Collaborative Research of Europa Through Exploration

Mission Concept Review

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Europa Extraterrestrial Life Survey

CRETE: Collaborative Research of Europa Through Exploration

Proposal Date: April 29th, 2010

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Mission Duration: February 29th, 2020- March 29th, 2029

Certification of Compliance with Applicable Executive Orders and U.S. Code.
By submitting the proposal identified in the Cover Sheet/Proposal Summary Information in response to this Research Announcement, the Authorizing Official of the proposing organization (or the individual proposer if there is no proposing organization) as identified below:

- certifies that the statements made in this proposal are true and complete to the best of his/her knowledge;
- agrees to accept the obligations to comply with NASA award terms and conditions if an award is made as a result of this proposal; and
- confirms compliance with all provisions, rules, and stipulations set forth in the two Certifications and one Assurance contained in this NRA (namely, (i) the Assurance of Compliance with the NASA Regulations Pursuant to Nondiscrimination in Federally Assisted Programs, and (ii) Certifications, Disclosures, and Assurances Regarding Lobbying and Debarment and Suspension).

Willful provision of false information in this proposal and/or its supporting documents, or in reports required under an ensuing award, is a criminal offense (U.S.Code, Title 18, Section 1001).

Summary

In response to the NASA Announcement of Opportunity (AO) regarding Team CRETE (Collaborative Research of Europa Through Exploration) has put together a possible design for the mission with a collaborative effort from The University of Alabama in Huntsville for the design of the lander and the focal of communication, ESTACA for the design of the orbiter, College of Charleston for the science instrumentation, InSPIRESS Level 2 for the design of a magnetometer boom and InSPIRESS Level 1 for the design of the QRR (Quake Rattle Role) payload. UAHuntsville, ESTACA and InSPIRESS Level 2 teams acquired the science goals from the College of Charleston and designed the spacecraft to fulfill those science goals on and around Europa's orbit.

- There is proprietary information in this proposal due to the fact that there are two prototypes in design process.
- The project involves a partnership with a non-US collaborator with the involvement of ESTACA in the design of the orbiter.
- There are no NASA civil servant personnel participating as CRETE team members.
- This project does have the potential to impact the environment with the use of multiple ASRG's (Advanced Stirling Radioisotope Generator)
- Team CRETE will follow standard NEPA (National Environmental Protection Agency) guidelines for use of radioactive material if proposal is approved.
- Mission: CRETE
- Proposing institution: University
- Proposing Launch Vehicle: High 5-meter fairing (Atlas V 551)
- RHU's (Radio Isotope Heater Unit) are used in the thermal to keep the propellant at normal operating conditions.
- Student collaboration is proposed through InSPIRESS Level 1 competition and Level 2 design and implementation of magnetometer boom.
- There is not a science enhancement option proposed.
- The total mission cost $1.37 billion.
- Team CRETES mission will not affect any historic, archeological or traditional cultural sites, or historic objects.
- This proposal DOES NOT contain information or data that are subject to U.S. export control laws and regulations, including Export Administration Regulations (EAR) and International Traffic in Arms Regulations (ITAR).

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Proposal Team Members Commitment through InSPIRESS (Discovery Announcement of Opportunity 2010)

"I acknowledge that I have been identified by name as a team member for the proposed project entitled "CRETE", which is being submitted in response to the Announcement of Opportunity, Discovery 2010, NNH10ZDA007O, and I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal. If you have any questions, please feel free to contact me at any time."

FACT SHEET

Collaborative Research of Europa Through Exploration (CRETE)

Science Goals & Objectives:

- Overall Goal: Explore the geological, physical, and biological aspects of Europa and search for habitable environments for past or present life.
- **Objectives**:
- Study the structure and composition of the surface, near-surface, and interior.
- Investigate the geologic activities that encompass Europa, and the processes that drives it.
- Search for traces of past or present life in a habitable environment.
- **Engineering Goal:**
- To satisfy the science goals.
- To design a cost efficient Spacecraft Mission to Europa under \$800M PI cost.
- Design a lander, that will include the telecommunication systems, command data handling system, thermal, propulsion, and power subsystems.

UAH

LANDER AND ITS SUBSYSTEMS

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PROJECT MANAGER

SCIENCE

CAMERON SELF
PRINCIPLE INVESTIGATOR

BOB JONES or AUSTIN DECATUR

PAYLOAD

ESTACA

ORBITER AND ITS SUBSYSTEMS

FLORENT COACHIN
PROJECT MANAGER

MAGNETOMETER BOOM

MARY ROBINSON
PROJECT MANAGER

Mission Management and Participating Organizations

Mission Overview:

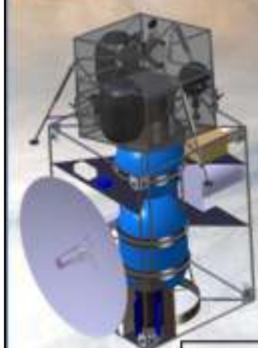
- Launch on Atlas V 551 (C3 of 12.8 kg^2/s^2, 4790 kg)
- Perform Venus-Earth-Earth Gravity Assist (VEEGA) trajectory
- Arrival at Jupiter/Europa ; Perform Braking
- Europa orbit insertion (EOI) in July 2028
- Initial, circular 200 km altitude orbit, 95° inclination
- Detach lander and safely land on Europa.
- Gather data and communicate results.

Key Spacecraft Characteristics:

- 4551 kg wet mass (orbiter + lander)
- 581 kg dry mass for lander (with 30% contingency)
- 709 kg dry mass for orbiter (with 30% contingency)
- Payload (orbiter + lander):
  - Total Mass: 100 kg
  - Total Power Required: 173 W
- 3 m High Gain Antenna (orbiter)
- Two-way Doppler at both X-/Ka-band capability and USO for radio science gravity investigation
- Data rate of ~ 150 kb/s to DSN 34m at Ka-band
  - Up to 7.3 Gb/day during Europa Science phase
- Data rate of ~ 180 uplink from lander to orbiter.
- Mono-propellant (MR-80B) Lander
- Bi-propellant (HiPAT) Orbiter
- Rad-hardened electronics
- 2 ASRG + Battery (Orbiter + Lander)
- 9-year lifetime

Lander Instruments

Instrument	Mass (kg)	Power (W)	Purpose
Raman	3	18	Study vibrational, rotational, and other low-frequency modes in a system.
Thermal Emission Spectrometer	3	6	Collect Infrared Data and Measurements
Mass Spectrometer	3	5	Measure mass to charge ratio of charged particles in determining masses and elemental composition of a molecule
Panoramic Camera	1	4	Imaging of local environment.
TOTAL	10	33	



Cost in Millions	
Orbiter	$664
Lander	$616
Launch Vehicle Upgrades	$68
NEPA	$22
Total	$1,370
Total PI Mission Cost Cap	$800
Over Budget	$570
% Over Budget	71%

Orbiter Instruments

Instrument	Mass (kg)	Power (W)	Purpose
Ice Penetrating Radar	26	45	Characterize the structure and composition of the crust down to 5km. Aid in determining interior structure and processes.
Laser Altimeter	5	15	High resolution mapping tool, determine the origin of various surface geological structures. Aid in determining interior processes.
Nephelometer	5	12	Measures the amount of particulate matter in the air.
Magnometer	3	4	Study the induced magnetic field
UV Spectrometer	6	5	Plume composition and regional mapping to surface vents. Detect and characterize biotic and prebiotic compounds.
Thermal Emission Spectrometer	3	6	Collect Infrared Data and Measurements
IR Spectrometer	16	25	Composition of organic and inorganic surface materials, effects of radiation sputtering, nature of exogenic materials, Presence and characterization of biotic and prebiotic compounds.
Narrow Angle Camera	11	14	Take science pictures.
TOTAL	72	120	

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D. SCIENCE INVESTIGATION

D1. Scientific Background, Goals, and Objectives

Jupiter is the archetype for the giant planets of the Solar System and for numerous planets now known to orbit other stars. Three of Jupiter's Galilean satellites are believed to habor internal oceans and are considered the key to understanding the habitability of ice worlds. Europa is believed to have a saltwater ocean beneath a relatively thin and geodynamically active icy shell. Europa is unique among the large icy satellites because its ocean is in direct contact with its rocky mantle beneath, where the conditions could be similar to those on Earth's biologically rich sea floor. Analogous to hydrothermal fields on Earth's sea floor, such areas on Europa could be excellent habitats, powered by energy and nutrients that result from reactions between sea water and hot rock. Chemical nutrients might also enter the ocean from above, as oxidants are generated through at Europa's surface from radiolysis. Potentially containing the necessary "ingredients" for life, Europa is the prime candidate in the search for habitable zones and life in the solar system. However, the details of the processes that shape Europa's ice shell, the fundamental question of its thickness, and methods for transport of materials between the ocean and surface, are not well understood. Figure D.1.1 shows two of these scenarios.

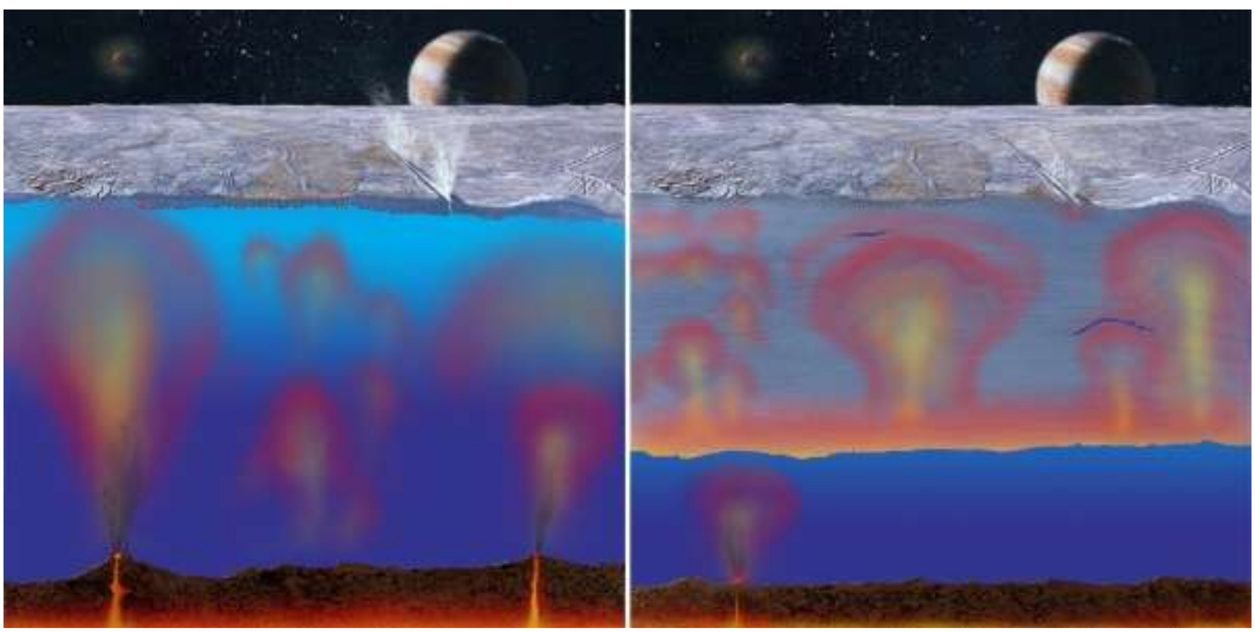

Figure D.1.1 Model showing two scenarios of crustal thickness on Europa. Left, thin crust over a deep "heated" ocean due to strong convection form hydrothermal vents and volcanism. Right, thicker crust with a layer of "warm" ice interface with the ocean.

Europa, Jupiter's second Galilean satellite, is among the most interesting targets for planetary exploration in the solar system. Mission studies have investigated many of the challenges associated with exploring Europa. Europa orbital concepts can satisfy a significant number of the science objectives but require extensive propulsion systems to achieve orbit while flybys mission concepts may have a more limited science appeal. Radiation levels near Europa require detailed design mitigation approaches and will highly influence any mission lifetime. The following goals and objectives have been proposed to expanding the body of current information and future proposed missions.

The overarching goal is to determine whether Europa harbors a habitable environment for past, present, and even future life. The Galileo mission spacecraft indicates that a global subsurface ocean with a volume nearly three times that of Earth's oceans may exist below the icy crust. The sub-surface marine environment may be similar to Earth's biologically diverse and rich ocean floor. The geological structure of the surface suggests that convection induced by hydrothermal vents and volcanism may exist below the surface. These vents could supply nutrients and warm the environment resulting in habitable conditions. Due to the surface structures strong implications of a sub-surface ocean, Europa has the highest probability of harboring life than any other planet/moon in our solar system. However, the processes occurring within Europa's interior are not understood. A mission to Europa would satisfy the following objectives:

1. Determine the interior structure and processes, and how those processes shape the icy crust/surface.
2. Determine the thickness of the icy crust, identify sub-surface water, and study the interactions between sub-surface ocean and icy crust.
3. Determine the surface and near surface composition, and chemistry with a strong emphasis on habitability.
4. Map the surface in high resolution, study the surface geological structures and understand their formation, and identify future sites for surface system exploration
5. Characterize the magnetic field
6. Observe the exosphere and identify the surface exosphere interactions.

Previous missions to Europa have provided a basis for Europa missions. The Voyager spacecraft entered Europa's atmosphere in 1979. Known from the ground to have a high-albedo surface and the infrared spectrum of water ice (e.g. Kuiper 1957), Europa had its first close encounter when the Voyager 2 spacecraft flew past in 1979. Images taken at a maximum resolution of about 2 km/pixel revealed a bright surface crisscrossed with long linear features, little topography, and few impact craters. Additionally, the Galileo mission left many questions to be answered by further missions. Future missions would serve to identify the presence of a subsurface ocean and how it potentially interacts with the surface in hopes of identifying current geologic activity.

D.2 Science Requirements

The Europa Jupiter Systems mission has highlighted the high priority scientific objectives required to make major advances over our current understanding of Europa: confirmation of an ocean, study of the ice crustal structure, geologic history of exchange between the ocean and surface, and the chemical composition of the non-water materials on the surface, including organics if present. Post-Galileo exploration of Europa presents a number of major technical challenges. Accomplishing the large number of the science objectives addressed by Europa scientists requires a more complex mission than a repeat of Voyager or Galileo-style flybys. In turn, this translates to a requirement to not only orbit Jupiter, but to orbit Europa while surviving and operating within Jupiter's trapped radiation environment long enough to achieve the major objectives. The overall proposed investigation to be performed is separated into six parts. In order to attain our scientific objective we propose the following high performance instruments.

In order to determine the interior structure and processes, and how those processes shape the icy crust/surface. Ice Penetrating Rader would aid in Characterizing the structure and composition of the crust down to 5km, as well as assisting in the determination of interior structure and processes. It will also contribute to the interior interactions by identifying warm ice and/or water pockets within the icy shell.

