LyTec-R-99-005

FINAL REPORT – TASK 1

Laboratory Demonstrations for PDE and Metals Combustion at NASA MSFC's Advanced Propulsion Laboratory

Order No. H-30549D

Period: Dec 1, 1999 through Dec 31, 1999

Submitted to:

National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

Attn: John Cole / Manager, Space Transportation Research
Advanced Space Transportation Program

Submitted by:

LyTec LLC
P. O. Box 1581
1940 Elk River Dam Rd
Tullahoma, TN 37388

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EXECUTIVE SUMMARY

This document is the Final Report under Task 1.0 of Phase I of contract Order No. H-30549D entitled: "Laboratory Demonstrations for PDE and Metals Combustion at NASA MSFC's Advanced Propulsion Laboratory". It is submitted in fulfillment of the final contract deliverable under Task 1.0.

The scope of work for this contract is inclusive of providing engineering and analysis support for experimental apparatus design, diagnostics, data acquisition, and test planning in support of Pulse Detonation Engine (PDE) and Metals Combustion experiments at the MSFC Advanced Propulsion Laboratory (APL). In addition, Phase I also has a designated task to provide on-demand consultation in the evaluation of advanced propulsion concepts related to plasma and MHD initiatives in application to access to space.

The principal activities during the final reporting period inclusive of December 1999 through the report submittal date are summarized in the following:

- LyTec continued its coordination efforts to facilitate communications and logistics for NASA MSFC with regard to the potential property transfer of the DOE SDI Pulse Power MHD Disk Generator and Magnet systems currently in storage at the University of Tennessee Space Institute (UTSI),
- Coordination and planning continued on LyTec's DoD Phase I SBIR activities on the virtual inlet with NASA MSFC ASTP in relation to a potential joint experimental program for study of coupled MHD generator/accelerator propulsion (AJAX simulator), submitted a Fast Track Application to the DoD with a defined Statement-of-Work for NASA support, Phase II proposal was under evaluation through the month of December and into January 2000 under a Fast Track Application,
- LyTec and its on-site engineering staff participated in test planning activities at APL on combustion and PDE tests,
- During this period, facility modifications were initiated and completed to increase the outside lab area (concrete pad and roof), leading to a slow down in active outside experimental activities to accommodate construction work,
- LyTec staff participated in NASA safety inspection of the ASTP APL related to equipment and facilities in the outside test bay where combustion and PDL apparatus are housed,
- Modifications on the metals combustor apparatus and diagnostics continued in support of test preparations,

- Worked on Firing Circuit Re-design for the PDE Initiator Tube to Allow for Higher Frequency Operation, conducted PDE Initiator Tube firings with the modified firing circuit designed for 30 Hz operation,
- LyTec engineering and management provided technical support to APL Staff as directed/requested on a variety of subjects including recent interest in the MHD Chemical Rocket Motor (MCRE). The MCRE effort formed subject material for Task II of this contract which was initiated through contract modification on March 31, 2000,
- Continued with coordination of ASTP proposed participation in LyTec's Virtual Inlet DoD SBIR Phase II program, announcement of Phase II award was given in mid-January and LyTec provided NASA MSFC with inputs for foreign funds request to HQ for use of foreign MHD accelerator facility and a finalized Statement-of-Work for the Fast Track (Phase III) effort around which the Phase III contract can be drawn.

At the end of this reporting period, all planned work under Phase 1.0 has been met within resources of that Phase. Construction work at the APL had been completed and efforts continued on planning for hot firings of the metals combustor and operation of the PDE initiator tube with PDE tests taking place in early April. Modification to the contract for initiation of the new Task (designated Task 3.1) had been accomplished. Work has been initiated on Task II and coordination efforts on that task with MSFC are underway. Documentation in support of the Phase III Fast Track contract is under evaluation.

TASK ACTIVITIES

The Work Breakdown Structure and Schedule for Phase I project activities is provided below. This schedule reflects the Phase I contracted period of performance and it remained unchanged through the base period of the contract. All periodic reporting requirements as called out on the schedule along with project milestone definitions were met through November.

The Final report for reporting last reporting period (December) was held until this submittal through informal agreement with the COTR to extend the effort at no additional cost.

