LIQUID ROCKET COMBUSTION PROCESSES

MULTI-TECH INC.

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TASK NO. II

Preliminary Accounting Outline

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  Task Statement

Preliminary Accounting Outline

FORWORD

This is a progress report on Task II, "Preliminary Accounting Outline". This is the second task on the engineering study "Literature Survey and Analysis of Liquid Propellant Rocket Engine Combustion Processes.

ABSTRACT

A preliminary accounting outline is presented. This outline is organized around a one-dimension element of a two-dimensional model which will accommodate local variations in behavior in respect to location and time. This element travels down stream at the velocity of the average gas particle and is designed to show the transverse differential conditions in the greater light.

The acquistion of the literature and the management thereof are discussed.

TASK STATEMENT

Abstract of Program Statement

This effort has been analyzed and set up in nine tasks. A literature search and analysis program has an initial search and acquisition effort followed by a period of intensive review and analysis.

The Preliminary Tasks are:

I Initiate the Survey
II Set-Up Preliminary Accounting Outline
III Prepare Preliminary Review of Major Information Gaps

The Intensive Review and Analysis Tasks are:

IV Combustion Processes
V Combustion Supported Waves
VI Stream Break-Up
VII Flow, Dispersion, and Mixing
VIII Completion of Descriptive Accounting Outline
IX An Assemblage of All Elements into An Intergrated Picture

TASK II <u>Set Up Preliminary Accounting Outline</u>

A preliminary accounting system will be set up to account for the energy, mass, and species balances occuring over the total period from injection to exit at the throat plane. This accounting will be step by step, volume-time element by element. The chamber's contents are not uniform in space or time. This accounting system will take the affluent materials and energies contributed from adjacent elements, subject them to the process steps of the space-time element under consideration, and this will become the effluent to be contributed to adjacent elements.

The report on this task will include:

1. Process flow diagram.
2. One dimension elements laid out for characteristics analysis in heterogenous systems.
3. Approaches will be postulated to accounting for the non-uniform effects of geometric position.

TWO-DIMENSIONAL MODEL

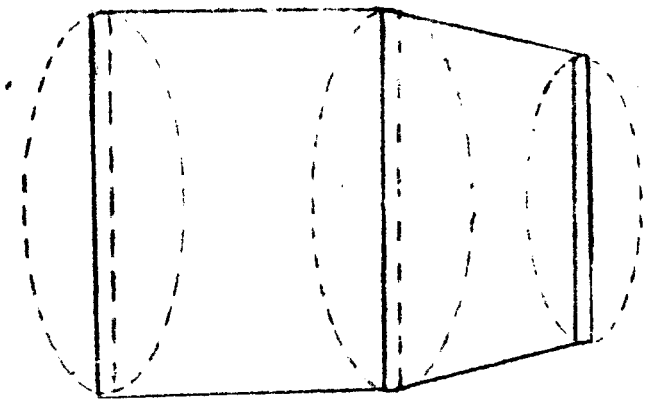
A thin slab section taken through the axis of a conventional chamber. The model starts at the injector face and runs to the "throat".

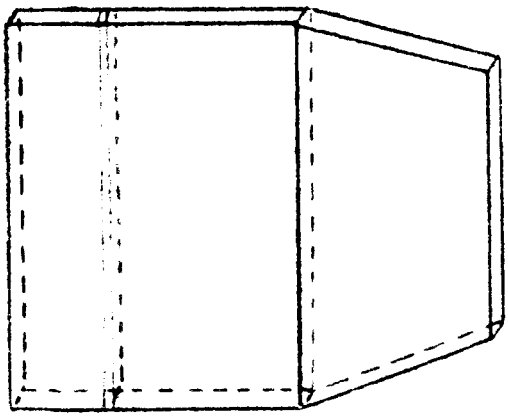
This model studied by assembling successive, one-dimensional elements oriented parallel to the injector face. These elments are identified with a given mass of gas generated near the injector face and moving downstream at the transverse average gas velocity. This element picks up mass and energy and in its expansion is accelerated downstream. The element overtakes and passes stream and drop fields. The element loses momentum due to the acceleration of the entrained condensed phases and gains momentum from the thermodynamic translation of the combustion energy to mechanical energy.