In determining the thickness of the icy crust, identify sub-surface water, and study the interactions between sub-surface ocean and icy crust we will aslo utilize the Ice Penetrating Radar. The Ice Penetrating Radar will reside on the orbiter. This radar was used on Mars to attain a vertical sounding of the polar ice caps. The sounding was able to reach a depth of 2km on Mars and will be able to accomplish a greater depth on Europa due to the colder ice. Additionally the IR Spectrometer will aid in this identification of non-ice components of Europa.

In terms of determining the surface and near surface composition, and chemistry with a strong emphasis on habitability, the use of a Thermal Emission Spectrometer will determine surface composition and chemistry. This instrument can determine the chemical makeup of a medium by its thermal radiation. Biological signatures such as carbon can be identified using this instrument. Additional the use of the UV Spectrometer Mass aims to detect the composition and dynamics of the atmosphere of Europa

The Laser Altimeter will satisfy the fourth objective to map the surface in high resolution, study the surface geological structures and understand their formation, and identify future sites for surface system exploration.The Altimeter is a mapping tool of which will use map much of the surface. This instrument will aid in the determination of the origin of certain geological structures. In particular we will use this instrument to identify subduction zones, which have yet to be found. Being able to study these geological structures in a higher resolution will enable us to determine more regarding the interior processes. As a high resolution mapping tool it will be implemented to determine the origin of various surface geological structures, which will also aid in determination of interior processes. The Altimeter will also aid in identifying the amplitude and phase of gravitation tides on Europa, as well as identifying quantitative morphology of Europa surface features. Additionally, a Narrow Angle Camera will be used to identify local-scale geologic processes on Europa, and a Panoramic Camera will be used to identify Europa's surface Morphology & topography.

The use of a Magnetometer will characterize the induced magnetic field and the interaction between Europa and Jupiter's magnetic field. Next, in order to observe the exosphere and identify the surface exosphere interactions we propose to utilize a Nephelometer, Raman

Spectrometer, a Magnetometer, a UV Spectrometer Mass, which aims to detect composition and dynamics of the atmosphere of Europa.

As a compliment to the mission, a payload of 10 geophones was designed by Decatur City Engineering Schools. More information can be found in the Table D.2.1TraceabilityMatrix, Section E.1, and I.2.2 Measuring the Magnitude of the Europan Tremors (M2ET).

Table D.2.1 Science Traceability Matrix

Science Contribution	Observables	Projected Performance	Mission Functional Requirements
Interior structure, ice/water interfaces, crustal thickness	Ice, radar waves	All instrumentation must perform in a low temperature high radiation environment	Operate while in Europa orbit
Topographical mapping, surface and subsurfaces processes, phase and amplitude of tidal forces. Morphology	Surface features		Operate while in Europa orbit
Surface composition, organic traces, Jupiter atmospheric composition (SEO)	IR emission		Operate throughout mission
Surface composition, organic traces, Jupiter atmospheric composition (SEO)	Thermal emission		Operate while in Europa and Jupiter orbit
Europa tenuous atmosphere composition, magnetospheric-atmspheric interations	Tenuous Atmosphere		Operate throughout mission
Geological processes, Jupiter cloud dynamics and structure (SEO)	Europa surface, Jupiter atmosphere		Operate throughout mission
Dectect subsurface ocean, atmospheric-magnetospheric interactions	Magnetic field, tenuous atmosphere		Operate throughout mission
Atmospheric tool for Jupiter (SEO)	Jupiter's atmosphere		Operate while in Jupiter orbit
Composition of cosmic dust particles in the Jovian system	Cosmic dust particles		Operate throughout mission

D.3 Threshold Science Mission

In case the mission needs to be descoped, a threshold mission has been designed to satisfy our goals and objectives despite less instrumentation. The threshold mission must include the orbiter in order to utilize minimal instruments and obtain enough data to satisfy the science objectives. However, the threshold mission does not include the surface system. Despite the surface systems greater capability of retrieving data on a molecular level, the orbiter will be able to satisfy all the necessary science objectives. The threshold mission will not include the

Nephelometer due to its sole purpose to satisfy the Science Enhancement Option (SEO), in section E.6.

Table D.3.1 Baseline Mission

Science Objectives	Baseline Mission
Determine the interior structure and processes, and how those processes shape the icy crust/surface.	Ice Penetrating Radar Laser Altimeter 10 Colibry's Geophones
Determine the thickness of the icy crust, identify sub-surface water, and study the interactions between sub-surface ocean and icy crust.	Ice Penetrating Radar 10 Colibry's Geophones
Determine the surface and near surface composition, and chemistry with a strong emphasis on habitability.	IR Spectrometer TES Raman Spectrometer Mini-TES Mass Spectrometer
Map the surface in high resolution, study the surface geological structures and understand their formation, and identify future sites for surface system exploration	Laser Altimeter PanCam
Characterize the magnetic field and it's interaction with the tenuous atmosphere	Magnetometer
Observe the exosphere and identify the surface exosphere interactions.	Magnetometer UV Spectrometer

E. SCIENCE IMPLEMENTATION

E.1 Instrumentation

Thirteen payloads have been selected to satisfy the science objectives and goals per the AO. Nine of those will carry out the science from orbit and four on the surface system. Four payloads will contribute to the SEO.

Orbiter Instruments

Ice Penetrating Radar

The classical method to determine the interior structure of a non-gaseous planet, such as the inner planets or our very own moon, is to deploy a seismic network that attains interior data through acoustical seismic waves. Europa, however, is unique in that the crust is predominantly composed of ice. This allows for another technique to gather interior data.

Radio echo sounding techniques have been employed to retrieve cryospheric sub-surface data on both Earth and Mars. Radio waves can penetrate into the ice and reflect at interfaces where ice characteristics are slightly altered. Therefore, the Ice Penetrating Radar has been chosen to determine subsurface data as an orbiter payload.

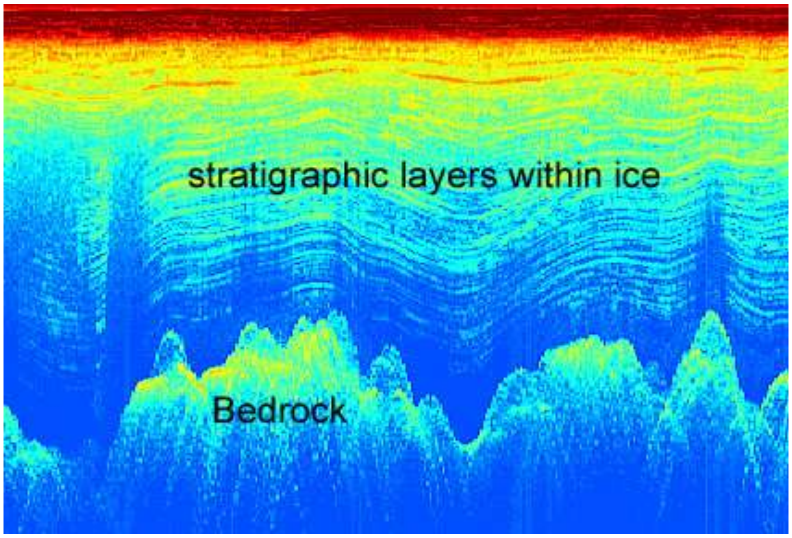

Figure E.1.1 Ice sheet radio-sounding

(over Antarctica. -- Image courtesy of the SOAR project at University of Texas)

The Ice Penetrating Radar will enable the observation of stratigraphic isochrones, interfaces between ice and water, detect pockets of water and "warm" ice, structure, and sub-surface composition. These internal layers will be observed to the depth of at least 3km with the full depth of the sounding extending 30km. Cryospheric radio soundings have been efficacious in determining the science and history of icy structures on Earth and Mars and will certainly be successful for Europa.

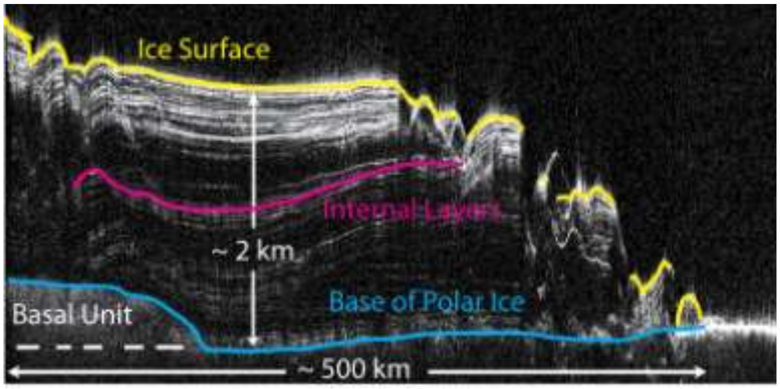

Figure E.1.2 Polar ice cap radio-sounding on Mars from the SHARAD mission

Laser Altimeter

The primary scientific objectives for the Laser Altimeter are to help characterize Europa's geologic history and the state of the interior. The altimeter transmits a laser beam to the surface, detecting the return reflection, and measuring the round trip time to map surface geological features. The spatial resolution is 1 to 2 cm from an orbital altitude of 100 km. High resolution topographical mapping and meticulous imagining of surface features will be obtained.

Figure E.1.3 Laser Altimeter experiment

The Laser Altimeter will accomplish the crucial imaging of surface features that will aid in the determination of subsurface processes. These processes include cryovolcanism induced convection, subduction, and whether or not the icy crust is decoupled from the rocky core by an ocean. The instrument will also detect the phase and amplitude of the gravitational tides. In addition to satisfying scientific objectives the Laser Altimeter will characterize future landing sites.

Three heritage missions have and currently are utilizing the Laser Altimeter. An earlier version of the altimeter flew on the Mars Global Surveyor. The instrument is currently aboard the MESSENGER mission to map the surface and determine interior processes on Mercury. The ICESat mission is currently utilizing the altimeter for terrestrial polar ice sheet data.

UV Spectrometer.

The UV Spectrometer will enable the observation of Europa's tenuous atmosphere. The primary focus will be observing the distribution of gases, primarily molecular Oxygen. This instrument will search for potential hydrothermal plumes and other potential surface-atmospheric interactions. Hydrothermal vents are theorized to exist beneath the “chaos” regions, such as the Conamara region. These regions will be studied using UV and near UV spectroscopy. Characterizing the potential hydrothermal vents and plumes is crucial to understanding the subsurface processes.

UV spectroscopy coupled with magnetronomy will determine the atmospheric-magnetospheric interactions. The implications radiation and magnetic forces have on the atmospheric generation, distribution of gases, and atmospheric depletion. Due to the low escape velocity, the atmospheric particles easily escape. However, those particles become caught in Jupiter's magnetic and rotate around the gas giant along Europa's orbit. This trail of particles is known as the "Europa torus." The interaction between the tenuous atmosphere and the "Europa torus" will be observed.

IR Spectrometer

IR spectroscopy will be utilized for surface composition analysis of the non-ice components. The IR Spectrometer will also discern the surface and near surface crystalinity and "type" of ice. IR provides increased spectral sensitivity towards surface impurities such as organic compounds which is a crucial component in the search for life. This instrument will contribute to the Science Enhancement Option (SEO). Please refer to Section E.6 regarding the SEO.

Thermal Emission Spectrometer (TES)

The Thermal Emission Spectrometer will map surface thermal anomalies, differential heating, and thermal inertia. This instrument has acquired a successful heritage with Mars rover and orbital missions. TES will contribute to the SEO (Section E.6).

Narrow Angle Camera

The Narrow Angle Cameron will provide high resolution visible imagery of local scale surface geological structures. A complement to the altimeter, the images will aid in the determination of subsurface processes. The camera will contribute to SEO (Section E.6).

Magnetometer

The Magnetometer will measure the flux of the magnetic forces induced by Jupiter and Europa. Coupled with UV spectroscopy, the Magnetometer will observe atmospheric-magnetospheric interactions. The implications radiation and magnetic forces have on atmospheric generation, depletion, and the distribution of gasses.

Nephelometer

The Nephelometer is purely an instrument for the SEO.

Aerogel Filter

Cosmic dust and debris will collected via an Aerogel Filter during the entirety of the mission. The flux in cosmic particles will be determined in Jupiter's magnetic field and in the Europa Torus. Particles expelled from Europa that reside in the Europa Torus may be collected

Lander Instruments

Raman Spectrometer

This experiment will measure the wavelength and intensity of inelastically scattered light from molecules. The Raman scattered light occurs at wavelengths that are shifted from the incident light by the energies of molecular vibrations. The mechanism of Raman scattering is different from that of infrared absorption, but when coupled with infrared spectroscopy a complementary surface composition analysis is acquired.

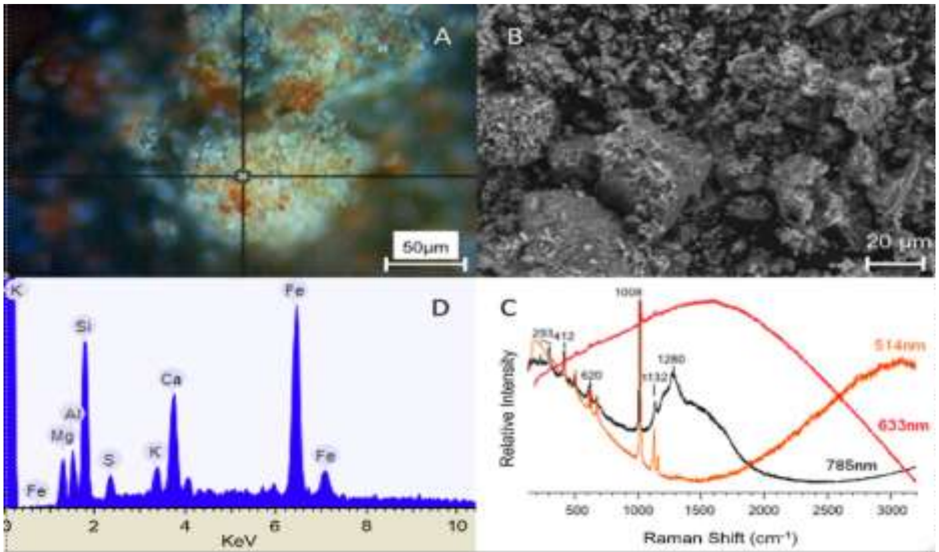

Figure E.4 Distinct micro-Raman spectra signatures of sample from the Little Hebe crater rim in Death Valley (B) simultaneously showing mineralogical and microbiological spectral signatures of various minerals. The assignments are supported by compositional EDX spectra (D), optical (A, 20X microscope objective), and Scanning Electron Microscope observations (B).
-- Image courtesy of Rosalba Bonaccorsi

Raman spectroscopy is commonly used to test levels of carbon and oxygen which are crucial elements in the determination of possible life. Other raman spectroscopy applications are structure determination, multi-component qualitative analysis, and quantitative analysis.