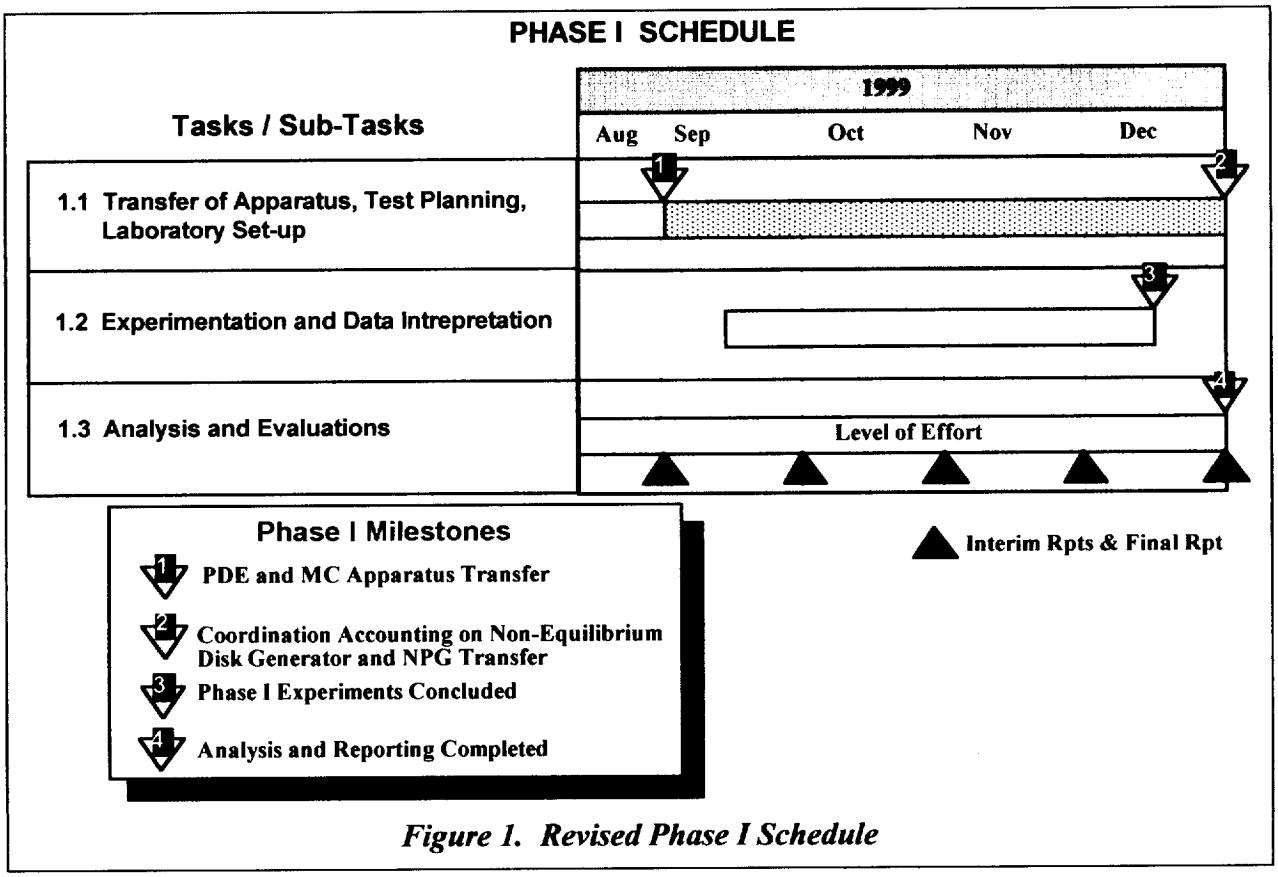

Figure 1. Revised Phase I Schedule

Through this final report, work was accomplished and completed on all tasks of the Statement-of-Work in compliance with the Statement-of-Work. Summary of reporting period activities under each task of Phase I is provided in the following topical subsections.

Task 1.1 Transfer of Apparatus, Test Planning and Laboratory Setup

Activities under this task during this period were level-of-effort with LyTec continuing to follow the developments related to transfer of equipment from the DOE to NASA MSFC.

As previously reported, LyTec has been consigned to provide assistance to APL personnel with regard to the potential transfer of DOE MHD equipment that is currently in storage at the DOE's Coal Fired Flow Facility (CFFF) located at the University of Tennessee Space Institute (UTSI). These equipment include a 10 MWe MHD disk generator and a cryogenic 4.5 Tesla magnet that were built by TRW in the early '90s under contract to the Office of Strategic Defense Initiative (SDIO) through the DOE. The disk and magnet were never used due to termination of the SDI program.

