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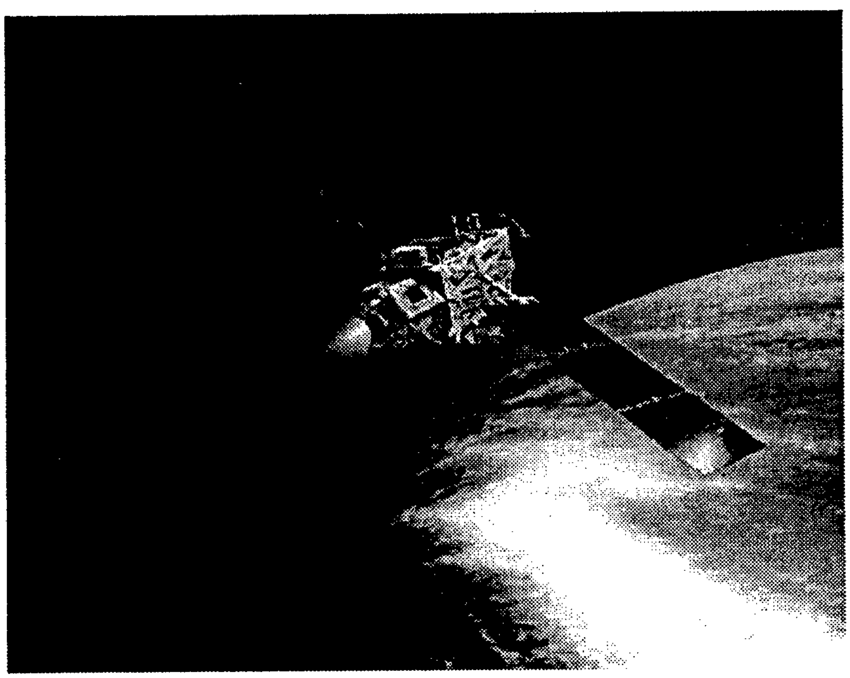

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Abstract

In the post cold war, the United States Air Force is challenged by the need for increased maneuverability of the U.S. space assets, and the need to reduce launch costs. These needs have spawned the Electric Propulsion Space Experiment (ESEX). ESEX will address key issues associated with high power arcjets. Measuring performance in space and interactions on the spacecraft of this new plasma propulsion system will provide the first step towards the operational use of high power arcjets. Currently, the program is nearing completion of the second phase, in which the subsystems are being built, tested, and integrated into a flight unit. In the third phase, the flight unit environmental tests will be performed. In the last phases, the flight unit will fly aboard the P91-1 spacecraft, the Advanced Research Global Observation Satellite (ARGOS) in late 1995.

Introduction

With depolarization of geopolitical conflict, the ability to predict the location of possible military conflict is difficult. This difficulty has increased the demands on the existing Air Force satellite constellations and has created the need for increased maneuverability. The increase in maneuverability can be accomplished easily by the addition of propellant. However, this solution costs dearly in limited spacecraft mass allocation. Therefore, a search is underway for new technologies that can fulfill the maneuvering requirements and avoid increasing propellant. The most promising near term solution to this problem is electric propulsion (EP)[1,2].

There are, moreover, many payoffs to using electric propulsion for orbit raising. EP upperstages can deliver greater payloads from LEO to an operational orbit. Additionally, launch vehicle flexibility can be gained on large satellites. A large satellite limited to a Titian IV with a conventional upperstage, can be launched on a smaller, cheaper, launch vehicle with an EP upperstage[3].

The arcjet appears to be the most likely candidate for orbit raising and maneuvering from amongst the many choices in EP engines. The arcjet is the most technologically mature and has a relatively high power (10's of kW's).

A 26 kW arcjet was chosen for the first Air Force electric propulsion flight experiment for the following reasons: the 26 kW thruster was state-of-the-art at the time of the inception of the ESEX program; an arcjet of this size can accommodate the current projections of available space power (30-50 kW); the relatively high thrust makes transfer trip time less than 100 days. Long trip times are unattractive to potential Air Force users.

ESEX is part of the Advanced Technology Transition Demonstration (ATTD), which is specifically designed to transfer technology from the government labs to the aerospace community.