Miniature Thermal Emission Spectrometer

The Mini-TES (Figure E.5) analyzes the mineralogy and thermophysical properties of the surface. It uses thermal spectra to determine what mineral and chemical composition of the surface. While there will be thermal spectroscopy conducted form space, the Mini-TES lander payload will provided higher resolution spectra of the surface area it analyzes. The Mini-TES covers a spectral range of 5 to 29 micrometers. It has a spatial resolution of 20 micro radians.

Figure E.5 Mini-TES experiment

This experiment will aid in the search for organic compounds as well as the determinations of non-ice surface constituents at the microscopic level. Mini-TES is a heritage instrument of the Mars Rover missions.

Mass Spectrometer

This instrument will provide molecular analysis in search of chemical compounds in the upper surface layer of Europa and measured atmospheric composition near the surface. The Mass Spectrometer, coupled with a gas chromatograph, is a heritage instrument of the Viking 1 Lander where it conducted soil and near surface atmospheric chemical composition and molecular analysis.

Panoramic Camera

The Panoramic Camera (Pancam) is a pair of high-resolution CCD imagers mounted on the Pancam Mast Assembly. The imagers are side-by-side on a "camera bar" to allow stereo imaging. The high resolution imagery of the surface and nearby geological features will enhance understanding of the subsurface structure and processes. The PanCam has been utilized on a plurality of Mars surface systems and has provided high resolution panoramic images of the Martian landscape.

Seismic Network

As a compliment to the subsurface analysis retrieved by the Ice Penetrating Radar, a seismic network has been designed as a payload. Ten geophones will be deployed from orbit and penetrate the surface. Europa's active and rapid geological processes result in frequent seismic activity. These geophones will measure the seismic acoustic waves as they permeate through the crust. This vertical sounding will complement the data retrieved by the radar. The specification for this experiment can be found in the traceability matrix with a more detailed description in I.2.2 Measuring the Magnitude of the Europan Tremors (M2ET).

E.2 Data Sufficiency

The information regarding this requirement can be found in Section D.3 and E.1.

E.3Science Mission Profile

The success of this mission is based upon a successful landing on Europa while the orbiter continues to take readings simultaneously. The goals and proposed objectives can be found in Section D.1, and these two components, Lander and orbiter, working cooperatively is the driving force to the mission. To determine the chemical composition of the icy crust using the Raman and mass spectrometer, the Lander must have a successful deployment and landing to begin its data collection. In addition to the chemical composition, the Lander, as extensively described in Section E.1, will take readings in the day time using a thermal emissions spectrometer.   The panoramic camera will also send live feed to the orbiter for continues views of the surface. Retrospectively, the orbiter will be constantly orbiting Europa with a low altitude to conduct data collection with the ice penetrating radar and laser altimeter. Data collection with the nephelometer, magnometer, UV spectrometer, and IR spectrometer will focus on cosmic dust, the magnetic fields around Europa, and the winds from Jupiter. Symbiotically, the orbiter and Lander components are the driving force, allowing for the completion of the science goals and objectives.

Outlined extensively in Section D.1, the goals and objectives are based upon the lack of information about Europa in the hopes that this mission will gather much more. While there have been some studies about Europa, a Lander has never been put on the surface to determine composition, and topography mapping has been limited. This information is crucial for determining geologic, chemical, and possible biologic processes in harsh environments such as Europa.

E4. Data Plan

Data collected by the orbiter en route to Europa will be continuously relayed to Earth to be processed by a small group of hired scientists. Readings from the Lander will be transmitted and saved on the orbiter, while the orbiter saves its continual data collection, to be later sent to Earth. Decoding will be the preliminary step, so that the data will be easily read and understood. During this process, the different data will be validated by similar data previously collected. The data will be published no later than one year with all of the preliminary results. To discern the qualitative content over several years, scientists, post doctorals, graduate, and undergraduate students will need to be hired. Post analyzing, the data will be archived for future use. Specifically each of the instruments will have their own set of data to be analyzed:

Ice Penetrating Radar: This device will only operate upon orbiting Europa, and during the solar day. Running at a low frequency (Section E.1), the receiver will measure the voltage and have a resolution to view the interior structure. The rate of data collection will vary due to the unknown chemical composition of the ice.

Laser Altimeter: This device will only operate upon orbiting Europa, for the duration of the orbit around Europa. The altimeter uses an infrared laser transmitter and receiver that measures the round trip time of the laser pulses from the orbiter to map the surface features. The rate of collection is 46.3 bps with a resolution of 1064 nm.

Nephelometer: This device will operate for the entire mission, taking readings at programmed intervals. Options for measurement are one minute, continuous, and 15 min STEL; and the nephelometer has data logging of 4000 records of STEL, Max, Min and average reading and k-factor.

Magnometer: This device will operate for the entire mission, taking readings at programmed intervals. The magnometer has a 16 bit analogue to digital convertor, and a recording rate of approximately 20 Hz.

UV Spectrometer: This device will operate for the entire mission, taking readings at programmed intervals. The UV spectrometer has a display up to 7 kinetics curves per run.

IR Spectrometer: This device will operate for the entire mission, taking readings at programmed intervals. The IR spectrometer has a scan velocity between 0.0158 cm/sec to 8.22 cm/sec.

Raman Spectrometer: This device will only operate once on Europa, during the solar day. Laser excitation wavelength is 785 nm +/- 0.5 nm, 2 cm^{-1} line width, stability <0.1 cm^{-1}, while the output power of the laser is 300 mW or lower.

Thermal Emission Spectrometer: This device will only operate once on Europa, during the solar day. The rate of data collection is 16 bps.

Mass Spectrometer: This device will only operate once on Europa, during the solar day. Scan rate for the instrument can go 12,500 amu/sec, with 32 sets (full scan/SIM) of 32 ions per function. Maximum acquisition rate is 65 scans/second for a full scan, or depending on mass range- up to 100 samples/second.

E.5 Science Team

Cameron Self- Principle Investigator (Major: Physics, Meteorology Concentration. Minor: Music)

The CRETE Principle Investigator is responsible for leading the team in designing all scientific goals, objectives and work for the proposed mission. The PI is liaison tothe engineering team to cooperate in discerning that all of the science requirements are being met with the design of the orbiter, Lander and instruments. The PI will also analyze the atmospheric processes of Europa and Jupiter (SEO), structural and topographic features once the data has returned.

Mary Bronaugh- Co-Investigator (Majors: Geology and Sociology. Minors: Psychology)

The Co-I is responsible for aiding the Principle Investigator in determining the science, and designing the goals, objective and work for the proposed mission as well as establishing continual contact with both the Principle Investigator and the other Co-Investigator. Being the resident geologists, the responsibilities of this position include analyzing the data contributing to the geologic processes once the data has returned.

Stephanie Vogtman- Co- Investigator (Major: Marine Biology. Minor: Theater)

The Co-I is responsible for aiding the Principle Investigator in determining the science, and designing the goals, objective and work for the proposed mission as well as establishing continual contact with both the Principle Investigator and the other Co-Investigator. Having a strong background in marine biology, the responsibilities of this position include analyzing the chemical and bacterial composition of the ice, the structural and topographic features once the data has returned.

E.6 Plan for Science Enhancement Options (SEO)

Jupiter contains the largest planetary atmosphere in the Solar System. It is composed of prodominantly hydrogen and helium with traces of other chemical compounds. Like Earth, Jupiter's atmosphere contains a troposphere, tropopause, stratosphere, and thermosphere. However, unlike Earth, Jupiter lacks a mesosphere and a solid surface below the troposphere. As the pressure incresses with decreasing height, the gasseaus troposhere gradually becomes a critical fluid.

Despite recent observations, much about the Jupiter atmosphere remains a mistery. There exists an understanding of the overal circulation and and dynamics, however, no real meticulous measurements and observations have been conducted of Jupiter's vast complex atmosphere. Therefore, the determination of Jupiter's atmospheric processes has been chosen as a science enhancement option for this mission.

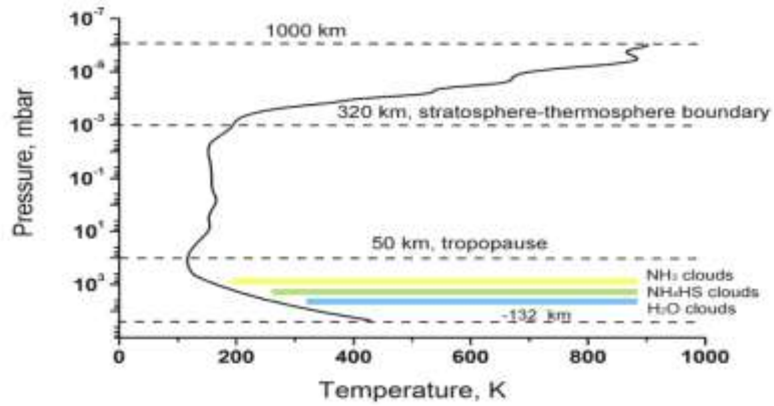

Figure E.6.1 Vertical profile of Jupiter's atmosphere

The atmosphere, in particular the upper atmosphere, of Jupiter will be studied using four orbital payloads. Three SEO payloads are components of the CRETE primary science mission. The atmospheric composition, circulation, cloud and storm structure, and dynamics will be observed. In addition, the cloud banding structure will be studied and related to the Hadley Cell Circulation experienced on Earth.

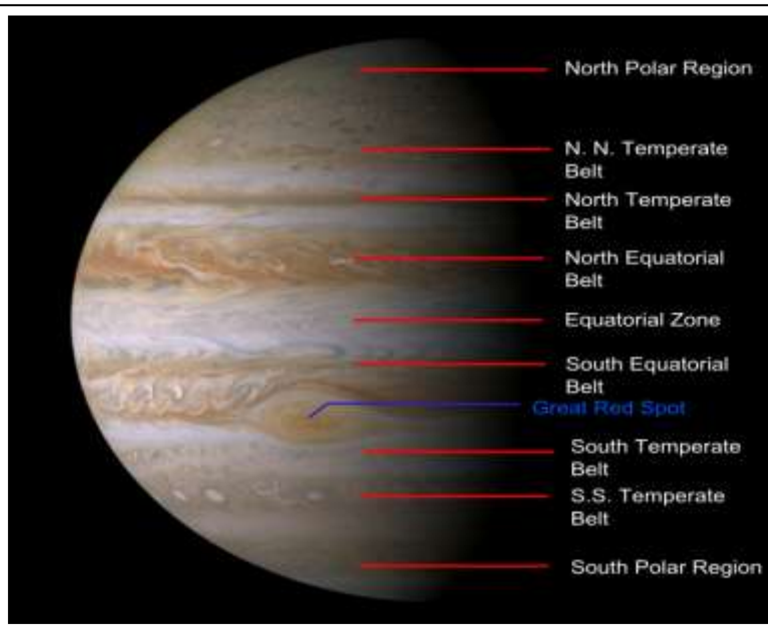

Figure E.6.2 Satellite image showing the different cloud belts. On Earth, these are called Hadley Cells.

Nephelometer: The objective of this investigation is to determine vertical extent, structure, and microphysical characteristics (particle size distribution, number density, and physical structure) of Jupiter's clouds over the range 0.1 to 10 bars. A single-wavelength, multiple-angle scattering nephelometer, with a gallium-arsenide LED source and solid-state detectors is mounted on the Probe, with appropriate external viewing geometry. A vertical sounding of the atmosphere down to the troposphere will be attained

IR Spectrometer and Thermal Emission Spectrometer (TES) : Both spectrometers will investigate the atmospheric composition. TES can detect thermal intertia, temperature anomolies, and differential heating therefore determining dynamics of the upper atmosphere, storm systems, and clouds

F Mission Implementation

F.1 General Requirements and Mission Traceability

The science goals and objectives along with the requirements for the engineering team, described in the Sections D and E, are taken into consideration to accomplish this mission. CRETE's engineering goal is to satisfy these science goals and objectives with a collaborative research and learning experience with national and international partners.

To accomplish the science, the CRETE mission will launch using an Atlas 551 rocket from Kennedy Space Center on February 29th, 2020. The AO specifies the launch date as December 31st, 2017 but the new date was chosen because CRETE will follow the Jupiter Europa Orbiter Mission's (JEO) VEEGA trajectory to get to Europa, which specifies the launch date as February 29, 2020. The CRETE mission architecture consists of the orbiter designed by ESTACA and the lander designed by the University of Alabama in Huntsville (UAH).

In order to accomplish the mission it takes 63 months (~5.25 years) to get Jupiter followed by 37 months (~3 years) orbiting around Jupiter and then finally getting into the orbit of Europa at the height of 200 km from the surface (Refer to Trajectory chart Appendix J.15.6 for detail). After arriving in orbit, the orbiter performs surface mapping for 3 months and then detaches the lander to land on the targeted site on the surface of Europa. The orbit around Europa will last for about 9 months; specific science data will be collected during this period and then will be communicated to the Earth. The orbiter will be able to see the Earth for 8 hours a day, hence about 7 Gb of data (per day) can be transmitted from the orbiter to Earth with a Ka Band frequency of 32 GHz. The data rate would be approximately 150 Kbps to Deep Space Network (DSN) using Ka Band. The lander will be able to communicate to the orbiter in 20 minute windows every 3 hours with a transfer rate of 180 Kbps. The detail about the data transfer is discussed in Sections F.2.3.1 and F.2.3.2 Telecommunication and Command Data and Handling section. A summary of mission concept of operation is represented in Figure F.2.1.1. The science requirements and the possible engineering solution are summarized in Mission Traceability Matrix (Table F.1.1).

