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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report, the sixth in a series on this subject, focuses on the NRL laser facility, new experimental results from it, and computer models for the experiments. The NRL facility continues to be upgraded in experimental and diagnostic capability in a sensible and commendable manner. The experimental plan is good and the experiments will continue to be powerful tools for understanding debris-air coupling processes for early-time. This tool is very appropriate to the collisional regime. We anticipate it to be a substantial contribution to the understanding of collisionless coupling also, both with and without magnetic fields. It remains very important to stay focused on the critical question of early-time debris-air coupling related to late-time spatial structures.

We recommend cataloging collisionless phenomena for consideration while continuing to perform collisional experiments. Early-time shadowgraphy with radiating ambient gasses should be considered. While aneurysms remain an interesting phenomena, we caution that they

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19. ABSTRACT (Continued)
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Early-Time HANE Simulation and Experiment

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May 1987

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1.0 INTRODUCTION AND SUMMARY

In 1985 JASON conducted its sixth summer study on the effects of high altitude nuclear explosives (HANEs) on the ionosphere and ionospheric communications. This year we concentrated on the upgraded NRL laser facility, new experimental results coming from it, and computer simulations designed to model various aspects of the experiment. We also heard briefings on the connection of certain phenomena, observed in STARFISH and CHECKMATE, to the early-time experimental results.

During the five years of JASON involvement in the DNA HANE program, many of the important physics issues have been identified and discussed at length in our earlier reports, so we forego detailed elaboration of the basic physics problems. This year's brief report will focus on current and projected work - both experimental and theoretical, including simulations - designed to address these physics issues.

Our general impression is that the NRL laser experiments are and will continue to be very powerful tools for understanding debris-air coupling processes for a certain part of the time history of the early-time regime. The accompanying theory and simulations, though presently incapable of dealing with all of the relevant physics and chemistry, are well-matched to the present level of experimental understanding of the collisional regime ($p > 1.5$ Torr). There is much hope that straightforward continuation of the present efforts (including careful consideration of finite UV radiation lifetimes in the coupling process) will lead to a broad understanding of collisional coupling, except possibly for very early times where details of the target-laser interaction are important and at times too large for the debris to be contained in the plasma chamber. However, this understanding will require the use of new diagnostics, some of them planned for the future but not yet in routine use. These include multi-spectral shear interferometry, possibly coupled with Faraday rotation measurements, and the coherent Thomson-scattering laser probe, possibly operated with a streak camera. Obstacles in the way of the blast wave may also be useful in the collisional regime, although these will be more interesting for collisionless shocks.

Both the level of experimental effort and the level of theoretical understanding are lower in the collisionless regime. It is evident that coupling diminishes as the ambient pressure goes down, in general accord with what simulations predict. But the influence of, and mechanisms for generating, magnetic fields are not well understood, nor is it clear why aneurysms do not form when collisions are reduced. Answering these questions will require more sophisticated two-dimensional hybrid codes.

Since very early-time laser-target interactions could very well lead to persistent structure effects at late times, it is important to study the widest possible array of target geometries, both experimentally and with simulations. Of special interest are back-illuminated targets, and targets designed to mimic CHECKMATE, which may well have produced many debris fragments that, though vaporized, maintained their identity for long times. This possibility, long espoused by Walt Chesnut, was dealt with in some detail in last year's JASON report on HANEs.

These and other issues are summarized in Tables 1-1 and 1-2 and the rest of the report supplies supporting detail. Our overall impression of the early-time HANE program continues to be good. We can envisage substantial understanding of both collisional and collisionless coupling, both with and without magnetic fields, emerging from this program. But the workers in the program must always keep one question foremost in their minds: How is early-time debris-air coupling ultimately related to late-time spatial structures? Answering this question is a formidable task.