The $18.5 million effort is funded by the Phillips Laboratory. TRW is the prime contractor. Olin's Rocket Research Company (RRC), Defense Systems, Inc. (DSI) and Ergo-Tech, Inc. (ETI) are the subcontractors. In addition, RRC's sister company Pacific Electro Dynamic (PED) is subcontracted to build the power conditioning unit (PCU)[4].

Objective

In order to transfer the high power arcjet successfully into operational use, the ESEX experiment has to accomplish two major objectives. The first is to develop reliable flight hardware which will successfully complete a test firing in space. The second objective is to gather data on key spacecraft integration issues, verifying that a high power arc plasma source can operate without adversely affecting a spacecraft's nominal operations.

To successfully demonstrate a high power arcjet that can survive launch and operate reliably in the space environment, the thruster performance will be quantified and compared with ground measurements. Ground performance data of EP devices has been historically encumbered by ground facility errors, creating the need for flight data[5]. Flight performance data will include thrust, specific impulse, and efficiency. Thrust will be derived from measuring acceleration and combined with spacecraft mass. Specific impulse will be derived from the propellant mass flow rate and thrust. Efficiency will be derived from the voltage current product (power) and the thrust data.

The arcjet spacecraft interactions that concern designers are radiated electromagnetic interference (EMI), plume contamination, and thermal radiation. In ground facilities, it is difficult to accurately measure plume contamination and EMI, since the vacuum chamber walls have a large effect on the plume.

A high power arcjet operating at 100's of amperes of current is a great potential source for EMI[6]. Although, spacecraft designers can work around EMI, it must first be characterized. ESEX's antennae will measure EMI in the GHz frequency range, corresponding to nominal satellite communication channels.

During life tests of the arcjet, tungsten is lost from the electrodes. Tungsten represents a serious contamination issue for solar arrays and optics. It is assumed this mass is ejected away from the spacecraft at close to the arcjet exhaust velocity. ESEX will measure the deposition of tungsten and other contaminants impinging on the spacecraft to verify this assumption.

The arcjet converts approximately 30 percent of its energy into thrust. Therefore, about 70 percent of the converted energy is either conducted to the spacecraft as heat or lost into space. Measurements of the conducted heat can be made on the ground. However, a large part of the expelled energy is radiated heat to the spacecraft from the arcjet plume, and can not easily be measured on the ground. The radiated heat is affected by plume size and shape, which is determined by the background pressure and vacuum chamber geometry. ESEX will measure the amount of thermal radiation impinging on the spacecraft during a firing[7]. Additionally, measurements of size and shape of the arcjet plume will be imaged at the Air Force Maui Optical Site (AMOS), in Hawaii.

Host Vehicle

ESEX is one of eight experiments scheduled to fly in late 1995 on the P91-1 spacecraft, Advanced Research Global Observation Satellite (ARGOS). ARGOS is managed by the Space Test and Small

Launch Vehicle Programs office at the Space and Missile Systems Center. ARGOS is being built by Rockwell International and will be launched by a Delta II, to a 460 nautical mile, 98.7 deg. inclination orbit. ESEX is scheduled to fire during the second phase of the flight, alternating with the Critical Ionization Velocity (CIV) gas release experiment.[8] Besides the instruments onboard ESEX, ground controllers will be monitoring the state of health of ARGOS. In the event of an unexpected adverse effect of the arcjet on ARGOS the firing will be terminated. Due the robust ARGOS design and the fact that arcjet operation is not mission essential, the ESEX experiment offers little risk to the host satellite.

One concern of ARGOS is the arcjet thrust vector alignment. In order for ESEX to make its measurement of thrust, the ARGOS reaction control thrusters will be deactivated during the ESEX firings. ARGOS will control its attitude with three reaction control wheels. If the thrust vector of the arcjet is misaligned with respect to the spacecraft center of gravity, the reaction wheels could be saturated and cause ARGOS to tumble. The arcjet can only be aligned on the ground to the geometric center of the constrictor, and it is assumed that the thrust vector goes though that center. ARGOS will be sending data of the change in reaction wheel momentum as part of its state-of-health and this will verify the assumption.