Table F.1.1 Mission Traceability Matrix

Mission Requirement	Mission Design Requirements	Spacecraft Requirements	Ground Systems Requirements	Operation Requirements
From Table B1	Rocket: Atlas V 551	Total Mass: 4790 kg	Duration: Daily 8 hour	Must maneuver to stay within the 200 km orbit
			Antenna Size: 3m gimbaled High Gain Antenna	
	Launch Date: February 29th 2020 C3 12.8 km^2/s^2	Wet Orbiter Mass: 3344kg Wet Lander Mass: 1207 kg	Data Volume Per day: 7Gb/day during science phases	
			Critical event telemetry must be transmitted from the spacecraft in real-time, in case the RF link is lost, but is not required to be displayed or analyzed in real time	No special maneuvers while in 200 km orbit because the the telecommunication systsem is on the oposing side from the science instrumentation
			Transmit Frequency: Ka Band/ 32 GHz	
	Delta V: Orbiter 2324 m/s Lander 1528 m/s	Total Power: 303W Orbiter - 160 W Lander - 143W	Power Available for Communications: 55 Watts	
	Mission Length: 109 months	Fits within shroud and meets within the max center of gravity requirements for the C22 adapter		
	Orbit Altitude: 200 km		Weekly tracking is used to perform navigation and assess the the health of the flight system	
	Orbit Type: Retrograde Orbit	Temperature Range: Room Temperature	Additional tracking will be scheduled to support spacecraft and instrument calibration activites, science operations ar the gravity assist flybys of Earth and Venus, and maneuvers to refine trajectory targeting before and after each flyby	
	Landing Site: Landing on one of the pole			
	Land on the surface of Europa with less then 9 Earth G's	Orientation: 95 degrees		

F.2 Mission Concept Descriptions

F.2.1 Mission Design

The CRETE mission shall launch from the Kennedy Space Center in Orlando, Florida on February 29 2020 using Atlas 551 with a maximum C3 of 12.8 km^2/s^2. The mission has an available launch window of 21 days starting from February 29 2020 since CRETE shall follow the JEO Trajectory. Launching on the first day of the launch window reduces the deep space delta V since it grows from 0 to 93 m/s (JEO Report 2008). The JEO Trajectory that will be used by CRETE is represented in Appendix J.15.6. The figure illustrates a detail time period distribution of the interplanetary cruise state from Earth to Jupiter, followed by orbit around Jupiter and finally getting into the orbit of Europa. A summary of mission concept of operation is provided in figure F.2.1.1. The full mission duration is estimated to be around 9 years from launch until end of the mission. The duration is broken down (Table F.2.1.1) as approximately 6 years of cruise from the Earth to the Jupiter, followed by approximately 2 years of orbit around Jupiter and finally getting in to the orbit of Europa to perform the science mission for 1 year. The orbit around Europa is a retrograde orbit at a height of 200 km from the surface. The orbital orientation of the space craft is 95 degrees. The orbit is nearly circular (JEO) and is around the poles of Europa.

Table F.2.1.1 Duration of the CRETE Mission (With reference to JEO Report 2008)

Phase	Time period
Launch	February 29th 2020 (21 day launch period starts)
Cruise	March 2020 to June 2025(~63 months)
Orbit around Jupiter	June 2025 to July 2028 (~ 37 months)
Orbit around Europa	July 2028-March 2029 (~ 9 months)

The ground station that will be used for the communication will be Huntsville, AL. The orbiter will be able to see the Earth for 8 hours a day, hence about 7 Gb of data downlink (per day) can be transmitted from the orbiter to Earth with a Ka Band frequency of 32 GHz. The data rate would be approximately 150 Kbps to Deep Space Network (DSN). The mission traceability matrix (Table F.1.1) shows the ground system requirements for the CRETE mission. Critical Events: The critical events defined in Table F.2.1.2 lists the events that will be implemented from launch until the end of mission. The critical events state the events that take place that enable the science objectives to occur.

Table F.2.1.2 Critical Event of the Mission

	Critical Events	
1	Launch from Kennedy Space Center using an Atlas V 551	
2	Once out of earth's atmosphere, detatch from the Atlas V and separate from fairing	
3	Perform a flyby of Venus to gain delta V for the VEEGA trajectory	
4	Perform two flybys of earth to gain delta V for the VEEGA trajectory	
5	Arrive in the Jovian orbit.	
6	Perform braking to slow down	
7	Arrive in Europa's orbit.	
8	Perform breaking to slow down	
9	From the orbiter, map Europa and from that information, define an optimal landing site on the north pole	
10	Detatch the lander from the orbiter	
	Orbiter	**Lander**
11		Maneuver the lander away from the orbiter
12		Using the ACS orient the lander
13	Using the ACS to maintain the orbital path	Perform breaking to slow down
14	Collect/Transmit the information from/to Earth	Using the ACS manouver the lander towards the optimal landing position
15	Collect/Transmit the information from/to Orbiter	Perform landing on targeted site
16	Compile data during the period of invisibility with Earth	Perform science experiments
17	Compile data during the period of invisibility with the Orbiter	Compile the information and transfer the data to the orbiter
18	Transmit the information to Earth	
19	Perform end of mission procedures	

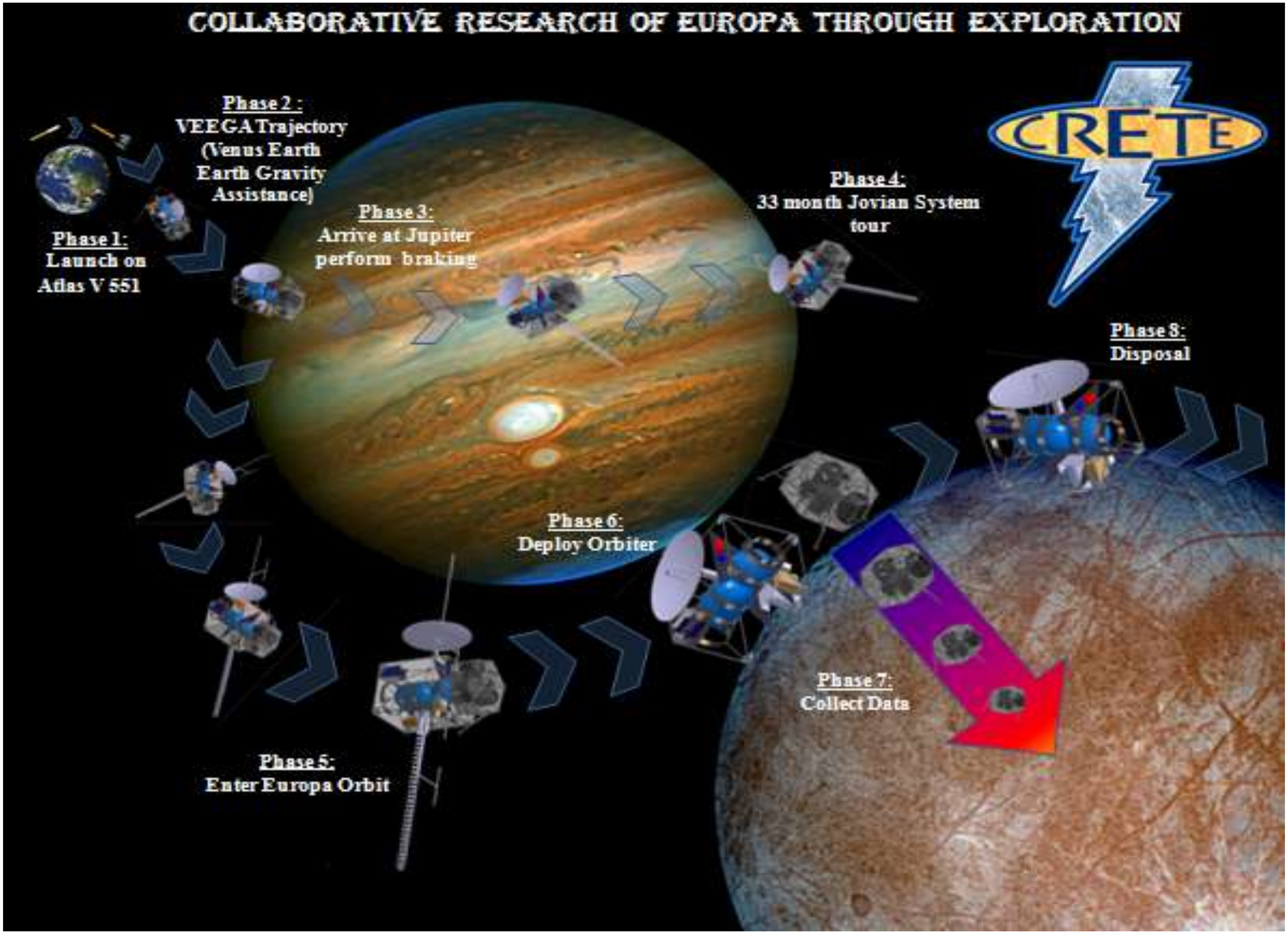

Figure F.2.1.1 Mission Concept of Operation

F.2.2 Launch Vehicle Compatibility

According to the Discovery Announcement of Opportunity (AO) 2010, the spacecraft should be compatible with Delta IV, Falcon 9 and Atlas V. The CRETE mission will be using the Atlas V 551 rocket to accomplish its objective. The other rocket that CRETE is compatible with is Delta IV M+ (5,4) but CRETE is not compatible with any of the Falcon series. The CRETE mission has been designed to fit within the constraints of the Atlas V 551 fairing. The C22 adapter that connects the Atlas V 551 to the CRETE assembly has a maximum vertical CG of 3.7m from the base of the adapter.

F.2.3 Flight System Capabilites

Figure F.2.3.1 shows the spacecraft within the shroud of the Atlas V 551. CRETE mission architecture consists of two major elements: the orbiter and the lander. The orbiter and its subsystems is by ESTACA and the lander subsystems are designed UAH.

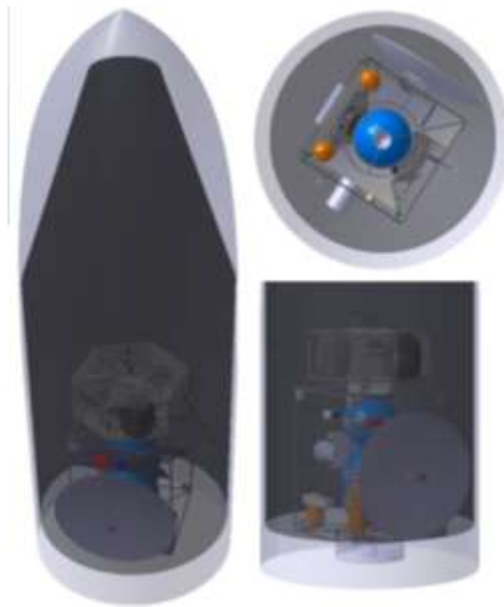

Figure F.2.3.1 Payload in Atlas V 551 Shroud

F.2.3.1 Orbiter

The Orbiter Subsystems Block Diagram is featured in figure F.2.3.1.1, and it shows the interaction between each subsystem. The CAD model in Figure F.2.3.1.2 features all of the orbiter's subsystems.

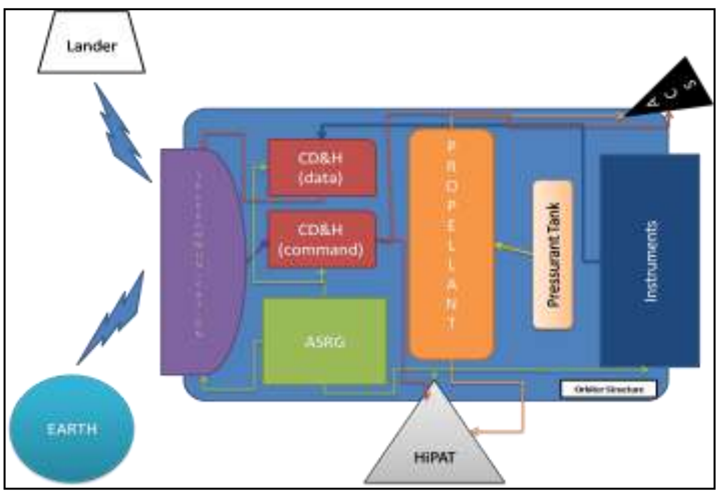

Figure F.2.3.1.1 Orbiter

Orbiter Structures:

The rectangular-shaped orbiter is designed to have a side facing the Earth and another facing Europa. A hollow tubular structure is chosen to save weight without affecting the strength of the structure. To simplify the structure, the propellant tanks are chosen to be the same diameter and are stacked in the center to ensure the stability of the orbiter. One of the main objectives for the design is to conserve mass; therefore, the structure is made of carbon composite instead of aluminum. The carbon composites are stronger than the aluminum alloy. The carbon is also chosen for its good properties, such as its good thermal stability, a small expansion coefficient, a high resistance to ambient effects, a high strength (mainly in the direction of fibers) and a high Modulus of Elasticity.

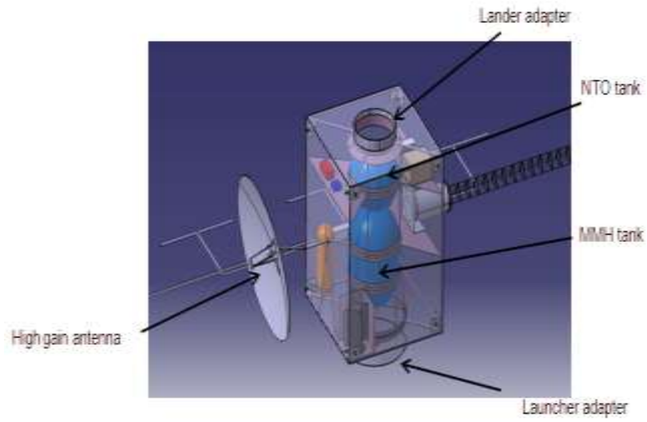

Figure F.2.3.1.2 Orbiter and its Subsystems

For the exterior structure, honeycomb panels are selected to have a solid surface with a minimal mass (about 50 kg/m^3), which is covered with thermal protection. The thermal protection is Multi Layer Insulation (MLI), which is light and efficient.

Orbiter Propulsion:

Previously mentioned, CRETE is utilizing a VEEGA trajectory with an orbital altitude of 200 km over Europa, for a total Delta V of 2324 m/s. Table F.2.3.1.1 represents the Delta V budget.The HiPAT dual mode engine is chosen due to its high performance and reliability. The dual mode allows small accurate impulses.

Table F.2.3.1.1 Delta V Budget (adapted from JEO Report 2008)

Activity	Delta V (m/s)	Comments
Launch Injection Clean-up	20	
Earth targeting Bias Allocation	50	
Deep Space Maneuver	96	
Remaining Interplanetary	50	
JOI Impulsion	618	Jupiter Orbit Insertion
Solar Perturbations	80	
Reducing Energy at Europa	100	
	200	8 m/s per encounter (25 encounters)
Europa Approach	165	
Small Maneuvers	10	
EOI Impulsive	792	Europa Orbit Insertion
Orbit Maintenance	143	1m/s per week during 33 months
Total	2324	

<u>*Propellant tanks*</u>*:*

Considering a total mass of 4790 kg, the propellant mass needed is estimated to be 2635 kg. Two tanks will be used, one filled with 1558 kg of Monomethylhydrazine (MMH) and one filled with 1324 kg of Nitrogen Tetroxide (NTO). The NTO tank has a volume of 1 m^3, and the hydrazine tank has a volume of 1.68 m^3. The NTO tank is a 1.242 m diameter sphere, and the MMH tank is a cylindrical tank of the same diameter. Only the MMH tank has to be specially designed for the mission because the other tanks are currently produced by ATK. The material chosen for these tanks is aluminum. The mass is 31 kg for the NTO tank and 55 kg for the MMH tank. Figure F.2.3.1.3 shows the location of the main engine on the orbiter.

