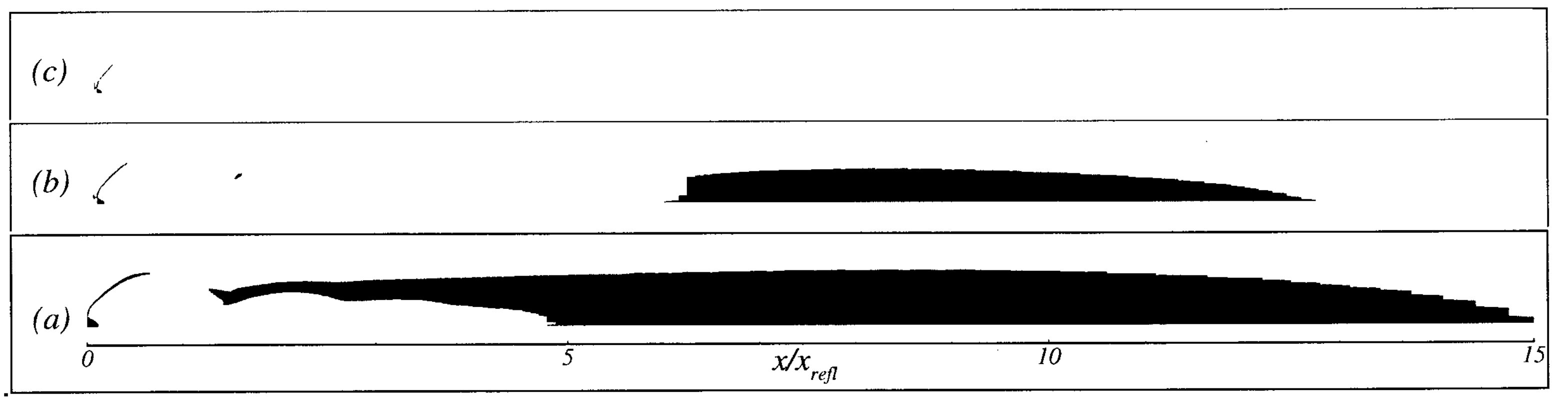
PREDICTED SMALL SCALE STRAIN RATE ACROSS THE PLUME

$x/x_{refl} = 2$



CONTOUR PLOT OF THE EXTINCTION MODEL BINARY SWITCH



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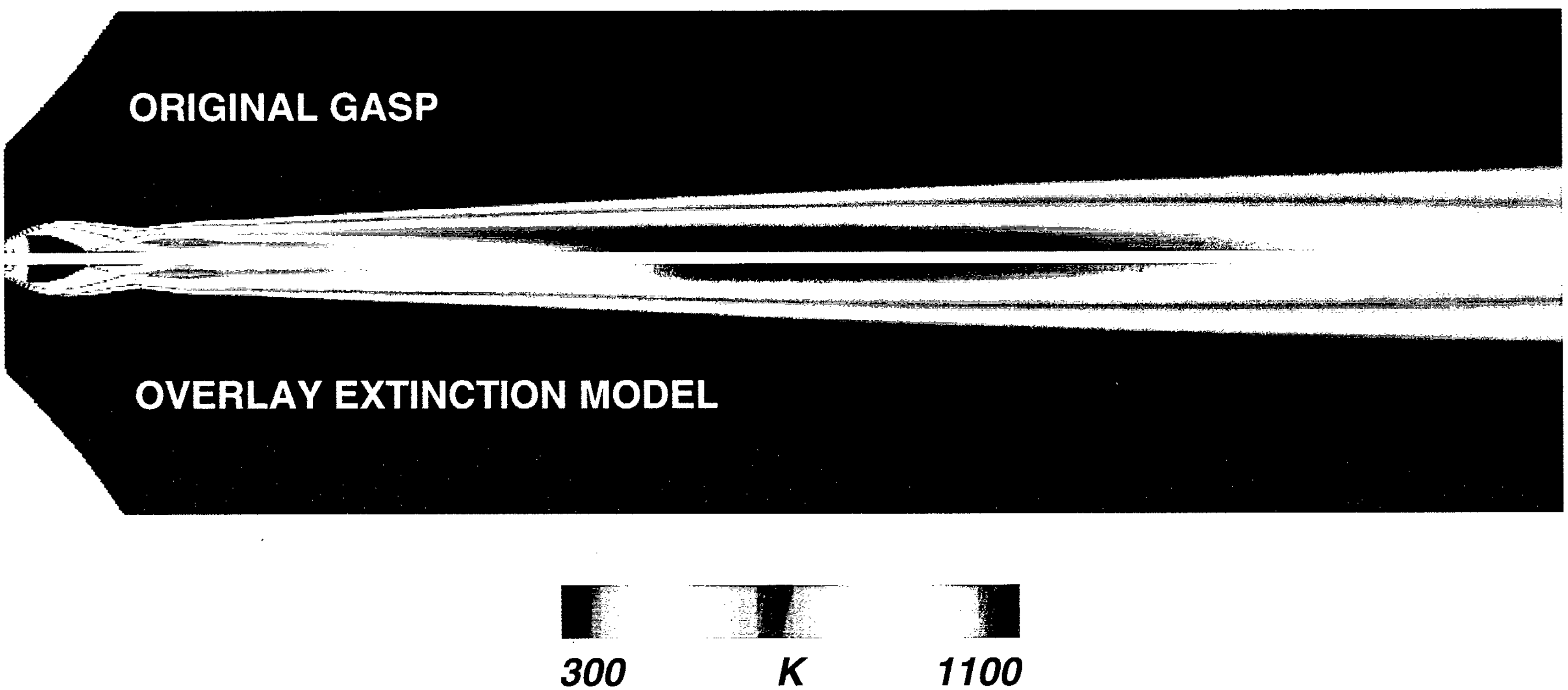
COMPARISON OF TEMPERATURE CONTOURS FOR THE ORIGINAL CODE AND WITH EXTINCTION MODEL AT 30 KM