TABLE 1-1

EARLY-TIME HANE SIMULATION ISSUES
EXPERIMENTAL

COLLISIONAL ($p > 1.5$ Torr)	COLLISIONLESS ($p < 1.5$ Torr)
DEBRIS-AIR COUPLING: AFTER 1 EQUAL-MASS RADIUS, FORMS NORMAL (RAYLEIGH-TAYLOR STABLE) TAYLOR-SEDOV BLAST WAVE. IS IT R-T UNSTABLE EARLIER? WHAT'S INSIDE?	**DEBRIS COUPLES POORLY TO AIR:** RUNS AHEAD OF BLAST WAVE; DEBRIS ELECTRONS FORM MAGNETIC PULSE. SOME AIR IONS REFLECTED ($V = 2V_D$)
ANEURYSMS: BULGES ON BLAST WAVE. FORMED HOW? WHEN? DECAY? IMPACT ON LATE-TIME STRUCTURE? RELATED TO LASER BEAM IN AMBIENT GAS? TO LASER-TARGET INTERACTION?	**NO ANEURYSMS:** WHY NOT?

DEBRIS-TARGET INTERACTION: NEED TO STUDY A VARIETY OF TARGETS (BACK-ILLUMINATED; DOUBLE FOIL; CAVITY; FRAGMENT-RICH)

UV PROBLEM: RADIATION LIFE TIMES NOT SHORT COMPARED TO DEBRIS TIME SCALES (UNLIKE REAL HANE). USE Xe OR MRC GAS AS AMBIENT.

DIAGNOSTICS: MULTI-COLOR SHEARING INTERFEROMETRY: COHERENT THOMSON SCATTER; FARADAY ROTATION; OBSTACLES (FORM COLLISIONLESS SHOCK?)

TABLE 1-2

EARLY-TIME HANE SIMULATION ISSUES
THEORY AND COMPUTATION

PRESENT EARLY-TIME CODES: 1D HYBRID (FLUID ELECTRONS, USUALLY MASSLESS). DO NOT ADDRESS STRUCTURE ISSUES. WELL-MATCHED TO CURRENT EXPERIMENTS EXCEPT FOR UV PROBLEM, ANEURYSMS.
NEW CODES NEEDED: 2D HYBRID. MAY REQUIRE SPECIAL-PURPOSE ARRAY PROCESSORS. WILL ADDRESS: SPONTANEOUS MAGNETIC FIELDS, SOME ASPECTS OF STRUCTURE FORMATION (ANEURYSM?). ALSO, CODES WITH FINITE UV LIFETIMES, RADIATION TRANSPORT. NEED MORE LASER-TARGET SIMULATIONS WITH A VARIETY OF TARGETS.
RELATION OF DEBRIS-AIR COUPLING TO STRUCTURE FORMATION: IS THERE A CLASSICAL R-T INSTABILITY AT ~ 1 EQUAL-MASS RADIUS? DOES IT HEAL LATER (CONDITIONS CHANGE TO STABLE)? FOR COLLISIONLESS CASE, DOES ANOMALOUS RESISTIVITY EXIST? DOES IT AFFECT STRUCTURE FORMATION?
LESSONS FROM SPACE PHYSICS: ANOMALOUS RESISTIVITY NOT WORKING WELL FOR AURORAS; BOW SHOCK; TAIL NEUTRAL LINE. INERTIAL EFFECTS AND SPATIAL GRADIENTS MORE IMPORTANT. NEED TO RE-THINK NRL-3076 VIEWPOINT.

2.0 THE NRL EXPERIMENT

In this section, we shall briefly present a few thoughts on the HANE simulation experiments underway at NRL. We shall not attempt to summarize them here since there is now plenty of written literature by the NRL group that does that. In general, we feel that the experiments have gone well so far. We especially like the way the NRL group accepts suggestions for experiments from outsiders, and the way they continually expand their diagnostic capability and improve existing diagnostics. With regard to the future, we believe that it is important for the experimentalists to take advantage of the full range of capability of their new apparatus as soon as possible. By this, we mean that as soon as the new diagnostics and the magnetic field coil are checked out, both collisionless and collisional interaction experiments should be run under a variety of target, laser, and magnetic field conditions. We believe that it is as important to begin cataloging collisionless phenomena for consideration by the High Altitude Working Group as it is to complete the studies of the collisional regime. Finally, before going on to specific comments and suggestions on the experiment, we wish to observe that the active role being played by Cliff Prettie in interferometry data analysis and by Bob Stellingwerf in working with the NRL experimentalists on production of narrow ion velocity distributions is a very good programmatic development. We hope that more of this active involvement by theorists and computationalists with the experimentalists will occur in the future.