Paperwork facilitating the transfer was sent from DOE to the MSFC contact. This paperwork authorizes transfer of property. The paperwork has been processed at MSFC. The equipment can be moved to storage at MSFC.

During December, the Coal-Fired Flow Facility at UTSI was formally transferred from the DOE to the university. UTSI has inventoried all transferred all government equipment at the facility for disposition. A request was made by UTSI facility operations that the TRW disk and magnet plus other ERC hardware/equipment on site at the CFFF be moved as part of their facility clean-up activities. This request was relayed to MSFC ASTP.

LyTec will facilitate the transport of this equipment at the direction of ASTP if so directed through December 31 or beyond as needed.

Task 1.2 Phase I Experimentation and Data Assessment

Work under Task 1.2 during this reporting period was active and centered around preparation and re-design of laboratory apparatus for metals combustion and PDE tests. Various elements of the apparatus were re-designed, refurbished and integrated into the systems and gas diagnostics as detailed below.

- As discussed in the November report, in preparation for firing of the powdered aluminum combustor, all orifices metering devices were replaced with in-line flow meters. The modification was successful implemented and calibration testing showed that the flow meters that were added in place of calibrated orifices allowed for a wide range of operation and easy adjustment/control of flow.

  Work on the combustor rig was curtailed in December by the active construction work going on at the APL. As discussed in the November Progress Report, a stainless steel insert was fabricated to be placed in the back of the burner head to increase the velocity to the 350 to 400 feet per second required over the present 165 feet per second velocity. Fabrication of the new plug was completed and the plug was placed in the feed system for the aluminum combustor to increase the fuel and oxidizer velocity into the combustor as necessary when operating on oxygen/argon and aluminum. No further tests were carried out on the aluminum combustor due to lack of Argon gas supply.

- Another problem discussed in previous Progress Reports was related to the feed system was that the measurement load cell used to determine the fuel flow rate is not accurate enough. In general, particle feed rate is determined by monitoring the weight loss of the feed storage chamber (fluidized bed) over time. We contend that a new, precision load cell is needed to accurately measure the weight loss of the fluidized bed that holds aluminum particle fuel for the combustor. A new load cell to replace the old one is estimated to cost around $400 to $500. LyTec engineering researched what are commercially available and made recommendations for purchase to the COTR. No further action has been taken on this request.

- Various small laboratory supplies and expendables as needed to support combustion experiments were specified for procurement.

- Work in the re-design of the PDE apparatus was active in this period. The original small pulse detonation tube that was delivered to the APL was designed specifically to be an

initiator for a larger PDE tube. The system was designed for use with acetylene and oxygen. However due to the availability and relative safety of hydrogen it is being used in place of the acetylene.

- The initiator tube was tested and determined to function best at about 15 Hz. This frequency was anticipated as the valving operates on AC power. This original initiator tube had two small valves and was limited to 15 Hz due to the time required for valve operation, i.e. 30, 45 or 60 Hz is not possible due to the time it takes the valve to physically open and close. To solve this problem and facilitate higher frequency operation, a new tube was built that has four sets of valves instead of the original's one. These valves are mounted radially around the tube to allow for equal path lengths between each valve to the tube. When each valve set operates at 15 Hz, the total speed will be 60 Hz. If higher speeds are desired more valves can be ganged together.

  The small pulse detonation gun (initiator tube) was fired on several occasions during November with frequency up to about 15 hertz on hydrogen and oxygen. Several problems that became obvious during this series of tests that had to be addressed. The first problem encountered was that the barrel needed to be water-cooled as it would become so hot that it caused the mixture to pre-ignite. A water jacket was made from copper tubing to overcome this problem. It also became obvious that there needed to be a buffer layer between the two gases and so the device was set up so that the hydrogen valve would be on longer than the oxygen valve to provide this layer.

- It was decided that the initiator would be easier to operate if the valves were driven with DC power instead of AC power. The solid-state relays (SCR) are only capable of switching AC power so these will have to be replaced with transistors. Replacement of the SCR's with transistors was researched in December. Various solenoid valve venders were contacted to determine commercial high-speed valves that might be usable on PDE devices. Work also progressed on replacing AC power to the valves with DC power. The original idea was to try replacing the SCR's with transistors. This worked well for one

valve but there was noise or cross-talk problems with multiple valves. Also tried using triacs but the same problem persisted. Followed suggestions from LyTec Tullahoma staff to reduce the feed back from the solenoids but this was also to no avail. However, some off-the-shelf solid state DC relays were found and tested which appears to have solved the problem.