The composition of the element will vary:

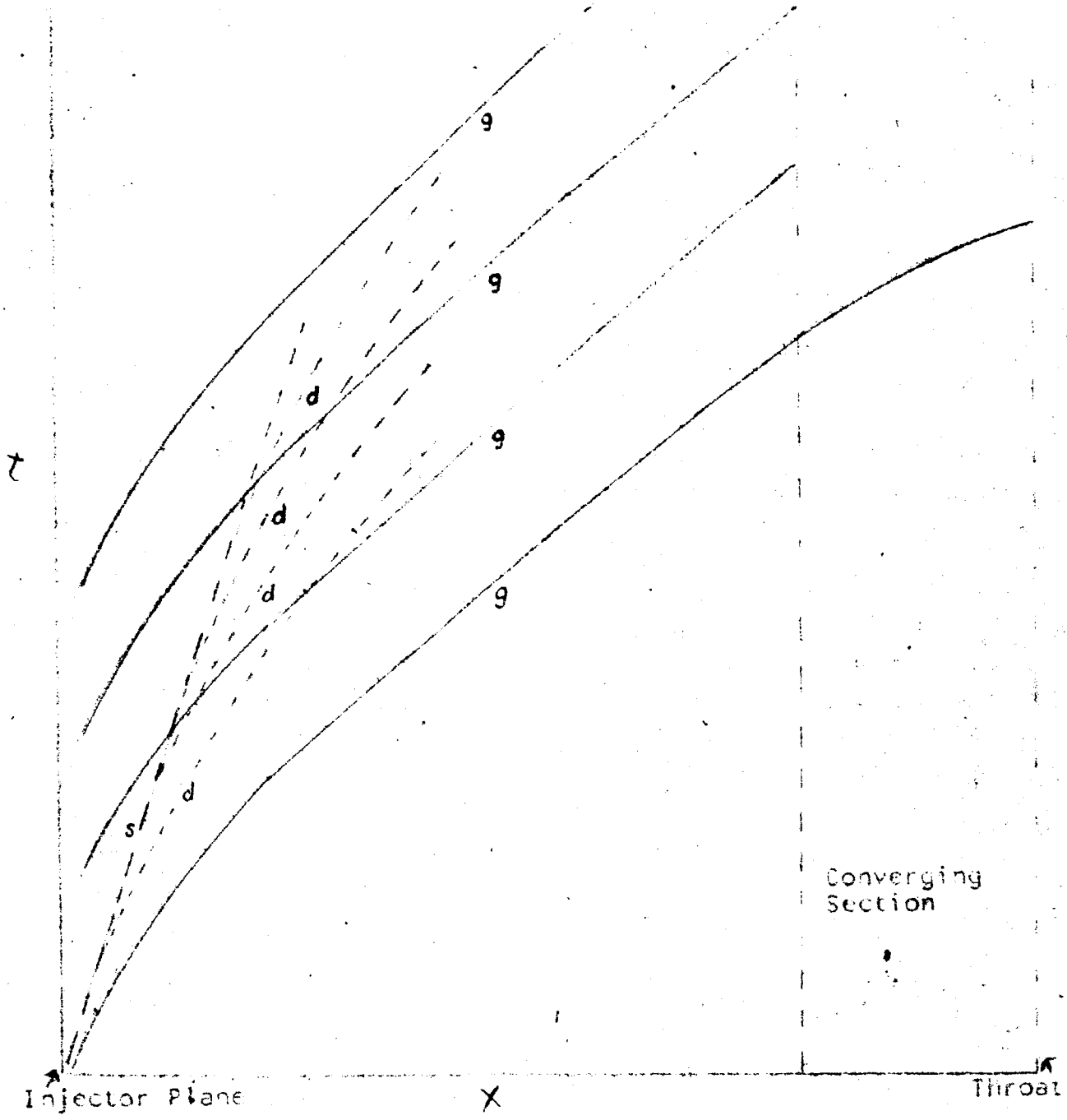
I. With respect to y and t due to positioning, dispersion, and wave of the streams or fans and alternation of propellants if they are un-mixed.