2.1 Coupling

In the absence of a magnetic field, the efficiency of coupling of the laser-produced debris plasma to the ambient medium seems to be well explained on the basis of classical collisional processes. However, the physics under which the laser-ablation plasma expanding into the ambient gas and plasma turns into a blast wave could use additional attention along the lines of the work presented in the May 1985, Early Time Working Group meeting at NRL by Lee, Molander and Elton of NRL. Very early time, $t < 40$ ns, shadowgraphy may also provide useful information. Perhaps early time shadowgraphy with radiating ambient gases such as the MRC mixture or just Xe would reveal an unstable debris/air interface.

At pressures too low for collisional coupling to be effective, ≤ 200 mTorr, there is evidence for weak collisionless coupling only with a transverse magnetic field present in the magnetic probe data as well as in the time-of-flight data, but the field strength and experimental volume to properly address collisionless coupling are only now becoming available. In the collisionless regime, we can expect to require measurements at larger distances and later times than in collisional experiments, and also along the magnetic field lines. All in all, we can expect a variety of interesting phenomena, some of which will probably not be anticipated, and which will no doubt take all of NRL's diagnostic capability and a major effort by the entire Early Time Working Group to understand. We are looking forward to seeing the first results soon.

2.2 Aneurysms

The aneurysm remains as mysterious as when first seen. Is it actually caused directly by the laser? Is it the last stage of an instability that occurs between the laser-ablation plasma and the ambient medium? If so, when does it form? Do self-generated magnetic fields play a role? Is it the opposite--the beginning phase of the break up of the blast wave into a turbulent front? In this case, some later time shadowgraphs are needed. What is its relationship to the classical Raleigh-Taylor instability, if any? These are all interesting questions, and experiments to obtain detailed plasma conditions in aneurysms, or designed to test hypotheses on the origin and nature of aneurysms are to be encouraged. However, we are concerned that the aneurysm is an artifact of collisional laser-disk target ablation experiments, and has no relationship to HANEs.

Unless the new, uniform profile laser beam impinging upon the <u>inside</u> of a curved target produces a debris plasma which forms an aneurysm, we wonder if it is in DNA's best interest to continue to expend so much effort on this phenomenon.

2.3 Obstacles

The use of spherical obstacles to determine plasma flow properties behind the blast wave, as discussed in a briefing to JASON by Guiliani, was very interesting. It suggested to us that the same thing might be done in collisionless experiments to determine at least qualitatively very quickly if there is a dissipation mechanism that allows a stationary bow shock to form. We expect that dark field shadowgraphy using the tunable dye laser will readily show up the existence of such a shock, while it will be a very difficult job to determine exactly what the dissipation mechanism is. Therefore, it makes sense to do the former before expanding the large effort necessary to do the latter. Finally, we note that it may even be possible to use a properly aligned, blunt ended probe (e.g., magnetic probe) as the obstacle.

2.4 Diagnostic Development

NRL is in the process of developing several new diagnostic methods and improving others to be able to better diagnose collisionless interactions and conditions in and behind the blast wave in collisional interactions. We are looking forward to results from both coherent and incoherent Thomson scattering, from resonant shadowgraphy and interferometry, etc. As discussed during the NRL presentations, we suggest that more detailed information can be obtained from Thomson scattering by the use of a fast multichannel device after the spectrometer (e.g., a microchannel plate streak camera, such as the Hamamatsu system, or an optical multichannel analyzer if no temporal dispersion of the scattered light is desired). In addition, the idea of 2 color interferometry in temporally separated probe laser beams, also discussed at the JASON presentations, in order to obtain interferograms at two times, should be seriously considered for implementation. Presumably the mirror needed to separate the two beams spatially after they pass through the interaction region is easy enough to obtain, although we recognize that delivering both doubled and a tripled probe beams to the interaction volume will not be so simple.