- Buffered the signals between the control computer and the test stand with an optical link to isolate the control computer from any high voltage signals that might come from the ignition system and from any noise signals from the solenoid valves.

- The recently acquired spectrometer was also worked on in November. It was determined that this device cannot be used with the detector presently available due to the shortness of the focal length of the spectrometer and the physical configuration of the detector. In order to overcome this problem, the spectrometer housing had to be modified and a new cover was made to allow the detector to be placed correctly.

- Work on expanding building 4549 is in progress with part of the foundation poured during November and roof construction underway in December-March timeframe.

- During December, the laboratory area was inspected by hazardous materials personnel who contacted safety. In preparation for this inspection, LyTec staff cleaned up the outdoor area as much as was possible before the safety inspection. After the inspection, a meeting was held with safety personnel to identify problems that were uncovered. Safety forwarded information about what to do about gas bottle storage, which is directly related to the LyTec laboratory activities. Began making plans for this needed modification when the new building is put in place. Specifically, a concrete block wall or 0.5 inch steel plate must be placed between oxygen and hydrogen bottles. Discussed this needed construction modification with the building contractor outlining what needed to be done to the existing structure on pad.

Task 1.3 Analysis and Technology Evaluations

- During this reporting period, the AJAX thermodynamic cycle analysis reported to NASA ASTP under the previous ERC contract was reviewed. This analysis was formatted into a joint AIAA paper (LyTec & NASA and presented at the AIAA Aerospace Sciences meeting in January of 2000.

- The subject paper was submitted in late January for consideration as a journal publication in the AIAA Journal of Propulsion and Power.

- During this reporting period under partial support from this task, LyTec was consigned by the Manager, Space Transportation Research to construct a program plan incorporating the AJAX propulsion initiative within NASA in relation to potential collaborative research with LyTec in submission of a Phase II SBIR proposal to the DoD. This activity was in follow-up to the coordination meeting discussed in last month's progress report and in the preparation of a Fast Track Phase II application. The Phase II SBIR proposal including the NASA Fast Track effort was completed and submitted December 3, 1999.

- The DoD SBIR Phase II application including the intricate NASA Fast Track effort was announced for award in January 2000. Work partially covered under this task was accomplished in early months of 2000 to facilitate contract award through coordination of procurement activities between WPAFB and MSFC.

- With submittal of the DOE SBIR Phase II proposal and its subsequent award, LyTec management worked with the Manager of Space Transportation, key NASA staff and procurement personnel to draft a application for direct funding to IVTAN (Moscow High Temperature Institute) for support to the planned Fast Track program. This was accomplished over the early part of the first quarter of 2000 and the application was submitted through NASA guidelines for approval.

- LyTec completed a finalized version of the Fast Track Statement of Work and submitted this through the Manager of Space Transportation to the MSFC procurement office for use in casting the Fast Track project as a Phase III SBIR contract. At the time of this

reporting, the model Phase III contract has been drafted and NASA procurement awaits final award of the SBIR to proceed with award of the Phase III.

- Also during this period, LyTec staff coordinated planning efforts for potential MHD AJAX simulator experiments with NASA Ames personnel. Two meetings were held related to this, one at the AIAA Reno conference and one at Ames Research Center.

PLANNED/SCHEDULED WORK

This reporting marks the end of Phase I of contract Order No. H-30549D entitled: "Laboratory Demonstrations for PDE and Metals Combustion at NASA MSFC's Advanced Propulsion Laboratory". All initial work defined under this PO has been accomplished. Continued efforts are underway to formulate a new Scope of Work for add-on LyTec efforts under the theme of Phase I since experimentation at the APL laboratory with the metals combustion and PDL apparatus are planned in the future.

LyTec has initiated work under Task 2.0 (P.O. Modification Task 3.1). This work is entitled: "Assessment of MCRM Boost Assist From Orbit for Deep Space Missions." A copy of the Statement-of-Work for this new task is provided as an Appendix to this Final Report. The Task 2.0 effort was initiated on March 31 with a six-week period of performance culminating in a Task 2.0 Final Report.