II. With respect to x and t due to gradients in break-up and consumption rates and to normal periodic fluctuations in stream and fan break-up.





Time - Distance plots of stream, drop and gas particles in rocket combustion chamber.



g. Trajectories of successive gas elements
s. Trajectory of stream starting with first gas element
d. Trajectories of drops shed by s and accelerated by gas drag

III PROCESSES WITHIN CELL ELEMENTS

STREAM ACTIVITIES

Stream Movements
Stream Displacement and Velocity Changes
Stream Mass Loss
- To Break-up
- To Evaporation

Mass Gain
Mass Loss

DROP ACTIVITIES

Displacement and Velocity Changes
Mass Gain
- From Adjacent Elements
- From Stream Break-up
- From Drop Break-up

Mass Loss
- To Adjacent Elements
- To Break-up
- To Evaporation

GAS ACTIVITIES

Mass Additions
- From Evaporations

Changes in Local Composition
Change in Local State
Response to State Changes
Accelerations
- Drag
- Growth
- Attenuation

Momentum Loss
- to Stream & Drops

IV LATERAL MOVEMENTS WITHIN

Gas Movements
Condensed Phase Displacement

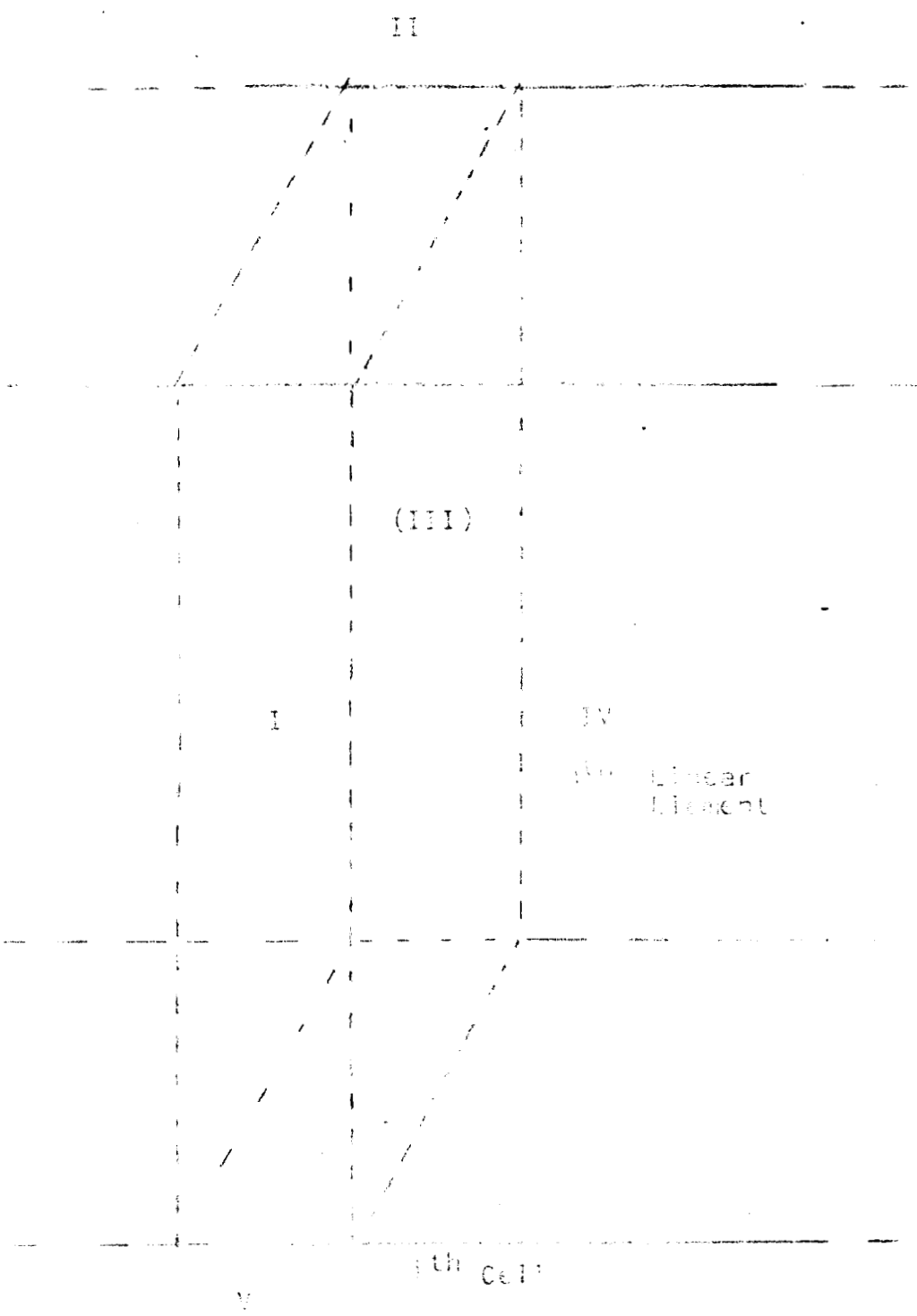
V CONTRIBUTIONS TO UP STREAM ELEMENTS

STREAMS

Location
Composition
Velocity Vectors
Structure & Shape
State
Mass Rate Efflux

DROPS

Location
Composition
Size & Velocity Distribution
Mass Rate Efflux



I INITIAL CONTENTS

GAS STATE AT START OF TIME INCREMENT

Composition
Velocity Vectors
Temperature(s)
Density
Heterogenity
Mass/Cell

CONDENSED PHASE

STREAMS

Location
Composition
Velocity Vectors
State
Mass/Cell

DROPS

Location
Composition
Size & Velocity Distribution
Mass/Cell

II CONTRIBUTIONS FROM DOWN STREAM ELEMENTS

STREAMS

Location
Composition
Velocity Vectors