Schedule

This effort is divided into six phases (fig. 1). In phase I, the initial design was completed and reviewed at the Preliminary Design Review (PDR), in July 1991. In phase II, TRW and its team have been fabricating and testing each subsystem. A comprehensive review of the fabricated hardware test results will be conducted in a Critical Design Review (CDR), scheduled for November of 1993. Phase II will be concluded upon completion of the flight unit integration. Phase III will consist of performing the environmental and flight qualification tests of ESEX. Phase IV will be the integration of ESEX to the ARGOS host spacecraft. Phase V will be the actual flight and Phase VI the reduction of flight data.

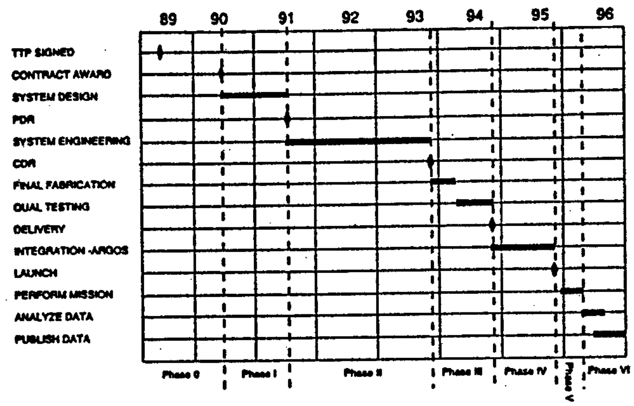

Figure 1
Schedule

Subsystems

ESEX is comprised of four major subsystems. The propulsion subsystem; the diagnostics subsystem; the command and control subsystem; and the power subsystem. In figure 2 an exploded view of the ESEX components are shown.

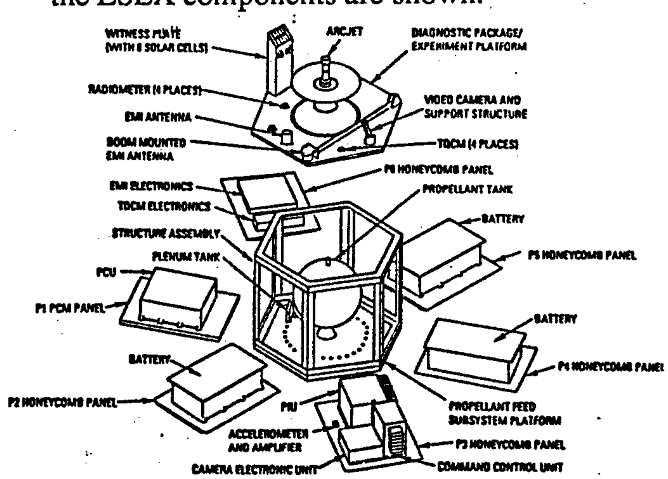

Figure 2
Subsystem Layout

The propulsion subsystem consists of the arcjet, PCU, and propellant feed subsystem (PFS)[9,10]. Currently, engineering models of all of these components have been built and will be tested in an integrated mission simulation test at RRC[11]. Upon successful completion of this test, flight versions of these components will be built and delivered to DSI.

The diagnostic subsystem consists of the video camera, radiometers, thermoelectrically cooled quartz crystal microbalances (TQCM's) and EMI antennae and electronics. Most of these components are built and undergoing tests as flight hardware.

The command and control subsystem or unit (CCU) will communicate with ARGOS via a MIL-STD-1553B data bus. A prototype of this unit is built and undergoing testing. The CCU will be refurbished for the flight.

The power subsystem consists of the Power Integration Unit (PIU) and the silver zinc batteries. The PIU distributes and conditions the 28 VDC power from ARGOS to all the ESEX subsystems. The PIU also contains the charger to perform the 100 hour recharge of the batteries between firings. A prototype of the PIU is built and undergoing testing, but will be refurbished for flight. Engineering model batteries have been delivered to RRC for the integrated mission simulation, and the flight cells have been construction.

Conclusion

There are many payoffs in the development of electric propulsion technology. In station-keeping, mission lifetimes can be increased. In orbit maneuvering, more maneuvers can be performed with the same propellant load. In orbit raising, more payload may be accommodated or downsizing to a smaller launch vehicle is possible.

The Air Force believes that EP technology will be important in a future where the U.S. will rely more on its space assets and allocate fewer dollars to perform those missions. ESEX will address the key issues associated with the operation of single high power arcjet or multiple low power thrusters. The ESEX program is an important first step towards fielding an electric orbit transfer vehicle and an electric orbit repositioning satellite.

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