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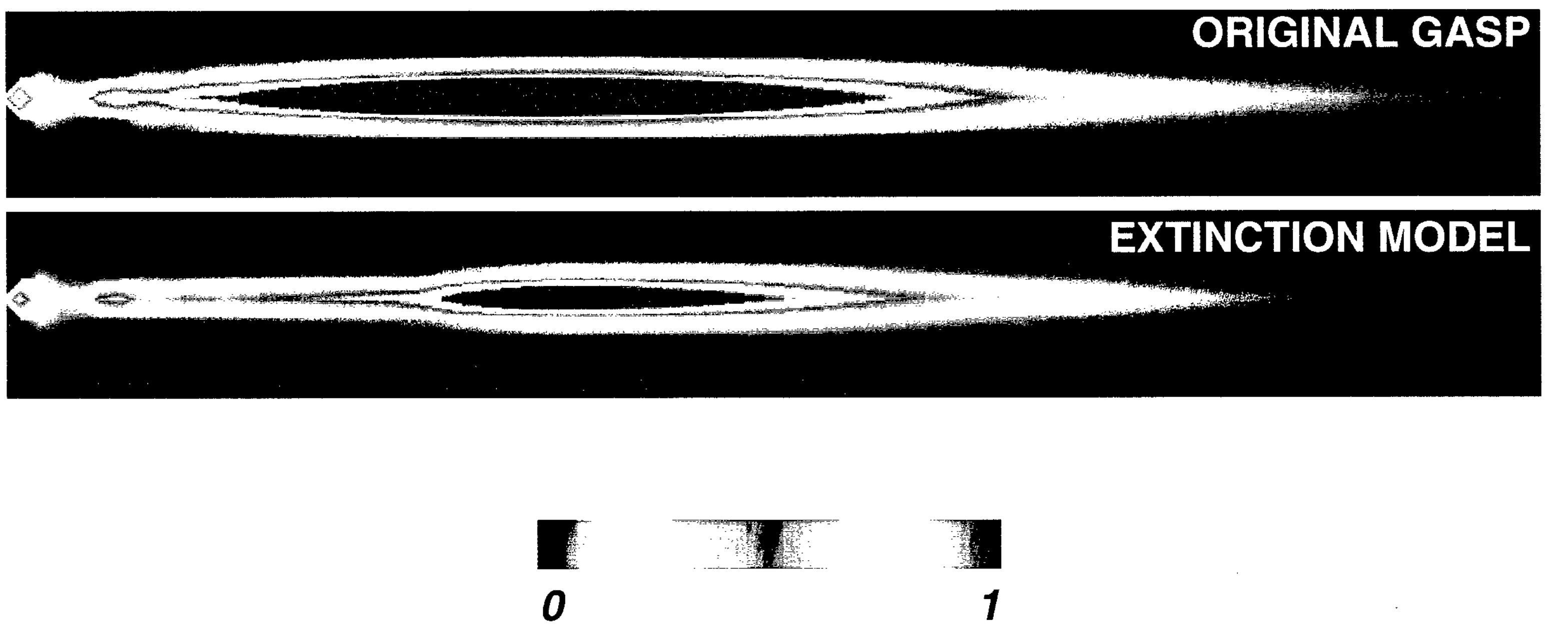
EFFECT OF EXTINCTION MODEL ON SPATIAL RADIANT INTENSITY PREDICTIONS AT 30 KM



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CONCLUSIONS

- RELAMINARIZATION MECHANISM IMPLAUSIBLE DUE TO HIGH PLUME CORE AND SHEAR LAYER TEMPERATURES

- DAMKOHLER EFFECT IS THE ONLY MECHANISM MODELED WITHIN MOST COMMERCIALLY AVAILABLE CODES, AND GENERALLY RESULTS IN GRADUAL SHUTDOWN EVENT

- CLASSICAL FLAME EXTINCTION MODEL FOUND TO PRODUCE RAPID AFTERBURNING SHUTDOWN EVENT AND SIGNIFICANTLY MODIFY RADIATIVE EMISSIONS CHARACTERISTIC

- FLAME EXTINCTION MECHANISM IS A PREVIOUSLY UNRECOGNIZED PHENOMENA OCCURRING IN ROCKET EXHAUST PLUMES