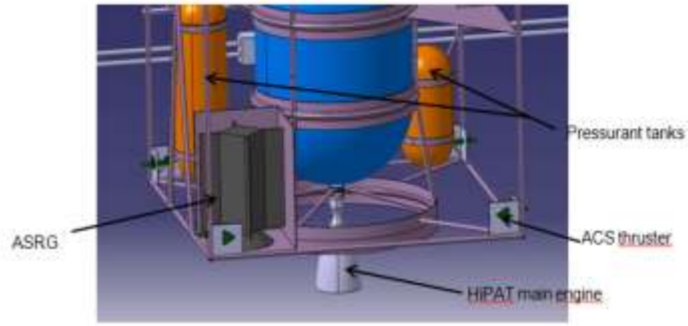

Figure F.2.3.1.3 Propulsion and Power

Pressurization system

CRETE will use a regulated pressurization system using two pressurant tanks (one for each propellant tank). The pressurant tanks will be filled with 10 kg (for the MMH system) and 6 kg (for the NTO system).

CRETE has chosen to use a Composite Overwrapped Pressure Vessel (COPV) tank for the pressurization system. The mass of these tanks is 15 kg for the NTO pressurant tank and 25 kg for the MMH, both with a diameter of 0.418 m.

Orbiter Attitude Control System

The spacecraft is three-axis controlled. Maneuvers are automated by the gimbaled main engine and the 16 Aerojet MR-111 4N monopropellant thrusters. There are two thrusters on each corner of the spacecraft. Three reaction wheels configured in orthogonal directions control torque. The wheels will speed up to create torques when a pointing error is detected. The ACS will use an inertial measurement unit (IMU), a sun sensor and a star tracker as shown in Figure F.2.3.1.4. A control law inside an onboard computer will determine the response to a disturbance.

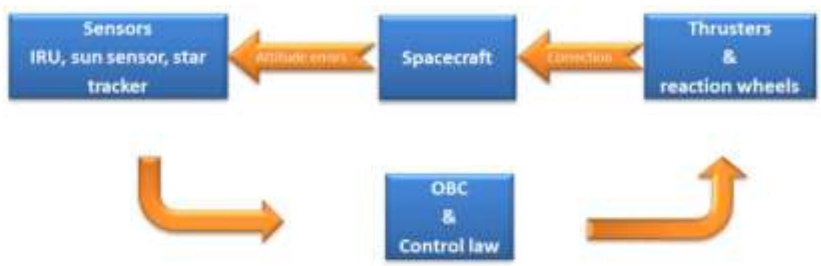

Figure F.2.3.1.4 Attitude Control System

Telecommunication

The orbiter is equipped with two main communication systems: The High Gain Antenna (HGA) is designed to ensure the communication with the Deep Space Network (DSN) ground systems. The HGA is a 3 m gimbaled antenna due to the distance with Earth. This antenna permits the sending of signals with a very high gain and amplifies the signals received. The HGA chosen is "Cassegrain Style." The width of the reflector permits the concentration of the uploaded information. The frequency should be adapted to the DSN and to avoid noise dispersion the Ka Band of 32 GHz is used.

Since the orbiter receives data from the lander, it will be equipped with a Middle Gain Antenna (MGA). To optimize the mass and the space, this antenna will be only mono wired. Each window for communication with the lander will represent 1.5 hours. The MGA receives about 180 Kbps Uplink from the lander. The antenna will receive information from the lander, encode with the onboard computers and send it to Earth through the HGA.

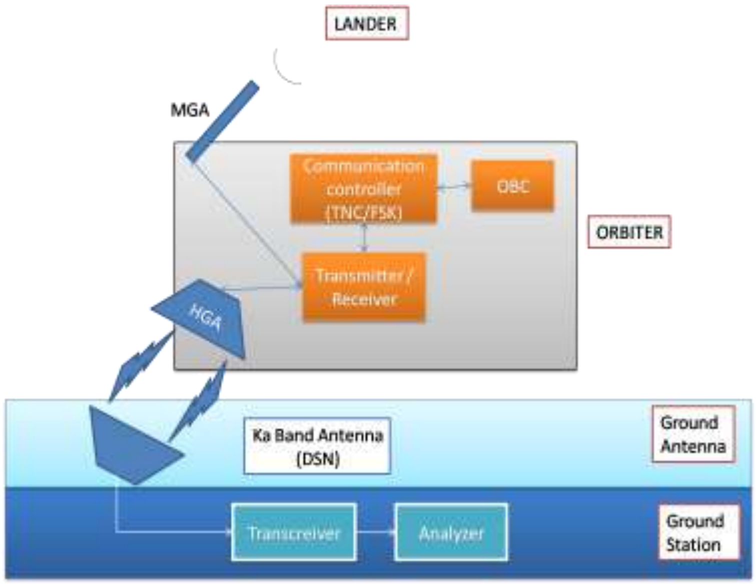

Figure F.2.3.1.5 Telecommunication system

The orbiter will include a small deep space transponder designed by the Jet Propulsion Laboratory, which unifies the communication functions (command detector, control function, telemetry modulator, etc.). This avoids having separated systems and ensures an optimized mass for the telecommunication management. The telecommunication system between the lander, orbiter, and the ground system can be seen in Figure F.2.3.1.5.

The HGA has an 8 hour window as a maximum period link with Earth. The global power consumption including the HGA, MGA , and transponders/controllers consume about 60W and have a mass of 70 kg.

Command and Data Handling

The data flow for command and data handling (C&DH) can be seen in Figure 2.3.1.6. Two computers are used for C&DH. One is specialized for data handling which controls the information flow from sensors, instruments, and antennas. The majority of the information is stored temporarily into the computer memory, waiting to be transmitted to Earth. C&DH handles three types of data: science data, lander data, and

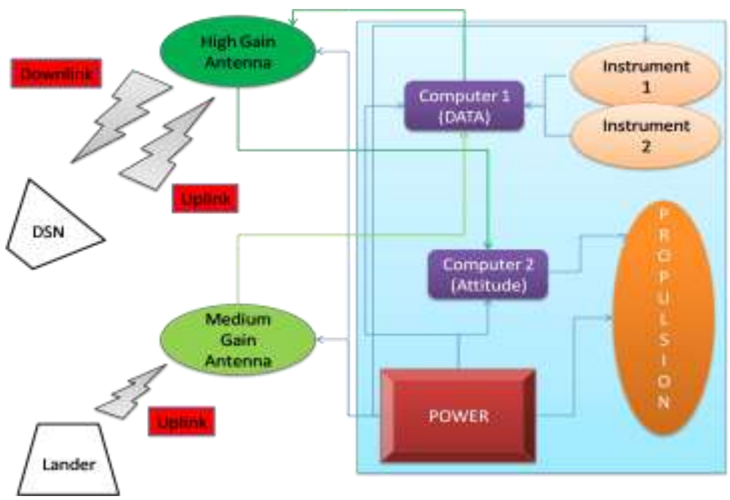

Figure F.2.3.1.6 Data Acquisition Synoptic

engineering data. The science data has the highest data storage, the lander has medium data storage, and the engineering data has minimal data storage. The science data will consist of information from each of the instruments such as the crust analysis of Europa. The lander data consists of information sent from the lander including subsystem functionality and lander instrumentation. The engineering data consists of orbiter functionality. The maximum downlink is estimated to approximately 2000 bps. Figure F.2.3.1.6 features the data acquisition synoptic.

The lander separation is the most critical data handling. The maximum data rate will be required during the orbit insertion and during the separation with the Lander.

The data storage unit used is a solid-state recorder. The throughput is approximately 20 Mbps, and the memory storage is between 2 Gbit to 20 Gbit. The whole orbiter C&DH weighs 50 kg and consumes about 40 W.

The data storage includes at least one period of data transmission missed and should not be used at this maximum load in the nominal phases. This means if there is a transmission problem the unit should offer enough capacity to store twice the data it had stored in the nominal phase. Thus, the margin should be about 50% of the estimated capacity. Figure F.2.3.1.7 represents the data flow synoptic.

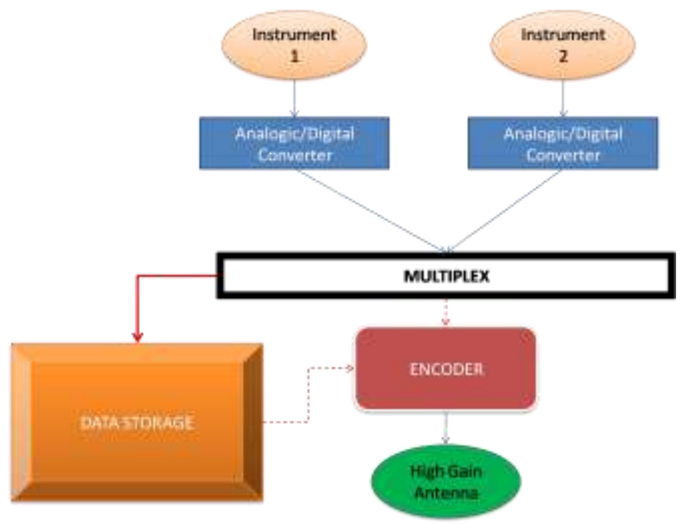

Figure F.2.3.1.7 Data Flow Synoptic

Power

The energy needed for each mission phase is detailed in the Appendix J.15.4. Since the second phase of the mission requires the most power, the power subsystem is designed for this phase. The instruments are separated during this phase because one ASRG is not powerful enough to provide the energy to all instruments at the same time. The total instrument power requirement is 115 W. An Advanced Stirling Radioisotope Generator (ASRG) is used as the power source for the orbiter. The ASRG provides a high-efficiency power source alternative to radioisotope thermoelectric generators (RTGs). Two types of ASRG are available: ASRG (650°C) or ASRG (850°C). Both ASRGs can provide the needed power for the mission. The advantage of ASRG (850°C) is that it can provide more energy than the ASRG (650°C).

Because the ASRG can provide the power needed for the whole mission, batteries will be unnecessary. The minimum power capability needed to meet all requirements including the thermal control is 125 W at end of life (EOL). Despite the power degradation of the ASRG (0.8%/yr.) both ASRGs can provide this power exceeding 10 years.

Buses are used to share energy. The majority of the past and present spacecraft use a 28V average DC bus voltage. This is because most of the equipment used on spacecraft is designed to run at this voltage. Therefore, a 28 V DC bus will be used. For additional fault tolerance, grounding is established. A representation of a block diagram for the power subsystem is shown in figure F.2.3.1.8

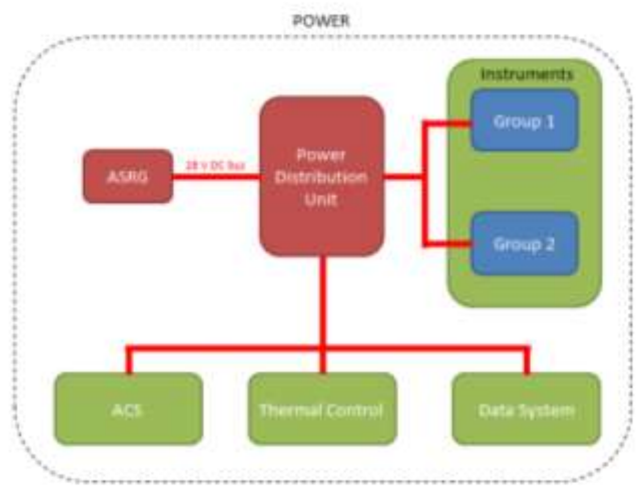

Figure F.2.3.1.8 Power sub system

Thermal protection

The thermal control subsystem provides temperature control for the flight system and instruments including the science instrument, propulsion module, electronics, and spacecraft bus. The spacecraft has three critical environments during the mission: the launch, Venus' orbit, and Europa's orbit. Due to aerodynamic heating, the launch payload-fairing temperature can be as high as 200°C. During the Venus' orbit environment, the temperature can fluctuate between -120°C and 150°C. Europa's orbit environment has temperatures varying between -190°C and -130°C.

Team CRETE estimates the operating temperature boundaries of the flight system to be between -13 and 46°C. Therefore, the thermal control subsystem must provide temperature control for the flight system within those boundaries.

To ensure this operating environment, Teflon MLI, shown in Figure 2.3.1.10, as well as reflective paint reduces the incoming radiation effects on all applicable surfaces. MLI also wraps each science instrument and electronic in order to maintain the standard operating temperatures. One Heat shield Fine Weave Pierced Fabric (FWPF) is used to protect the orbiter from the ASRG radiation. *FWPF* is a carbon composite composed of graphite fibers woven in three dimensions. In addition, a single-layer low emissivity heat shield protects the enclosed elements from radiant heating from the nozzle as well as heating from the rocket plume. For additional radiation shielding, Aluminum and Tantalum layers can be used.

As shown in Figure 2.3.1.9, a series of louvers located about the perimeter of the spacecraft bus will enable emission of radiation and electronic dissipation heat. The opening of the louvers exposes the radiator underneath and allows the spacecraft to cool. A network of sensors and a control system continually monitors and optimizes the louver-radiator system for the various thermal environments that the spacecraft will experience.

The thermal control system uses the heat output of ASRG-850°C as heater. If this heat is not enough, Radioisotope Heater Units (RHUs) will be added to provide heat. Moreover, heat switches can passively control the temperature of warm electronics or instrumentation without the use of thermostats and heaters, thereby reducing power requirements as well as the need for heater control circuitry and software. If the thermal control detects a contingency case, it will use a thermostat and thermoelectric cooler to handle internal temperature.

