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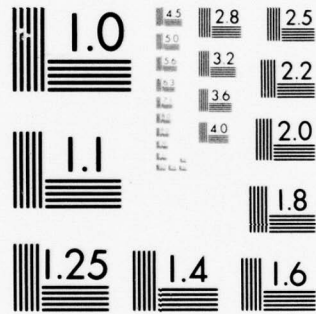
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ELECTRONIC RADIATION IN THE VICINITY OF
SYNCHRONOUS ORBIT SATELLITES: Literature Search

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through instability and/or the presence of plasma boundaries. Both theoretical and experimental references are included in each category where possible.

The breakdown of Plasma, which is a 'necessary' condition to the generation of discharge currents in plasma, is a much studied phenomenon both theoretically and experimentally. The references 6a of this report, together with the bibliographies associated with each reference, provide a representative information base to support either a critical review of important elements of breakdown and electrical discharge literature from about 1960 to the present time, or an ordered resume of breakdown characteristics as determined in that time period.

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ELECTROMAGNETIC RADIATION IN THE VICINITY
OF SYNCHRONOUS ORBIT SATELLITES:
LITERATURE SEARCH

1. INTRODUCTION

A satellite at synchronous altitude acquires a charge, sometimes of extreme magnitude, which can adversely affect on-board electronics by subjecting them to large electromagnetic stress. A possible source of such undesirable radiation, for example, can originate from the power coupled from breakdown currents flowing near the satellite. Another potential source of disruptive radiation occurs if the charged satellite excites an unstable plasma to radiate from the plasma interior or boundaries. Instability can possibly produce a turbulent wake with associated noisy radiation. Though all these mechanisms are possible sources of undesirable radiation, emphasis is initially placed on discharge phenomena.

It is important to develop realistic estimates of the levels of radiation associated with the satellite motion through the complex and variable magnetospheric plasma. Plasma behavior is modelled by equations that contain defining plasma parameters and a number of characteristic terms. The more complex the plasma model, the more difficult is the solution of the plasma equations. Realistic calculations should use the simplest plasma models that adequately predict discharge currents and/or waves excited in unstable plasma.

This report begins the task of generating realistic estimates of satellite radiation levels and is concerned mainly with acquiring and

categorying a suitable information base. The report is intended to present a systematic approach and to exploit the present state of the art of plasma physics where possible and profitable. The accompanying literature search provides an overview of this many sided subject as it applies to the objectives of the investigation.

The mechanism responsible for disturbing radiations produced by a charged satellite's interaction with its plasma environment depends in one instance on the time dependent behavior of a plasma that changes due to external and/or self-consistent fields. In the other instance, radiation depends on the excitation of the complex plasma medium.

In the first case, it is required to know the initial conditions of the medium and to have models to describe behavior at later times. In the second case, it is required to know the dispersion characteristics of the medium and interaction criteria that determine the excitation of waves or oscillations in the body of the plasma or at boundaries.

In either case, the appropriate plasma model used to predict currents, or waves and oscillations can be generated by estimating certain plasma parameters (see Figure 2). These depend fundamentally on particle species, densities, energies, cross sections for various reactions and field strengths.

The block diagram of Figure 1 displays the components of the plasma medium (ambient and satellite generated) that contribute to the total environment.

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The literature search is organized into categories as displayed in Figure 1. The elements of Figure 1 are further discussed on Page 5 .

It was judged useful to include an appendix to the report, in which the following items are given as additional information:

- A. A list of defining plasma parameters in general use.
- B. A block diagram displaying the relationship between plasma parameters that define a plasma model.

The literature search also includes a list of references related to the lightning discharge mechanism, because this familiar and much studied phenomenon has features that resemble those of the charged satellite:

- A charge separation mechanism powers discharges in each case.
- \bar{E} fields must become intense enough to break down the medium (ionize it) so that discharge currents can flow.