2.5 Target Variations

Firstly, we reiterate our suggestion in last year's report that spherical, or perhaps hemispherical, targets should be irradiated from the inside instead of continuing to emphasize flat targets.

Secondly, we suggest attacking the question of structure with target variation. Irregular structure in laboratory simulations of HANE's can arise from plasma instabilities even when the illuminating laser beam and target are optimized to yield a very uniform initial expansion. Irregularities presumably will also arise from inhomogeneties introduced at the very beginning of the laser-target interaction. We recommend that this second cause of irregular structure be purposely explored. In particular we encourage the use of a wide variety of inhomogeneous targets. Target irregularities could include variations in constituents, density and shape. Target illumination and probe radiation aspect angles could also be varied. The idea behind these irregular targets is to simulate a nuclear device which disassembles asymmetrically, e.g., CHECKMATE. The relevant question is, do these irregular targets produce irregular structure in the expansion after the energy release, e.g., jets, aneurysms, turbulence? If so, does the structure heal or grow? A further thought is the possibility of making a nuclear device which produces enhanced structure and hence enhanced nuclear effects, e.g., on satellite communication links. Target shape irregularities are a fertile field for invention. Targets with holes have been tried. Some further suggestions are targets with highly variable thickness, either random or quasi-periodic with constant or varying scale sizes. The idea here is to produce a highly irregular debris cloud, even breaking off chunks of the target. Targets with randomly rough or wavy surfaces, bosses, holes nearly completely through the target, etc., are possibilities. Density and constituent inhomogeneities could be accomplished by having blobs of heavier or lighter material or voids inside the target material, like a plum pudding.

2.6 HANE Simulation

Ultimately the NRL experiments are intended to help us understand HANE phenomena that are inadequately explained. The new NRL apparatus should make quite reasonable HANE simulation experiments possible in the near future. Therefore, we suggest that certain conditions should be selected on the basis of their relevance to a particular HANE and studied in detail from early time ($t < 20$ ns) to late time (few 100 ns) in a series of shots with all possible diagnostics brought to bear. The goal would be to put together as complete a picture of that case as possible for in-depth consideration by interested parties, including anyone outside the Early Time Working Group who might be interested. For example, NRL shot number 14823 at 200 mT may have had weak coupling that occurred before $t = 40$ ns because the debris speed (375 km/s) is lower than the vacuum debris speed (450 km/s) under the same laser-target conditions. Was there some anomalous slowing down before t = 40 ns? Furthermore, at 200 mT coupling may be some sort of collisional-collisionless hybrid. STARFISH data exhibited aspects of both collisional and collisionless coupling, and the magnetic precursor and the following debris blast wave in NRL shot 14823 are somewhat reminiscent of STARFISH data. Therefore, the conditions of that shot might be appropriate for intensive study.

3.0 SUPPORTING THEORY AND COMPUTER SIMULATIONS

Most of the phenomena of HANEs, as well as the NRL experiments are beyond analytic understanding so computer simulations are important. However, present-day simulations of the collisionless regime run the risk of begging one or both of two critical questions: 1) How does collisionless coupling take place? 2) How is spatial structure generated?