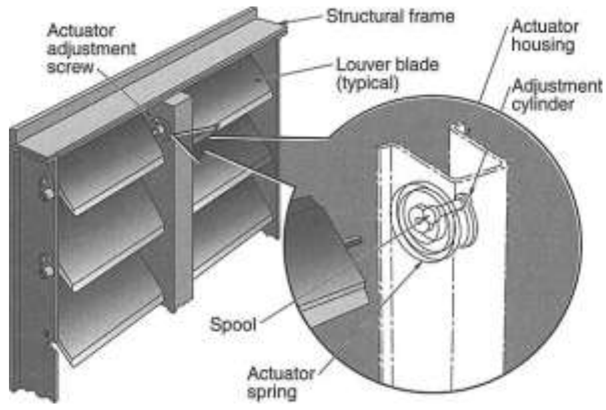

Figure F.2.3.1.9 Louver assembly schematic

F.2.3.2 Lander

Figure F.2.3.2.1 represents the lander with the major subsystems fully labeled with the maximum dimensions. The subsystems were arranged to keep the center of gravity and utilize the arrangement of the structure as well as possible. The telecommunications system was placed on the top for maximum orbiter visibility. The thermal chassis is placed in the center of the arrangement to keep the center of gravity in the center as much as possible. The thermals chassis contains the payload (science instrumentation), ASRG and CD&H. The propulsion subsystem was

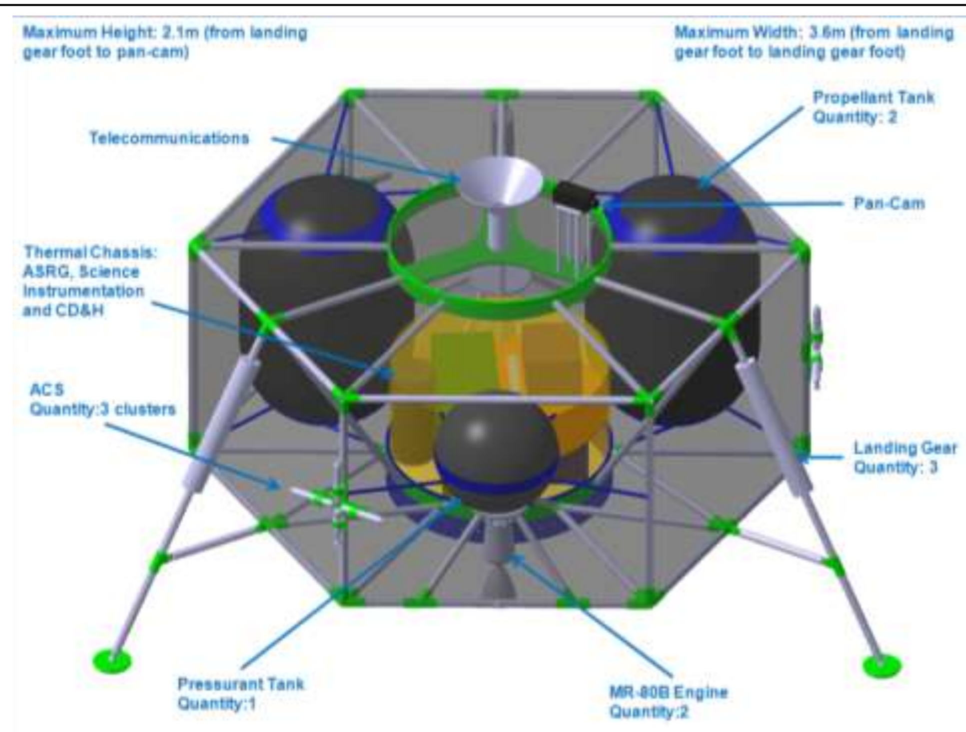

Figure F.2.3.2.1 Lander Dimensions and Subsystems

arranged to comply with the needs from the amount of engines and the size/amount of the propellant/ pressurant tanks. All of the subsystems were arranged within the hexagonal shape to conserve mass as much as possible.

Figure F.2.3.2.2 represents the block diagram of the lander and how each subsystem interacts with the other subsystem. The figure shows the subsystems that need power from the ASRG, the information transmitted from and to the CD&H for the science data and the ACS, pressurant tank to propellant tank to MR-80B's and to ACS, and telecommunication from the lander to the orbiter. Table F.2.3.2.1 represents a summary of each subsystem with the total masses, power, data budget/total.

Table F.2.3.2.1 Subsystem Budget Summary

Subsystem	Mass (kg)	Power Requirement (W)	Data (Kbps)
Structures	99	0	0
Telecommunications	35	40	180
CD&H	32	45	0
Thermal	90	0	0
Propulsion	68	568	0
ACS	8	187	0
Payload	10	33	3
Power	39	0	0
Cabling	25	0	0
Totals	406	873	183

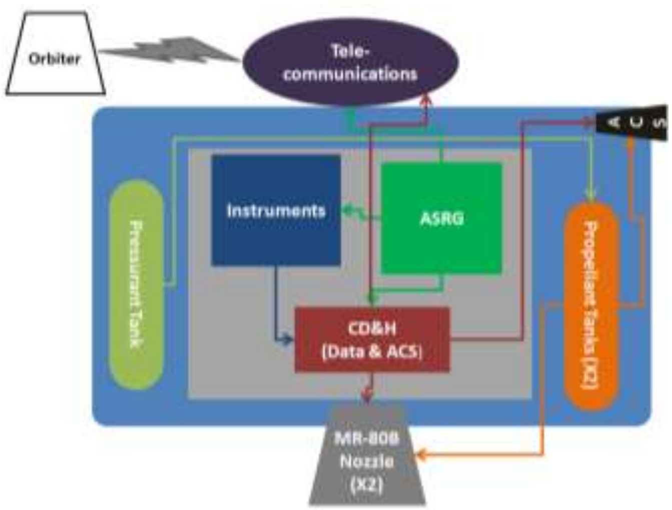

Figure F.2.3.2.2 Lander Block Diagram

Subsystem Descriptions
Structures

The lander and the orbiter were designed with one mechanical interface between them being an adapter similar to the C22 adapter. Explosive bolts will be utilized in order to separate the lander from the orbiter and to separate the orbiter from the Atlas V 551. The main objective of the structure was to make sure that the payload safely arrives on the surface of Europa. A summary of the structures with individual descriptions and function for the interfaces can be found in the appendix J.15.1.

Lander Structures:

The six sided layout of the lander was chosen to be the starting point of the design and to hold all of the other subsystems. The main structure was designed to implement more inexpensive types of off the shelf materials (tubing) instead of the primary structure needing to be machined. Secondary structure for corner fittings were incorporated into the design instead of using welds because of the high impact loads that the design will endure while landing. As shown above in Figure F.2.3.2.1, the landing gear structure encompasses all of the other subsystems and supports have been implemented to stabilize those subsystems.

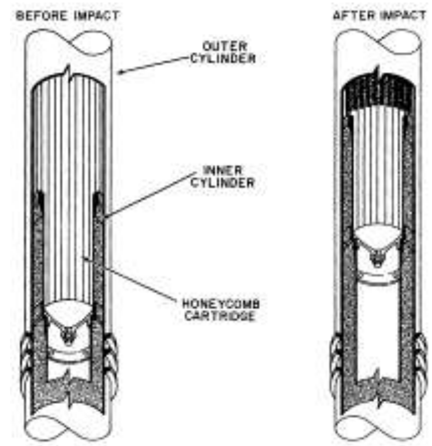

Figure F.2.3.2.3 Honeycomb Energy Absorbers

http://heroicrelics.org/info/lm/landing-gear-strut-honeycomb.html

Landing Gear:

In the design of the landing gear since a six-sided lander was chosen in the decision analysis there were two choices for the landing gear either six struts or three struts to keep the CG (center of gravity) in the center as much as possible. Three legs were designed to take the 9G impact of the load of the landing. The analysis of the landing gear incorporated a worst case scenario if there were only two gears that landed in the initial impact at twelve degree tilt. Honeycomb energy absorbers Figure F.2.3.2.3 were used in the design of the landing gear to absorb a fraction of the impact loading.

Internal Structure:

A strut assembly was designed with various gauges of 7075-T651 aluminum tubing to withstand the remainder load of the impact landing, the thrust that is implemented by the two MR-80B engines and the launch loads.

Thermal Instrument Chassis:

A thermal instrument chassis container was designed in the center of the assembly to house all of the electronics with multiple shelves to hold the science equipment, control and data handling system and the ASRG. Further detail on the thermal chassis can be found in the thermal section.

Analysis:

Analysis on the lander support beams was implemented to determine the preliminary sizing of the structure at a maximum stress concentration area where the landing legs met the rest of the bus structure. It was calculated that the honeycomb energy absorbers would undergo a 2.01*10^4 N force. It was estimated that the honeycomb would absorb a third of the total force. Analysis on the adjoining beams were used to calculate the cross sectional sizing of the of the aluminum tubing. The max stress was calculated to be 1.08 MPa. Analysis on this section is found section in the appendix J.15.1. A factor of safety of 1.5 was implemented as a result for the design of the structure.

Command and Data Handling

The lander will have a RAD750 computer system to be used for command and data handling. The RAD750 computer was chosen because it can perform the command processing for the mission, and it is hardened against radiation for 100Krad. Since the lander's electronics will be shielded from radiation, it is expected that there will not be any radiation getting to the computer, but in case any does the computer can handle 100Krad. This computer will handle command and telemetry processing and will have memory for stored commands as well. Also, it will have computer watchdog functions, functions that ensure the software aboard the spacecraft is working properly In case problems occur during the mission, the computer watchdog functions will automatically switch the computer to emergency mode. This system will require 45W of power and will weigh 32kg, which includes the system storage as well.

In order to save the data from the instruments, a 500 Mbit SSDR will be used. Considering that the lander will be able to uplink with the orbiter about every three hours for 20 minutes at a time, and considering the data rate of the instruments in total is 3 Kbps when using the pan cam intermittently as space permits; it has been calculated that the most data that will be stored at any given time should be approximately 50 Mbits. However, if the lander must go 24 hours without linking with the orbiter, it has the capacity to hold that data.

Telecommunications

The telecom system for the lander will be a medium gain X-band system. X-band frequencies were chosen because they are more stable from noise than the Ka-band and also take less power and weight. The system will be comprised of two transponders and receivers, two sets of controllers, a horn antenna, and two traveling-wave tube amplifiers. This system is redundant in order to ensure the data collected by the lander gets transmitted to Earth. The total power needed for this system is 40W. The total weight for the system is 38.5 kg. The data rate is going to be 180 Kbps uplink and downlink. This rate allows the lander to send all of the data from the three hours during which it could not communicate to the orbiter and all housekeeping data to the orbiter during the 20 min window given during each link. Missing an uplink or downlink is not a problem due to a 500 Mbit solid state data recorder (SSDR). Since the instruments only take 270 Mbits per day and 11.198 Mbits per hour, this size SSDR lets the lander store over 24 hours worth of data at a time.

The lander will have four modes. These four modes are dormant mode, landing mode, data acquisition modes, and emergency mode. The dormant mode will be the mode the lander will be in until the lander is ready to land on Europa. During this mode, the lander will not record any science data and all systems will be off. All power, except the power needed to run the computer, 10W, will be routed to the heaters heating the propellant tanks. When the lander is ready to land it will enter landing mode. During this mode, the lander will also not take any science data and all system resources will be focused on landing softly. This mode, for a millisecond, will need 232 W, which with the secondary battery can be handled. The power then returns down to a much lower level. Once the lander has successfully landed, it will be in data acquisition mode. During this mode, it will take in data and transmit that data whenever the orbiter is in range for a link up. The power used hwen the lander is not linked to the orbiter is 78 W. When the lander is connected to the orbiter the lander uses 118 W, which the secondary battery will aid with. As long as no major error occurs, this will be the mode the lander remains in for the remainder of the lander's life. However, if a major error does occur, the lander will enter emergency mode, where it will focus purely on sending what remaining data is on the SSDR to the orbiter, which requires 85 W.

Power

The power supply for the lander will be one of the NASA supplied Advanced Stirling Radioisotope Generators (ASRG). The ASRG is currently still in development, but the current prototype operates at 600°C, produces 143W of electricity at beginning of life, produces 500W of heat, and is only 20.2 kg. The ASRG will produce 91.06W at end of life with a 30% margin taken out. Once landed, the power needed by the lander will only be 78.488 not including the power needed to recharge the battery. Thus the rest of this power can go to recharging the secondary battery used during linking with the orbiter.

Since the ASRG is always producing power, and the lander systems do not need to be run during the seven years it will take for the orbiter to reach Europa, there will also be a shunt radiator to dissipate the electricity as more heat energy. In order to regulate the voltages going into each member of the system needing power, there will be dc-dc regulators for each needed input voltage. The ASRG will produce 91.06W at end of life with a 30% margin taken out. Once landed, the power needed by the lander will only be 79 W not including the power needed to recharge the battery. Thus the rest of this power can go to recharging the secondary battery used during linking with the orbiter.

There will be a secondary battery for landing and to boost power during peak loads, which is when the lander is linking with the orbiter and landing. This battery will be Nickel-Hydrogen due to its reliability, its use in the past, and its ability to recharge. The battery will be the same cell used on the International Space Station as according to *Elements of Spacecraft Design*. The lander will have five cells producing 264 W of power and weighing 13.5 kg. Considering the biggest load will be during the landing, which requires approximately 568W, the batteries power plus the power supplied by the ASRG will be enough to handle all loads placed on the space craft. This large of a battery was chosen because it does not require much mass and would ensure that the lander can handle all loads. Given the mass of the battery, the mass of the entire power system will weigh 38.5kg. Including cabling, this comes to 65 kg.

Propulsion

For the propulsion system trade study, there were two possible means for the lander to reach the surface of Europa. The first included the use of a propulsion system to slow the vehicle down; the other would have the lander reach the surface with penetration (Europa Jupiter System Mission Report 2009). The CRETE lander and its payload are only able to handle 9 G's of impact or less. As non-Earth based penetrators have never been implemented successfully and would have resulted in the damage of the scientific instruments due to the faster acceleration, using a soft lander was the better option.

Several engines of various propulsion system types were provided to select for the lander. All of these engines are manufactured by Aerojet. These included the MR-104D and MR-80B monopropellant engines, R-42, R-4D, and AMBR bipropellant engines, and the HiPAT High Performance Liquid Apogee Thruster. Information regarding each engine's design characteristics, performance, and risk are provided in Appendix J.15.2.3 Figures a-g. The MR-80B engine was determined to be the best choice for the CRETE lander, due to the fact that the engine can provide a 100:1 throttle ratio, and the Thrust-to-Weight calculations for this engine satisfies the needs for the lander. Thrust-to-Weight calculations are located in Appendix J.15.2.3. Two MR-80B engines are necessary for the propulsion system, in which they each will have a mass of 8 kg, provide a wide thrust range of 31 N to 3184 N, and have an ISP of 210 s. The engine's size encompasses a length of 0.4 m and a nozzle diameter of 0.2 m. The engine is based off of the MR-80 engine, which was used for the Viking missions, and the MR-80B will be used for the Mars Science Laboratory mission.

Table F.2.3.2.2 Propulsion System Mass

Element	Quantity	Mass (kg)	Total Mass (kg)
Hydrazine		862	862
Tank	2	4	8
Helium		5	5
Tank	1	35	35
MR-80B Engines	2	8	16
Lines and Valves		4	4
Propulsion Mass (excluding propellant)			68

The Delta-V budget for the lander propulsion system is 1528 m/s. Hydrazine is a commonly used propellant that is compatible with the MR-80B and can also be used for the ACS subsystem; therefore, hydrazine shall be the fuel for the lander. The CRETE lander includes a 3.5% margin and a 5% contingency to the required propellant load, making the lander a conservative system with a total propellant load of 862 kg for the propulsion and ACS subsystems. Overall, the propellant margin includes that of nominal to meet the Delta-V requirement and additional to meet mass growth.