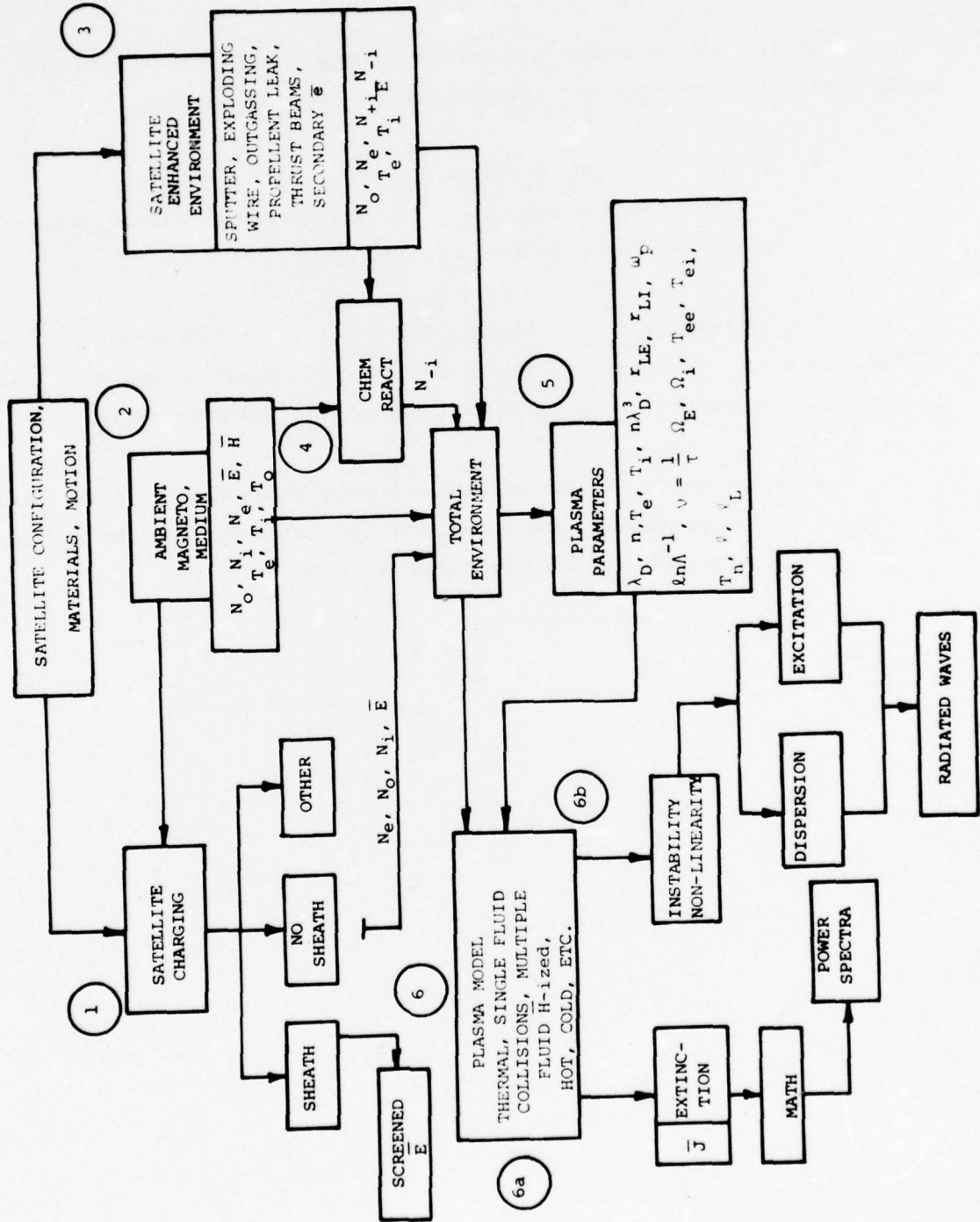


Figure 1. Flow Chart Satellite Charging Literature Search

The categories 1 through 6 a, b displayed in Figure 1, identify independent areas of literature search that are "input" to the tasks of estimating radiation incident to a synchronous orbit satellite from external media. Before estimates of discharge current generated spectra or of waves and/or oscillations excited in unstable plasma can be attempted, a description of the plasma medium is necessary. Only then, can the synthesis of a suitable plasma model be initiated to generate the desired estimates and predictions in accordance with the state of the art plasma physics.

The categories 1, 2, 3, 4 determine the total plasma environment, and each category is a somewhat independent area of theoretical and experimental research. The symbols N_o , N_i , N_e , \bar{E} , \bar{H} , T_e , T_i , T_n are descriptive of the basic constitution of the medium (particle densities, energies and the interacting field environment). The relative magnitude of ambient particle fluxes is also an important determinant in Category 2 and is not shown in Figure 1. The other symbols are defined as follows:

$$\begin{aligned}
 N_o &= \text{number density of neutrals} \\
 N_i &= \text{number density of ions} \\
 N_e &= \text{number density of electrons} \\
 \bar{E} &= \bar{E} \text{ fields} \\
 \bar{H} &= \bar{H} \text{ fields} \quad \left. \vphantom{\begin{matrix} \bar{E} \\ \bar{H} \end{matrix}} \right\} \text{externally applied and self consistent fields} \\
 T_e &= \text{electron temperature} \\
 T_i &= \text{ion temperature} \\
 T_n &= \text{neutral temperature}
 \end{aligned}$$

In the neighborhood of a synchronous satellite, the above items can be complex functions of position within a Debye length of a satellite surface where discharges must originate. Part of the task of estimating discharge currents, for example, is to introduce reasonable simplifications and approximate plasma models in regions sensitive to breakdown and lying within this sheath.