Structure & Shape
State
Mass Rate Afflux

DROPS

Location
Composition
Size & Velocity Distribution
Mass Rate Afflux

OUTLINE OF LIQUID

A

Injection System

Feed System

Pressure Differentials

Orifice System

Pattern
- Gross
- Unit

Propellant Feed
- Gas-Gas
- Gas-Liquid
- Liquid-Liquid

Injection Rates

B

PROPELLANT PROPERTIES

Volatility

Viscosity

Surface Tension

C

CHAMBER GEOMETRY

Injector
- Symmetry
- Curvature

Chamber Style

Contraction Ratio

I

STREAM CONTENT IN ELEMENT

Stream Input

Stream Composition

Stream Distortion

Stream Loss
to Drop Formation

Stream Leaving Element

α

STREAM DISTORTION AND BREAK-UP

Undistorted Streams
- Reading Rates
- Waving Rate
- Shedding Rate

Impinging Streams
- Fan Spread
- Fan Wave
- Fan Break-up

A, B, C INPUT (DESIGN) DATA

ROCKET COMBUSTION

MULTIPLE PHASE TRANSPORT β

Lift

Drag

Shear

II

DROP CONTENT IN ELEMENT

Drop Mass Input
- Distribution of
  - sizes
  - velocities

Composition Distribution

Drop Mass Addition
- From Streams
- From Drops

Drop Mass Loss
- To other Drops
- To Evaporation

Change in
- Velocity Distribution

Drop Output

III

GAS CONTENT IN ELEMENT

Initial Contents

Local Mass Additions

Local M/R

Local Energy Release

Differentials in $\dot{M}$ and $\dot{Q}$

Gross Mixing

Gas Acceleration

Drag of Condensed Phases

Movement of Element

COMBUSTION PROCESSES γ

Local Combustion
- Transport processes about a drop
- Local M/R, pressure and relative velocity
- Energy Release Rates
- Changes in Species

Turbulent Gas Combustion
- Turbulent Mixing
- Combustion in Turbulent fields
- Energy Release
- Change in Species
- (Combustion under super-critical conditions)