The propulsion system consists of a regulated pressure-fed system, which was chosen to ensure that there would be constant, predictable thrust throughout the mission. The mass breakdown of the propulsion system is located in Table F.2.3.2.2. Two cylindrical propellant tanks, each filled with approximately 431 kg of hydrazine, supplies propellant to one MR-80B engine, as well as a portion of ACS thrusters. The tanks are made of carbon-fiber composites and contain a propellant management device (PMD) to assist in removing the propellant from the tanks and into the engines. The inner diameter is 0.8 m, and each tank weighs 4 kg, resulting in a total mass of 8 kg. An additional spherical pressurant tank supplies the necessary pressure to the two propellant tanks. The tank is filled with 5 kg of helium, which was chosen for its performance and low molecular weight. The pressurant tank is also made of carbon-fiber composite and has a mass of 35 kg. The mass of the lines and valves for the main propulsion subsystem and the ACS subsystem are an estimated 10% of the combined masses of the three tanks, which results in approximately 4 kg of lines and valves. Overall, the propulsion subsystem has a total mass of 68 kg. A diagram of the Propulsion and ACS subsystems is located in Figure F.2.3.2.4.

Attitude Determination and Control

Once the CRETE lander departs from the orbiter, it will begin its descent towards Europa's surface. There is not a designated location for the lander to reach to conduct experiments; therefore, the lander does not need to orient itself to a specific coordinate, nor does it need to set itself into a specific position. The requirements for the CRETE ACS subsystem are to stabilize the spacecraft as it descends and lands onto Europa's surface. The lander will utilize Aerojet's nine MR-111E engines and three MR-106E engines, and they are both flight-proven monopropellant engines. There are three sets of four thrusters that are positioned equally on the lander. The MR-111E engines will face in the left, right, and upward positions and account for slight attitude adjustments. They each have a mass of 0.33 kg and provide a thrust range of 0.5 N to 2.2 N. The MR-106E engines will be positioned

Table F.2.3.2.3 ACS System Mass

Element	Quantity	Mass (kg)	Total Mass (kg)
MR-111E	9	0.3	2.7
MR-106E	3	0.6	1.8
Star Tracker	2	0.4	0.8
IMU	2	0.8	1.6
		ACS Mass	6.9

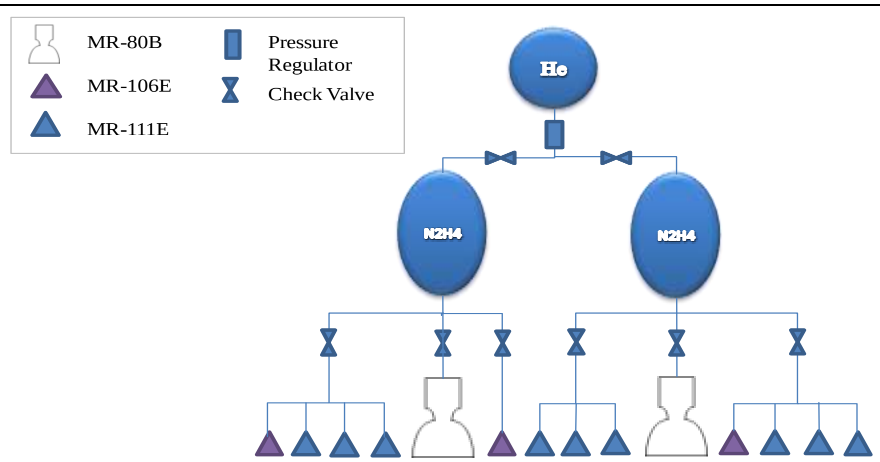

Figure F.2.3.2.4 Propulsion and ACS Subsystems Diagram

in the same direction as the MR-80B engines and are meant to assist in stabilizing the lander against the main propulsive engines. These engines have a mass of 0.635 kg and have a thrust range of 11.6 N to 30.7 N. Additional specifications for both engines are located in Appendix J.15.2.3. In addition, two star trackers are situated on the lander, and there are two Inertial Measurement Units (IMU) within the payload chassis, where the instruments are situated. There are two star trackers to increase the accuracy of the lander's position, as well as provides an extra unit if the other were to fail. There are two IMU units for the same means of having a backup, as well. The ACS system mass inventory is located in Table F.2.3.2.3. Figure F.2.3.2.4 represents the propulsion and ACS systems.

Thermal

CRETE must survive and operate in two very different environments. First, CRETE must survive the launch from Earth to Space. The launch is to take place in a February to March time frame with a probable launch from Cape Canaveral, FL. This allows an estimate of temperature to be between 6 to 27 degrees Celsius on the day of launch. CRETE must then be able to sustain itself in the inner solar system. Secondly, the CRETE lander must survive and function in Europa's atmosphere. The temperature in this environment can be as cold as -223 degrees Celsius. Radiation is another major factor in this mission. Europa's environment has high radiation content. Other forms of radiation will occur from solar energetic particles during the interplanetary cruise, galactic cosmic rays during the interplanetary cruise, and trapped particles in the Jovian magnetosphere during the Jupiter tour and the orbits at Europa.

The most desirable approach for the thermal control system is a passive approach to save power and to simplify the system. After much research, it was decided that Multilayer Insulation (MLI), radioisotopes, louvers, component shielding and chassis shielding would be used for thermal and radiation shielding system. The decision analysis for the material for each of these components can be seen in Appendix J.15. Special thermal systems include the ASRG. From a thermal standpoint, this will be used as a heater since it outputs 500 Watts of heat.

MLI has three basic components that make up the main thermal properties, plastics, metals and spacers. The weight of thermal blankets is typically negligible so and the risk were rated the lowest. Risk was considered negligible because all materials had been used on previous missions to Jupiter and the outer solar system. Thermal and shielding efficiency was rated the highest priority because the main concern of the system is to keep components at operating temperatures. Cost was also rated high because the budget is limited.

According to the decision analysis, the material for the plastic, metal, and spacers shouls be Kapton, Aluminum, and either Dacron or Silk. Kapton was rated the highest in thermal efficiency because it was used in the Cassini Mission and in the Galileo Mission. Aluminum was rated the highest because the cost was much cheaper than the others compared and the risk was minimal due to it also being used on the Cassini mission. Dacron and Silk rated the same number, but for different reasons. The cost of silk was slightly higher but it had a higher thermal efficiency than Dacron.

For radiation protection, component shielding and chassis shielding were chosen. Data was gathered from Juno and Galileo since their mission will consist or consisted of orbiting around Jupiter. Juno will be operating in the more harsh regions of Jupiter's radiation and magnetic fields, so data gathered from that mission was considered lower risk. The materials considered from the trade study were Titanium, Tungsten-Copper, and RXF1. Iron was not used in the decision analysis because of research done for the Juno mission. The research shows that even though Iron is a very good material to reject radiation, it would not survive the launch into outer space.

Louvers will be incorporated into the system to account for the extra radiation seen from the sun in the inner solar system. This component in the system is quasi-passive meaning that there will be no power to open and close them, but there will be moving parts. The louvers will be coated with two different materials so that when one reaches the higher operating temperature it will expand and open the louvers. Whenever it cools down near the lower operating temperature, the louvers will close. The louvers will be opened only be to dissipate the heat equivalent of the radiation absorbed from the sun. When the louvers are closed, it is assumed that there is no heat loss due to them.

A titanium vault with a thickness of one centimeter will be used to shield the components in a chassis while tungsten-copper will be used for certain component shielding. Both of these are used on the Juno mission while tungsten-copper is also used in the JEO final report. RXF1 is a polyethylene-based material that NASA has been testing that is supposedly lighter and provides more radiation shielding than traditional materials. The decision analysis for these materials came to be very close contenders. Shielding Efficiency was the highest weight factor with risk being the lowest. Titanium won, not because it was the highest ranked item out of every attribute, but because it is the most practical. Tungsten-copper will still be used for certain component shielding because it has the most shielding properties with the least amount of volume.

RHUs were not evaluated in the decision analysis even though they were included in the research. These were added because the thermal calculations showed the propellant would not be within the correct operating temperatures in the system. To keep the propellant within its operating temperature, 130 RHUs will be used with each emitting 1 Watt of heat. Assuming that each RHU is in view of both the inner walls of the spacecraft and the titanium chassis and that they are evenly distributed throughout the lander, this will add an additional 70 W of heat to each the chassis and the inner wall. Each component's operating temperature was calculated with a 3 degree margin. Component operating temperatures can be seen in the table below.

Table F.2.3.2.4 Various component operating temperatures in Celsius

Operating Temperature Ranges in ˚C		
Component	**T_cold**	**T_hot**
Telecommunications	-10	50
Electrical Power	-5	26
Cables	-15	55
Propulsion	6	55
Structures	-45	65
Antennas	-160	95
MLI	-160	250

The MLI is extremely efficient. With 15 layers of insulation, the system only loses 66 Watts of heat out of the 705 Watts seen by the walls of the lander in space. Only 59 Watts of heat is lost out of the 565 Watts of heat emitted during the tour at Europa. The RHUs only weigh one 1.4 oz apiece, while the MLI mass is 6 kg, and the titanium chassis and component shielding mass is 78 kg, giving the thermal subsystem an overall mass of 90 kg. Figure F.2.3.2.4 shows the operating ranges of various components.

F.2.4 Additional Mission Elements:

The following element is designed by the Sparkman High School InSPIRESS Level 2 team.

F.2.4.1 InSPIRESS Level 2-Magnetometer Boom

A Magnetometer is a device that is used to measure the strength and direction of a magnetic field. This is required because the magnetic fields or magnetosphere of Europa will be constantly colliding with particles from Jupiter, as well as heavy interference from the radiation belt, in Jupiter's exosphere. CRETE will need to be able to know direction and consistency of this field at all times to maintain contact, as well as instrument durability. It is for spacecraft tracking and signaling, and may be accompanied by high and low gain antenna. The Boom itself will be using two composite segments, the inner segment is going to be attached to the base, by a base hinge, and the outer segment is going to be attached to a shoulder-hinge. The base hinge will employ an over-travel and deployment assist spring, which will be released by the actuator, and extend, triggering the same spring-type motion by the elbow hinge. When fully extended, the boom will reach 2 meters out from the base, and the base is a meter in length itself. The Boom will be machined out of aluminum, bronze, or beryllium copper, because they are non-magnetized metal alloys, and the cheapness of the metals as well as the little thickness needed is said to be quite advantageous in design. The either Beryllium Copper or Carbon Fiber tubes that the boom will utilize are also nonmagnetic, and their low density minimizes the mass budget of the boom and design. The Boom is designed in mind to be able to be stowed for launch in no more than 1m of space, and have very low power requirements due to the elbow hinge held in a bracket, using a deployment assist spring to extend. There will be no power required to aid in the deployment system. The mass will be minimized to the mass due to clamping and the necessary release mechanisms. The mass is 19kg and cost are still unknown but the space usage is $2m^2$ and power usage is 20W.

F.2.5 Flight System Contingencies and Margins

The total mass carried by the Atlas V 551 is 4790 kg. The allocated dry mass to the orbiter is 709 kg dry mass (inclusive of 30% contingency) and 2635 kg of propellant which includes usable amount, 5% margin added to it, 1% outage and 0.5% loading error. Hence, the orbiter wet mass is 3344 kg. Table 2.5.1 represents the mass for each orbiter subsystem.

The allocated dry mass is 581 kg (inclusive of 30% contingency) and 626 kg of propellant which includes usable amount (601 kg), 5% margin added to it (30 kg), 1% outage (6 kg) and 0.5% loading error (3 kg). Hence, the lander wet mass is 1207 kg. Table 2.5.1 represents the mass for each lander subsystem.

Table 2.5.1 Summary of Mass breakdown (Along with Contingency) for orbiter and Lander

Mass Margins and Contingencies							
Atlas V 551 Mass (with a C3 of 12.8 kg^2/s^2): 4790 kg							
Orbiter Wet Mass: 3344 kg				Lander Wet Mass: 1207 kg			
Allocation	Actual Mass, kg	Contingency %	Contingency Mass, kg	Allocation	Actual Mass, kg	Contingency %	Contingency Mass, kg
Propellant	2635			Propellant	626		
Dry	496	30%	213	Dry	406	30%	175
Subsystems				Subsystems			
Payload	90	Accounted in the 30%.	Accounted in 213 kg.	Payload	10	Accounted in the 30%.	Accounted in 125 kg.
Structure	150			Structure	99		
Power	30			Power	39		
Cabling	12			Cabling	25		
CD&H	24			CD&H	32		
Telecommunication	24			Telecommunication	35		
Propulsion	143			Propulsion	68		
ACS	11			ACS	8		
Thermal	12			Thermal	90		

After accounting for all this mass, there is 5% margin which can allocated as the design grows. Since, orbiter and lander has each have 30% contingency for design growth, CRETE meets Jet Propulsion Laboratory (JPL) standards for mass which states that "the new design shall use 30% or more growth from the Preliminary Mission and System Review (PMSR) depending on the nature, maturity amount of the new technology/concepts, and complexity of the design" in the Mass Margin Guidelines (JPL 2008 Guidelines).

F.2.6 Mission Operation Plan

All the ground system operations will be done from Huntsville, AL. The testing for this mission will be done in Huntsville, AL and integration in Kennedy Space Center, Florida (Refer to Section F.5 for details). The orbiter flight system will contain information about the path, but for security and reliability reasons the systems will send information to earth about its position instead of it being totally autonomous. Then the ground systems will decide which information should be sent to the orbiter case by case, especially for the critical events as the separation with lander, the orbit insertions and the delta V after each fly by. Maneuvers will not be performed during phases of interaction with others planets.

The High Gain Antenna will be specifically for communication with the Deep Space Network that supports interplanetary spacecraft mission. This is where all the commands will be downloaded to the orbiter from the ground operations. The orbiter will be able to see the Earth for 8 hours a day. Also, it will be collecting 7 Gb of data per day. Given that the data rate is approximately 150 Kbps to Deep Space Network (DSN), it will be possible to send all 7 Gb collected back to Earth during the 8 hours of link time. The lander will be transmitting approximately 180 Kbit/s. These are the max data transfer rates.

The data transferred uplink and downlink by both the orbiter and the lander will vary since only a few of the instruments will be on and collecting data for a given period of time. Hence, depending on the instruments in working mode, the data rate will vary but will not exceed the amount specified above in any case. The detail layout of data transfer is discussed in section F.2.3.1 Orbiter and F.2.3.2 Lander Telecommunications and Command Data & Handling. Figure F.2.3.1.7 represents the data flow synopsis.