The Category 5 representative references address the task of estimating plasma parameters that are suitable to define plasma models. The plasma parameters are defined in Appendix A.

Category 6 includes references relevant to the task of selecting an appropriate plasma model sufficient for the objectives of interest. The definition of plasma models is given in Appendix B.

The references 6A apply to the Task of estimating the \bar{E} field strength producing breakdown of plasma, the conductivity of the plasma and other conditions critical to discharge currents produced in the broken down plasma, as powered by the satellite induced charge separations. The references are chosen to deal with elements of analysis essential to estimating currents realistically and in the present state of the art of plasma physics.

The references 6B apply to waves and oscillation produced in unstable plasma.

2. BIBLIOGRAPHY OF REPRESENTATIVE REFERENCES

Although discharge of a charged satellite can occur either through material breakdown within the satellite itself or by breakdown of the external medium, this literature search examines only the case of radiation produced in the external medium. Strong discharge currents require that the plasma be broken down (ionized by electron impact). Hence, the region of interest must contain sufficiently strong \bar{E} fields. This limits the region of interest (in the case of discharge phenomena) to the plasma sheath enveloping satellite surfaces, because the fields are screened in regions beyond the sheath.

The plasma models must be sufficiently realistic to describe a plasma that is not quasi-neutral and also include the relevant inelastic, elastic and diffusion processes that determine the magnitude of breakdown \bar{E} fields and the subsequent time dependent behavior of plasma. Other radiation mechanisms depending on plasma instability may not necessarily be confined to the plasma sheath or necessarily require that plasma be electrically broken down.

The initial conditions for the plasma in the sheath depend on the satellite charging process and possibly on its time dependent behavior in building up charge and \bar{E} fields. The references 1.1-1.7 are concerned with this process. Reference 1.3 is particularly oriented toward formulating the basic physical and mathematical model of satellite charging.

The breakdown of plasma in the sheath can be investigated theoretically, leaving the initial conditions open, and using a suitable set of plasma equations (model). The magnitude of the minimum breakdown \bar{E} field depends to a large degree on the amount of easily ionizable material present. Thus, the products of the interaction of ambient particles with the satellite surfaces that produce neutral particles (e.g., neutrals reflected, +ions neutralized, outgassing, sputtering) are possibly critical to breakdown characteristics. Also relevant to breakdown are the changes in the medium produced by products of thrusting systems. A neutral system may produce easily ionized or attaching molecules. An ionized thrust beam (satellite generated) can clamp the satellite potential to some lower value manifested in plasma external to the sheath. These considerations are the subjects of references 3.1-3.4.

Because unusual chemical reactions can occur in the presence of the discharges, the references 4.1 and 4.2 are included. Of most interest is the possibility of negative ion formation and the effect on breakdown of low ion mobility compared to the mobility of electrons.

The references of Category 5 consider criteria in standard use to develop plasma models.

The references 6A are chosen as representative of those that are concerned with both theoretically oriented and applications oriented aspects of plasma behavior. The list of DDC reports on Electrical Arc and Plasma contains a mix of theoretical and experimental investigations of breakdown

9.

behavior of plasma. Similarly, a theoretical and experimental mix can be found on more general plasma subjects in references 6A6-6A12. The reference 6A16 is of practical interest, as it parameterizes the cross sections of inelastic reactions (exciting, ionizing) through a "Maxwellian Model". A similar approximate modelling of reactions in the collision integral may be sufficient for the breakdown investigations of interest.

The references 6B, dealing with instability are chosen to be representative. Reference 6B1, which has also been cited elsewhere, presents an extensive bibliography. Once the appropriate plasma model is determined (refer to Figure 2 in the Appendix) it is expected that a considerable narrowing of the field of relevant references can be readily effected.

The references 6B3 and 6B4 examine the dispersion expressions using linear theory. Other references seem to establish the ability of linear theory to predict stability, though non-linear theory (refer to 6A21) is needed to describe the unstable behavior. The references 6B5 and 6B6 investigate the two general categories of plasma instability independently.