COMBUSTION SUPPORTED WAVES δ

Combustion Irregularities

Local Pressure Relief

Wave Accentuation

Wave Growth

Wave Coordination of Combustion Activity

Intrachamber Processes Affecting Contents of Elements

I, II, III Contents of the Element and Their Changes

INJECTION SYSTEM	A
Feed System	10
Flow Variations	
Pressure Differentials	20
Site to Site Variations	21
Temporal Variations	22
Orifice System	30
Taper	31
Smoothness	32
Entrance & Exit	33
Sharpness	33-1
Angle	33-2
Pattern	40
Local	
Showerhead	41
Impinging (streams)	
Doublet	42
Triplet	43
Other Multiples	44
(Like on Like -1)	
(Unlike on Unlike -2)	
Presurface Mixing	45
Concentric	46
Gross Arrangement	48
Annular, Alternating Fan	
Wall Side Arrangement	
Spud	49
Propellant Feed	50
Gas-Gas	51
Monopropellant	-1
Premixed	-2
Injector Mixing	-3
Post-Injector Mixing	-4
Gas-Liquid	52
Preinjector Mixing	-1
Injector Mixing	-2
Post-Injector Mixing	-3
Liquid-Liquid	53
Monopropellant	-1
Premixed	-2
Injector Mixing	-3
Post-Injector Mixing	-4

INJECTION SYSTEM A(cont)

General

Transport of Entrained Solids	-5
Transport of Entrained Liquids	-6
Transport of Entrained Gases-for Throttling	-71
-for Turbulence Control	-72

PROPELLANT PROPERTIES B

Vapor Pressure - T - P Relations 10
Viscosity - T - P Relations 20
Surface Tension - T - P Relations 30
Density - T - P Relations 40

Reactance 60

"Performance" Relations 80

CHAMBER GEOMETRY	C
Chamber Style	
-Conventional	10
Annular	20
Reverse Flow	22
Spike Nozzle	24
Chamber Taper	30
Contraction Ratio	40

CONBUSTION SUPPORTED WAVES

Steps	Function of
∂ 10	I 13, 14, A 10, 20, 30, 40
∂ 20	∂ 10, ∂ 30
∂ 30	III 20, 30, 0
∂ 50	∂ 30, III 20, 30, I 10, 50, II 10, 20, 30
∂ 60	∂ 30, III 30, 60
∂ 80	A 10, I 10, 20, II 10, 40 III 10, 20

COMBUSTION SUPPORTED WAVES 9

Combustion Irregularities 10
$\Delta h/(\Delta t, \Delta x, \Delta y)$ 12
$\Delta s/(\Delta t, \Delta x, \Delta y)$ 14
$\Delta \dot{m}/(\Delta t, \Delta x, \Delta y)$ 16

Local Pressure Relief 20
Wavelets 22
Shock Waves 24

Wave Accentuation 30
Inphase Mass & Energy Additions 32
Accoustic Tuning 34

Wave Attenuation 50
Defraction due to Non-uniformities of Gas Medium 52
Interference due to Condensed Phases 54
Momentum Losses due to Condensed Phases 56
Accoustic Loss 59

Wave Growth 60

Wave Coordination of Combustion Activities 80

COMBUSTION PROCESSES

Steps	Functions of
γ 10	I 11, 12, II 12, 14, III 13, 14
γ 20	III 20, 21, 40, δ 20, I 12
γ 30	γ 20, B 30, III 12, 14
γ 50	III 40, 60 δ 60, 80
γ 60	γ 50, B 80
γ 80	I 20, II 20, 30, III 20, 40

COMBUSTION PROCESSES Y

Local Combustion
Transport Processes about a Drop 10
Local M/R, Pressure and Relative Velocity 20
Energy Release Rates 30

Turbulent Gas Combustion
Turbulent Mixing 50
Combustion in Turbulent Fields 60
-Energy Release 62
-Species Change 64