The first question is begged in one standard procedure using MHD (multi-fluid) theory, with plasma-kinetic phenomena modeled by anomalous transport coefficients, in the spirit of Lampe, Manheimer, and Papadopoulos (NRL-3076). In principle, such an approach would be capable of dealing with formation of spatial structure (such as shocks aneurysms), but one would not be at all sure that the coupling had been described correctly. This sort of modified MHD approach is widely used in modeling magentospheric phenomena (Earth's bow shock, magnetic tail, etc.) and does indeed show spatial structure. However, there are three important problems of magnetospheric physics where the very concept of anomalous resistivity has been seriously questioned, and where plasma-kinetic effects are better understood as resulting from finite inertia and transit-time effects. These are the bow shock, the neutral line in the tail, and the aurora. (We would not be surprised to see the analysis of AMPTE comet formation also not yield to a simple anomalous-resistivity approach.) In all these cases specific inertial effects have been found which account for the observed phenomena, while anomalous-resistive effects have been difficult or impossible to justify. In the aurora, for example, there is no lack of plasma turbulence or means for generating the turbulence through instabilities, but nearly all the turbulent modes have electric fields $\underset{\sim}{E}$ which are very nearly perpendicular to the earth's magnetic field $\underset{\sim}{B}$, so that they are ineffective in impeding motion along $\underset{\sim}{B}$ as anomalous resistivity would demand. Instead, inertia provides for a finite transit time ~ ℓ/V, where ℓ is the length of an auroral field line and V a typical particle velocity. To some extent the inverse time V/ℓ plays the role of a "collision" frequency, although there are no actual collisions. Careful examination of inertial effects show that they do not even lead to constitutive equations of the usual form $\underset{\sim}{J} = \overset{\leftrightarrow}{\sigma} \cdot \underset{\sim}{E}$. For the aurora, one finds $J_{||} \sim (Ne^2/mV)(\phi_E - \phi_I)$ where $J_{||}$ is the current along $\underset{\sim}{B}$, $\phi_{E,I}$ is the electrostatic potential at the equator and at the ionosphere on the field line, and the rest of the symbols have their usual meaning. Similar modifications are found for the bow shock and neutral line problems.

When finite inertia effects are involved, macroscopic length scales play an important role in determining the effective collision tensor $\overleftrightarrow{\sigma}$ (or its modification), and one cannot specify $\overleftrightarrow{\sigma}$ on the basis of microscopic homogeneous plasma physics, as in Lampe et al. It may be possible in the near future to construct a scheme similar in spirit to that of Lampe et al., in which anamalous resistivity is, as appropriate, replaced or modified by finite-inertia and transit-time effects depending on macroscopic length scales, and it would then be useful to run MHD codes incorporating this modified scheme. Spatial structures would emerge as a self-consistent result of balancing MHD and plasma-kinetic responses. An example of this is already found in the auroral problem, where this balance correctly predicts the overall latitudinal width of an auroral arc.

The second question, how is spatial structure formed, tends to be begged in hybrid simulations that use fluid (usually massless) electrons and particle ions. This type of simulation fully exercises the capacity of large modern computers, and it is very good at dealing with collisionless coupling, but not very good at dealing with a spectrum of spatial scales, whether externally-imposed or self-consistently generated. The hybrid simulations presented at this year's HANEs briefings were one-dimensional, but we are informed that two-dimensional codes are in the offing, perhaps a year or so away. These 2D codes will be indispensible for understanding intrinsically two-dimensional phenomena such as spontaneous magnetic field generation and aneurysms, and we strongly urge that they be developed with an eye toward handling structure formation as well as possible. Some thought should be given to the possibility of building a special-purpose array processor that might have unusual powers in this direction. While these machines are very fast, they often have the disadvantage of requiring a relatively long time to program. One such machine is the massively parallel processor (MPP) at NASA Goddard Space Flight Center. This machine contains a few hundred microprocessors that run concurrently. The MPP has the advantage that it is currently in use for similar problems and a user community exists. It may well be that special purpose computers are not cost effective for the task at hand. However, this is the time to consider them, i.e. before resources are already expended on conventional computers. Use of a special purpose machine for lab HANE modelling would provide DNA with a sample of what such machines are capable. This experience would then provide DNA with some idea of their application to other DNA problems with high computational loads.

We have already said that laser-target interactions may profoundly affect early-time structure formation, and continuation of computer simulations in this area will be vital.

Finally, we comment on the role of simulations in the collisional regime, where collisional MHD plus chemistry, radiation, and charge exchange are the important ingredients. Present codes should be modified to incorporate finite UV radiation lifetimes (unimportant in real HANEs, but important for the NRL experiment which is over in less than 1 μsec). In a typical present-day code, UV radiation is either instantaneous or it can be turned off altogether, and the latter seems to fit experimental data better. Presumably an even better fit would come from properly incorporating finite radiative lifetimes.

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