The possibility of a radiating turbulent wake developing should the plasma be unstable has been mentioned briefly in reference 1.3. The conjecture was applied to a satellite moving through the ionosphere. Whether this possibility is also applicable to the magnetospheric medium is perhaps even more conjectural. However, the references 6B7 and 6B8 on turbulence have been included as possibly relevant references.

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 FEB 71 71P BENENSON, D. M. ; CENKNER, A.

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 M. ; TAYLOR, P. ; BENEDETTO, K. R. ;

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 AUG 70 278P HUNTER, A. M. , III;

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DESCRIPTIVE NOTE: TECHNICAL REPT. JUN 66-MAR 67,
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 EXPERIMENT.

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LOW FREQUENCY INSTABILITIES IN INHOMOGENEOUS
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RESEARCH ON UNSTABLE OSCILLATIONS IN ENERGETIC
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DESCRIPTIVE NOTE: FINAL TECHNICAL REPT., 1 MAR 65-30

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ON AN EQUATION RELATED TO NONLINEAR
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3. CONCLUSION AND RECOMMENDATIONS

An initial review of the literature in the categories chosen for literature search reveal that all categories are much involved with various aspects of plasma physics. A critical review of the literature in each category then appears to be a logical next step. However, because the objectives are relatively narrow, requiring the estimation of radiation incident to a synchronous satellite, it is expected that the depth to which each category need be investigated, can be correspondingly moderated.

Assuming that radiation produced by discharge currents in external media is the most likely source of undesirable external radiation, suggests that analysis begin with the electrical breakdown of diffuse plasma. A plasma model which includes a set of expression for charge continuity, current or momentum density and energy balance and is descriptive of a suitable multi-component plasma is first generated. The model is chosen to apply to a range of plasma parameters descriptive of the synchronous satellite's tenuous particle and field environment.

Electrical properties such as conductivity and self inductance of discharge streamers is then estimated. The synthesis of discharge current wave forms can be undertaken as determined by the time dependent processes of charge separation, plasma breakdown, discharge streamer growth, and discharge current flow with equalization of charge separation.

In focusing investigation in this manner, a range of estimated current wave forms and their spectra corresponding to a range of satellite plasmas can be generated. These can be compared with experimental measurements and with satellite data as a basis to refine or alter plasma models and calculations.

APPENDIX A
PLASMA PARAMETERS

β - ratio of plasma pressure to \bar{H} pressure = $8\pi n \frac{kT}{B_0^2}$

η_σ (cm^{-3}) - particle density (specie σ , $\sigma = e \rightarrow$ electron)

$T(\text{ok})$ - absolute temperature

$B(\text{G})$ - \bar{B} field in Gauss

λ_D (m) - Debye length = $\sqrt{\frac{\epsilon_0 kT}{e^2 (1 + Z^2) n_e}}$ (MKS units)

$\frac{4\pi n \lambda_D^3}{3}$ - number of particles in a Debye sphere

ℓ (cm) - characteristic scale of plasma region

λ (cm) - mean free path = C_{th}/ν

ν (s^{-1}) - collision frequency of a particle

u_\perp is velocity \perp to \bar{B}

r_{LE} (cm) - electron gyration radius = $m_e u_{\perp E}/eB$

r_{LI} (cm) - ion gyration radius = $m_I u_{\perp I}/eB$

Ω_E (s^{-1}) = $e B/m_e c = \frac{u_{\perp E}}{r_{LE}}$ = Larmor frequency of electrons

Ω_I (s^{-1}) = $e B/m_I c$ = Larmor frequency of ions

λ_L = mean distance of closest approach \rightarrow PE. = K.E

(i.e., $\lambda_L = Ze^2/kT = 1.67 \times 10^{-3} Z T^{-1}$)

$\lambda_n(\Lambda^{-1}) = \lambda_n \frac{\lambda_D}{\lambda_L}, \Lambda^{-1} = 4.9 \times 10^{14} T^{\frac{3}{2}} n^{-\frac{1}{2}}$

NOTE: Λ is an important parameter which indicates the degree to which collective effects exceed individual particle effects.

$$C_{th} = \text{thermal velocity} = \sqrt{\frac{3kT}{m}} \quad m = \text{particle mass}$$

$$\lambda_B = \frac{h}{mC_{th}}$$

NOTE: $\lambda_B \ll \ell_L, \eta^{-\frac{1}{3}} \rightarrow$ quantum effects are negligible

$$\omega_p (s^{-1}) - \text{plasma frequency} = \frac{C_{th}}{\lambda_D} = \left(\frac{4\pi n_e e^2}{M_E} \right)^{\frac{1}{2}} = 5.6 \times 10^4 \sqrt{n_e}$$

$$\tau = \frac{1}{\nu} = \text{average time of one collision}$$

$$\delta = \frac{\text{electrostatic energy}}{\text{thermal energy}} \approx \frac{e\phi}{kT}$$