Combustion under Supra-Critical Conditions 80

MULTIPLE PHASE TRANSPORT

Steps	Function of
β 20	I 12, II 14, III 13, 14
β 40	I 12, II 12, 14, III 13, 14
β 60	I 12, II 12, 14, III 13, 14

MULTIPLE PHASE TRANSPORT	β
Lift	20
Drag	40
Shear	60

STREAM DISTORTION AND BREAKUP ∝

Sto, s	Function of
∝ 10	I 11, 12, 13, 14, III 13, A 10, 20, 30, 40
∝ 20	I 11, 12, 13, 14, 20 III 13, 60, A 10, 20, 30, 40
∝ 30	I 11, 12, 20, III 13, A 10, 20, 30, 40
∝ 50	I 11, 12, A 10, 20, 30, 40
∝ 60	∝ 30, III 13, 60
∝ 70	∝ 30, 60, 70

STREAM DISTORTION AND BREAK-UP

d

Undistorted Streams	
Beading Rate	10
Waving Rate	20
Shedding Rate	30
Impinging Streams	
Fan Spread	50
Fan Wave	60
Fan Break-up, Location	70
Shearing Rate	80

GAS CONTENTS OF ELEMENT

Steps	Function of
III - 10	A-50 γ 20, 30, 60, 80 B 10, 60, 80
III - 20	III 13, 14, B 10, I 10, 20 α, γ 30
III - 30	A 10, 20, 30, 40, 50, B 60, 80, I 10, 40, II 12, 40, III 20
III - 40	A 40, 50, γ 50, δ 60, 80
III - 50	III 20, B 80
III - 60	III 30, δ 10, 20, 60, 80
III - 70	III 50, 60, β 20, 40, 60, II 40, I 50
III - 80	III 30, γ 30, 60, 80

GAS CONTENTS OF ELEMENT III

Initially defined gas contents 10
Source 11
Local Compositions 12
Local Velocities 13
Local States 14

Local Mass Additions (from evaporation) 20
New Local M/R 21
Local Engergy Releases 22
Species Change 23

Differentials in Mass Additions and Energy Release 30

Gross Mixing 40
Energy Release 41
Species Change 42

Gas Acceleration 50

Gas Lateral Movements 60

Momentum Exchange with Condensed Phases 70

Movement of Element to New Time- Location Station 90

DROP CONTENTS IN ELEMENT

Steps	Function of
II - 10	II 90 (from previous element)
II - 20	I-12, 13, 14, 20, 40, III 13, 14, 50, 60
II - 30	II 10, III 13, 14, 50, 60
II - 40	II 10, I 30, 40, 20, 40, 60 III 13, 14, 40, 50, B 20, 30
II - 50	II 10, B 10, 20, 30, 40, III 13, 14, 20, 40, 50, 60
II - 90	II 10 - 50

DROP CONTENTS IN ELEMENT 11

Drop Population Overtaken by Element 10
Size Distributions 12
Velocity Distributions 14

Drops Added by Stream Shedding 20

Drops Added by Drop Shedding 30

Changes in Location & Velocity of Each Drop Size 40

Changes in Mass of Each Drop Class Size 50
Evaporation 51
Shedding (or break-up) 52

Drop Population Leaving Element 90

STREAM CONTENTS IN ELEMENT

Steps	Function of
I - 10	A 10, 20, 30, 40, 50, B
I - 20	A 10, 20, 30, 40, γ 50, 60, 70 III 10, 40, 50, 60, β 20, 40
I - 30	I 20, β 60, III 13, 50, 60, 70
I - 40	β 20, 40, III 13, 40, 50, 60 C 30, 40
I - 50	I 10, 20, 30, 40, β 20, 30, 60 III 70 λ 54, 56
I - 90	I 10, 20, 30, 40, 50

STREAM CONTENTS IN ELEMENT 1

Stream Overtaken by Element 10
Dimensions 11
Velocity Vectors 12
Instabilities 13
Periodicities 14
Stream Distortions 20

Stream Mass Loss Due to:
Drop Formation 30

Stream Displacement 40

Momentum Exchange with Gases 50

Stream Leaving Element 90