APPENDIX

TASK 2.0 DESCRIPTION AND STATEMENT-OF-WORK

ASSESSMENT OF MCMR BOOST ASSIST FROM ORBIT FOR DEEP SPACE MISSIONS

The research proposed herein is to provide to NASA ASTP, technical and feasibility evaluations on the potential use of an MHD chemical rocket to enhance the mission performance in orbit-boost-to-escape for deep space missions. The mission scenario under review includes use of beamed energy (e.g., microwave) from an orbiting power platform to an orbiting deep space probe to provide the electric power needed to drive an MHD accelerator – chemical rocket (MCMR). The MHD assisted rocket firing augments impulse of the rocket motor utilizing energy (fuel) that is not on-board. This concept is a vision by NASA ASTP as a prospective means for enhancing vehicle acceleration to acquire higher velocity and improved trajectory - to reduce deep space mission time (such as, a manned mission to Mars).

LyTec proposes to evaluate the perceived mission scenario and to perform analysis and tradeoff studies to access the capability of the MCRM to achieve the NASA mission objective.

Program Objectives

The project has two objectives:

1. To provide assessment of the orbit-boost-to-deep space mission and its overall system configuration in relation to system requirements that are specific to operation of an MCRM driven craft and the proposed mission; and,
2. To provide first-order analysis to define design requirements for an MCRM and evaluate the propulsion performance of an MCRM as applicable to the deep space mission.

Statement of Work

The statement of work for the proposed project is defined in Table I. The project is structured into three tasks:

Task 1.0 Mission and Configuration Analysis

Task 2.0 MCRM Performance Mapping

Task 3.0 Management and Reporting

STATEMENT OF WORK

Task - Title	Task Description
1.0. Mission and Configuration Analysis	Under this task, LyTec will conduct background studies to determine/define criteria related to the mission and the system configuration as is required to perform the technical analysis of the MCRM orbit-boost-to-deep space under Task 2.0. • LyTec will conduct background and literature searches to familiarize key researchers on the mission and NASA objectives. • LyTec staff will coordinate/communicate with NASA experts and visionaries to determine a comprehensive definition of the mission & system configuration. • LyTec staff will communicate with NASA, National Laboratories and outside experts to determine the state-of-the-art and capabilities/capacities of the different system components comprising the overall system and the mission concept. • LyTec will set on paper a "*ground-rules criteria set*" as is needed to support the analytical efforts of Task 2.0. This set will express the underlying technical assumptions/definitions used, system and component specs (size, capacity , operational) and other unknown factors; underlying the analysis - to serve as a means of judging the project results and its conclusions. (This effort/foundation will be critiqued with NASA technical management during the early part of project to assure NASA needs are met and that synergism exists in the problem definition.)
2.0 MCRM Performance Mapping	This task is the focal task for the project. Under this task, analysis will be performed to evaluate the MCRM and its unique sub-component requirements to determine the performance and capability of this unique system to meet the mission requirements. • LyTec will utilize existing in-house computational resources to analyze the operation and performance of the MCRM as constrained to the mission definition. • LyTec will perform analysis of propulsion measures (Isp, acceleration, acceleration times, mission times, etc.) of the MCRM system encompassing trade-off studies on operational variables; i.e., weights, fuel load, fuel type, energy conversion and efficiency measures, etc. • LyTec will produce graphs, maps, and other visuals that portray key propulsion and mission performance measures for the mission/system concept that can be used to guide NASA in future initiatives toward this concept.
3.0. Management and Reporting	Under this task, all project management and reporting will be accomplished. This task will serve as a focal point for conduct of all contractual matters and direct communications with the NASA project management. • A Final Report will be written documenting work on each task, reporting on conclusions drawn from the work, and providing recommendations for future efforts.

Schedule

A period of performance of six (6) weeks from contract award/initiation is proposed.

Key Personnel

LyTec proposes two key staff personnel to conduct the proposed project. John T. Lineberry, LyTec President will serve as Program Manager and Principal Investigator over this program. He will be responsible for both technical evaluations and for meeting of all contractual requirements.

Dr. Harold J. Schmidt, LyTec Senior Scientist, will provide analytic support to this project with specific emphasis on system configuration requirements related to MCRM operational needs.

Dr. James N. Chapman, LyTec consultant, will serve as Principal Research Scientist and provide expert analysis and background studies in support of the project and its findings.

Deliverables

A final report will be the single deliverable for this proposed project.

REPORT DOCUMENTATION PAGE

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LYTEC LLC

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LyTec LLL
1940 Elk River Dam Rd
P. O. Box 1581
Tullahoma, TN 37388

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13. ABSTRACT *(Maximum 200 words)*

Report provides status reporting on activities under order no. H-30549 for the period December 1 through December 31, 1999.

Details the activities of the contract in the coordination of planned conduct of experiments at the MSFC Advanced Propulsion Laboratory in pulse detonation MHD power production and metals combustion.

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