$\delta \rightarrow$ small implies plasma behaves thermodynamically as a perfect gas,
 $p \approx nkT$

$\alpha =$ degree of ionization

$$\alpha < 10^{-4}, \quad N_E \ll N_N \quad \text{weakly ionized}$$

$$\alpha > 10^{-4}, \quad N_N \ll N_E \quad \text{strongly ionized}$$

APPENDIX B
PLASMA MODELS

FIGURE 2

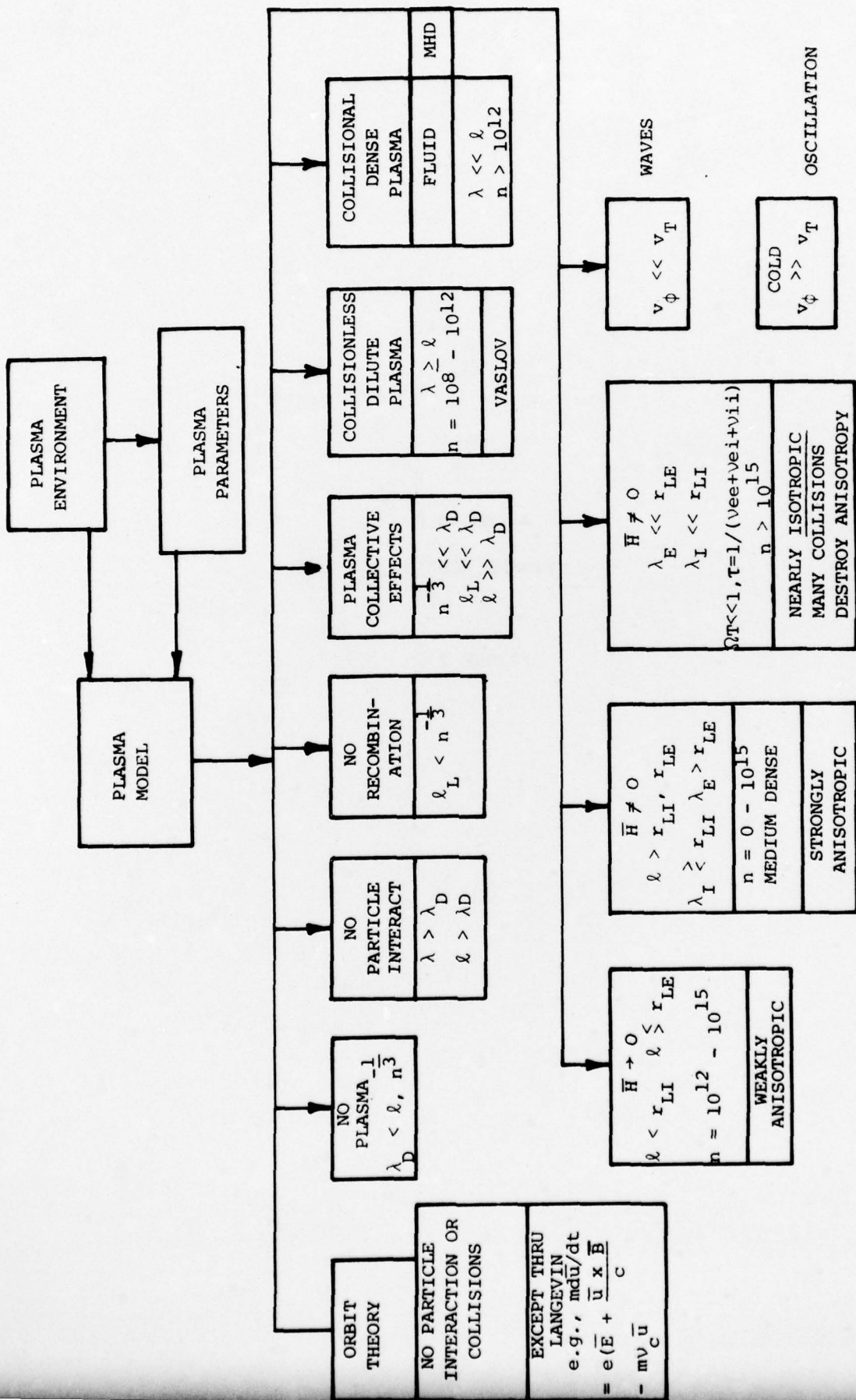


Figure 2 Plasma Models