F.3 Development Approach

The primary challenges of a mission to Europa include Jupiter's radioactive environment, planetary protection, high propulsive needs to get into Europa's orbit, and the large distance from the sun and Earth. Radiation being the life limiting parameter for the flight system, it is imperative to understand the environment that the mission will enter into and to use data and experiences gathered from NASA, academia, Department of Defense, Department of Energy, and industry to instill the radiation-hardened-by-design concept at the mission concept level.

CRETE began studying system engineering processes as listed in section 3.4 of the NASA Systems Engineering Handbook and referenced this book as needed for guidance. Trade studies have been a primary tool used in decision analysis for trajectory, propulsion, thermal, geophysical exploration, subsystems, payloads, structures, power, and telecommunications. In addition, risk analysis of trajectory and landing were performed to assess risks associated with the trajectory from Earth to the orbit of Jupiter to the orbit of Europa and landing in Europa's highly radioactive environment. The purpose of the risk analysis of trajectory is to consider the time for travel to Europa, the mass of the payload that can be carried, and the power consumption required.

System engineering processes were defined to establish methods for risk mitigation and improve operational and functional requirements for system interfaces, configuration management and associated processes. First the team determined stakeholders and what was to be achieved according to stakeholder mission objectives and operation objectives. Then the stakeholder requirements were analyzed and compared to AO requirements and NASA guidelines to see what could actually be achieved to make the mission a success. A concept of operations was developed to bring all stakeholders in agreement as to what product was to actually achieve. In addition, the mission architecture was designed, trade studies were performed and decision analysis tables were constructed. These processes were repeated until a uniform decision was agreed upon by the team. Through these processes the team decided which orbiter to use, what trajectory path to take and what risks were involved.

A work breakdown structure is then constructed to list technical requirements definition. This system engineering process uses shall statements to establish the design boundary. Design constraints are used at this juncture. The interfaces between spacecraft and lander are connected through an adapter. The lander contains three propellant tanks and engines enclosed in a hexagonal body frame. All instruments and software will be in the center of the hexagon for maximum protection. The team also performs technical risk management throughout this phase to determine possible failures and risks and how to mitigate them. Reliability and product assurance was minimized by researching prior missions and using previously tested hardware and software. There will also be testing verification and validation on new technology used.

ESTACA is responsible for the design and success of the orbiter and have worked diligently with team CRETE to make sure interfaces run smoothly.

There are several risks determined however the most critical risks are radiation, planetary protection, material durability, hardware and software reliability and cost. These areas are being studied the most to avoid risk and provide proper alternate solution in case of failure. This would enable the mission to perform science objectives in case of failure and remain within cost. These processes are worked on by all team members in some fashion or form then a discussion or meeting takes places to make sure all data is accurate and all final decisions are agreed upon unanimously by team as well as understood by all members. Eventually these processes will lead into product transition and implementation when all design issues are finalized. At that time the design will freeze and configuration management will be put into place to maintain all document control. Any changes will have a engineering change order issued and there will be a weekly project meeting to discuss issues, concerns, changes and progress. In the event there is a test failure or inadequate performance a team of chosen engineers will convene to determine percent accuracy and decide whether to use or discard technology.

The National Environmental Policy Act (NEPA) protects, enhances, and preserves the human environment. NEPA's goals to is cause the agency to think of the environment first and foremost so agencies will choose a method with the least impact on the environment. Early planning is required to give appropriate consideration to the environment. This information must be readily available to the public also.

F.4 New Technologies/Advanced Developments

Each of the materials rated the highest in the decision analysis for the thermal control system are regarded Technology Readiness Level (TRL) 6 or higher. The Aluminum 7075-T651 that composed the majority of the lander's structural composition has a TRL value of 6 due to it not being documented as having traveled on any space missions. However, aluminum alloys similar to this have traveled on other missions and performed adequately. Each Multi-Layer Insulation component has been used in various space missions and is rated as TRL 8. The titanium chassis shielding system has been through many successful tests for the JUNO mission. Various tests modeled the radiation that the system will be subject to during its mission. The titanium significantly reduced the radiation that was seen by the components. Tungsten-Copper has also been tested in multiple missions and can shield sensitive modules. Since a titanium vault has not flown in space, it is given a rate of TRL 6 since the system has been fully tested yet not flown. For the power, two prototype ASRGs are being used and a NiH_2 battery that has flown on the International Space Station missions is also being used. Therefore, the power would receive a TRL level of 3 due to the prototype ASRGs. The CDS, Telecom, and Cabling subsystems have all been used on previous space missions and would therefore receive a TRL rating of 8 for each section. The MR-80B monopropellant engine is a unit that is still currently in development; therefore, it has a TRL value of 3. For the ACS, the MR-111E and MR-106E engines are being used. The MR-111E is based off of the MR-111, which is flight-proven because it has flown on the Intelsat 5 and multiple other missions. The MR-106E is purely flight proven and has been used on the MARS Odyssey test program. Based off of this information the TRL for the ACS is 4. Most of the instruments in the payload have flown on previous missions; therefore, this section would receive a TRL level of 6. The total TRL level for the lander was achieved by weighing the section TRL level due to how much mass that section had. Table F.4.1 shows how the lander TRL level was calculated, and that came out to be a 6. However, the robustness was tested by changing the TRL value for any one section and it was determined that a conservative estimate of 5 should be used for the lander TRL. The orbiter TRL was determined using the same weighted by mass technique. The total value came out to be 5 for the orbiter. It also passed a robustness test. Table F.4.2 shows how the orbiter TRL level was calculated.

F.5 Assembly, Integration, Test, and Verification

The assembly, integration, test, and verification activities will occur throughout the Assembly, Test, and Launch Operations (ATLO) Phase of the Europa Mission. The information in this section has been obtained from the Jupiter Europa Orbiter Mission Study 2008. The information obtained from this reports helps to provide a more detailed picture of how CRETE's instrument development effort fits into the overall Assembly, Integration, Test, and Verification plan for the entire Europa Mission.

The integration and test efforts will be accomplished through a combination of system analysis, modeling and simulation tools, engineering development unit hardware and test beds, flight software test beds utilizing simulations and Engineering Model (EM) hardware, flight system functional/environmental testing, and readiness testing. All testing will be performed by the ATLO system engineers with extensive support from subsystem and instrument engineers as well as the actual operations team. End to end data flow testing and tool suite validation will be

Table F.4.1: TRL

Lander	Mass (kg)	Total Mass %	TRL	TRL Weight	Orbiter	Mass (kg)	Total Mass %	TRL	TRL Weight
Structure	99	23	6	1.4	Structure	150	30	6	1.8
Thermal	90	21	6	1.3	Thermal	12	2	6	0.1
ACS	8	2	4	0.1	ACS	11	2	4	0.1
Power	39	9	3	0.3	Power	30	6	3	0.2
Cabling	25	6	8	0.5	Cabling	12	2	8	0.2
Propulsion	68	16	3	0.5	Propulsion	143	29	3	0.9
Telecom	35	8	8	0.7	Telecom	24	5	8	0.4
CD&H	32	7	8	0.6	CD&H	24	5	8	0.4
Payload	33	8	6	0.5	Payload	90	18	6	1.1
Total Lander	429	100	-	6	Total Lander	496	100	-	5

performed in all functional and performance tests. An Operational Readiness Tests (ORTs) will be performed to assess the infrastructure and team's ability to execute the operational phases of the mission.

A Developmental Test Model (DTM) will be used as the EM for the integration and test efforts. This will help to alleviate any risk that might be incurred by having to wait for the actual Flight Model (FM) in order to perform tests to ensure that the system will operate as advertised. The FM will be incorporated in parallel with the DTM since the team will be performing static and modal testing. The DTM will be used to fit checks as well as cable and mass mock ups.

Finally, this DTM will be used to support trailblazer activities once it has completed the test and integration functions. The trailblazer activity will be used to ensure that the procedures and processes for integrating the flight system and instruments. This will ensure compatibility and streamlining during launch preparations. Planning will begin in early Phase C where requirements and storyboards will be used to help engineers understand the constraints imposed at launch. In Phase C, mock ups of the hardware and facilities are created to physically simulate the integration. In Phase D, the Ground Support Equipment (GSE) and the DTM will be setup at the Cape to walk through the simulated installation process to ensure adequate clearances, procedures, and safeguards.

The ALTO process is designed to provide verification of the flight system design and workmanship by subjecting the flight system to a demanding series of functional, operational, and environmental tests, while also maintaining the integrity of the planetary protection approach. Initial assembly begins with delivery of the flight system primary structure, the propulsion subsystem, and the electrical cable harness. Each electrical subsystem undergoes vibration, thermal, pyroshock, Electromagnetic Compatibility/Interference (EMC/EMI) and magnetic testing/characterization, and any sterilization processing prior to ATLO.

Each subsystem with electrical functionality is integrated using assembly plans and test procedures that ensure mechanical and electrical safety which have been verified in the test bed. Once all of the engineering subsystems are safely integrated and fully functional at the system level, the instrument payloads developed by engineers from team CRETE will be integrated with the spacecraft to complete the flight system.

Environmental testing includes a comprehensive system level test that will ensure the flight system has been verified to operate in the expected environments of the mission. At the subsystem level, the flight hardware will be tested to acceptance levels and durations to ensure sufficient radiation hardness has been achieved. The system level testing will include acoustics, vibration and shock, thermal balance, and thermal vacuum. Functional tests will then be performed after every environmental test in order to ensure that test effects have not degraded system level functionality.

Prior to delivery to the launch site, the flight system will be housed in a non-flight bio-barrier and will then be trucked to the launch site. Functional testing will be performed before and after shipment to ensure no degradation to system performance was caused by shipping. The ASRGs will be delivered to the launch site separately by the Department of Energy (DOE) where they will be test fitted to the flight system to insure proper integration.

Final testing, propellant loading, and integration of the launch vehicle will be performed prior to launch, at which point the entire flight system will be mission ready. More extensive testing will be necessary for the new technologies, which are the ASRGs and MR-80B engines. Based on the Testing and Integration plan, it appears that all integration and test activities will be completed in time for the proposed launch date.

F.6 Schedule

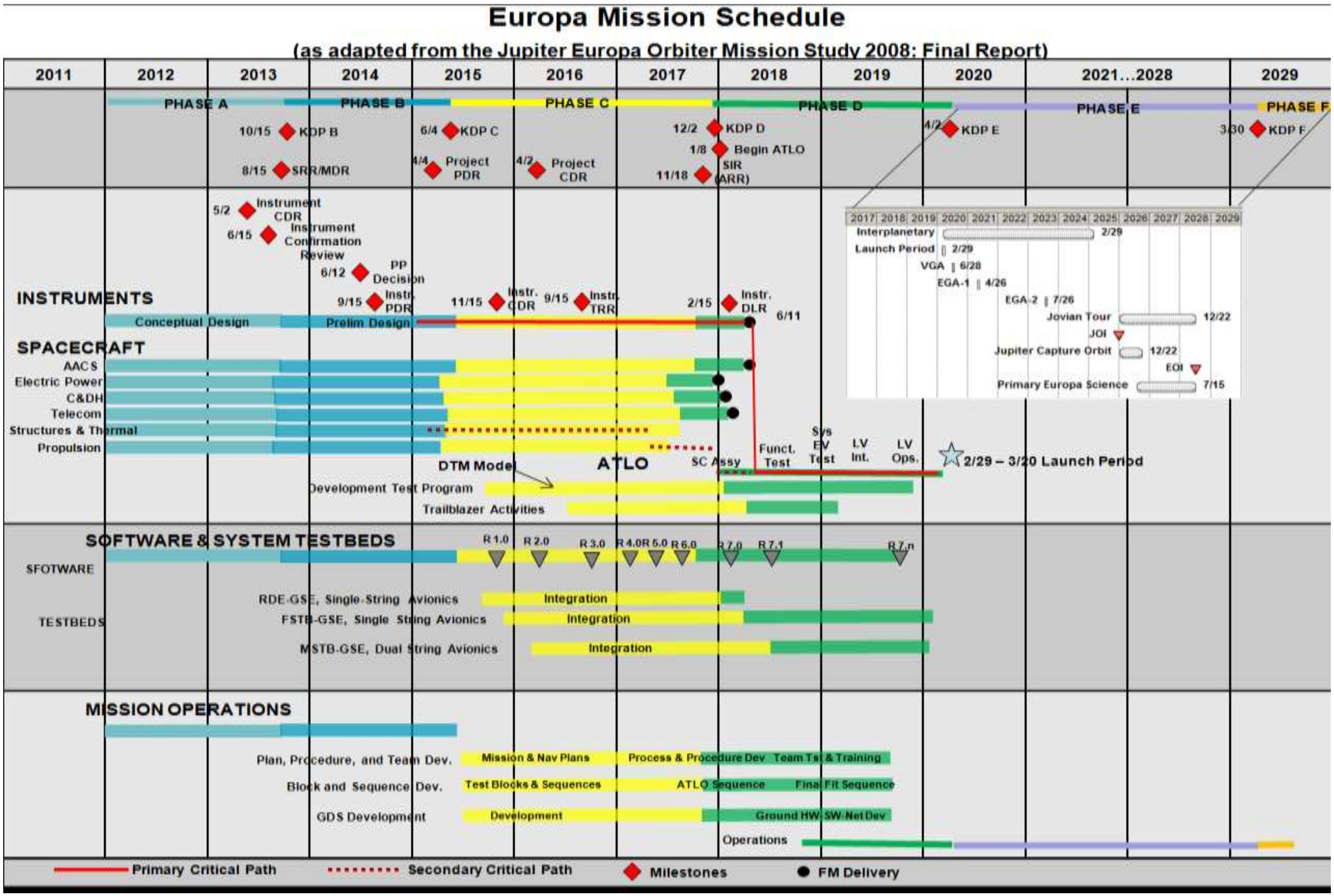

Figure F.6.2 CRETE Europa Mission Schedule

G Management

G.1 Management Approach

The Figure G.1.1 below represents the hierarchy of the management system for the CRETE Mission. The UAH is the lead organization for the CRETE Mission. Dwiti Patel is the CRETE Mission Project Manager and is responsible for managing the entire mission. College of Charleston is headed by Cameron Self, who is the Principal Investigator. The PI is responsible for defining the science for this mission.

The PI and the Co Principal Investigator (CoPI) set the requirements for the engineering team. These requirements are communicated to the engineering team at the weekly meeting with the PM and Chief Engineer (CE), Brady Fitch. The science requirements for the orbiter are communicated by the PM to the ESTACA team, headed by Florent Chochain, ESTACA Project Manager, during the weekly meetings. The science requirements for the lander are communicated by the CE to the UAH team during the weekly meetings.

ESTACA has a requirement for the magnetometer boom that will be communicated to the PM. The PM will then pass the information to the Sparkman High School Point of Contact (POC), Justin Wilson, who will then pass the information given by ESTACA to the Sparkman High School PM, Mary Robinson.

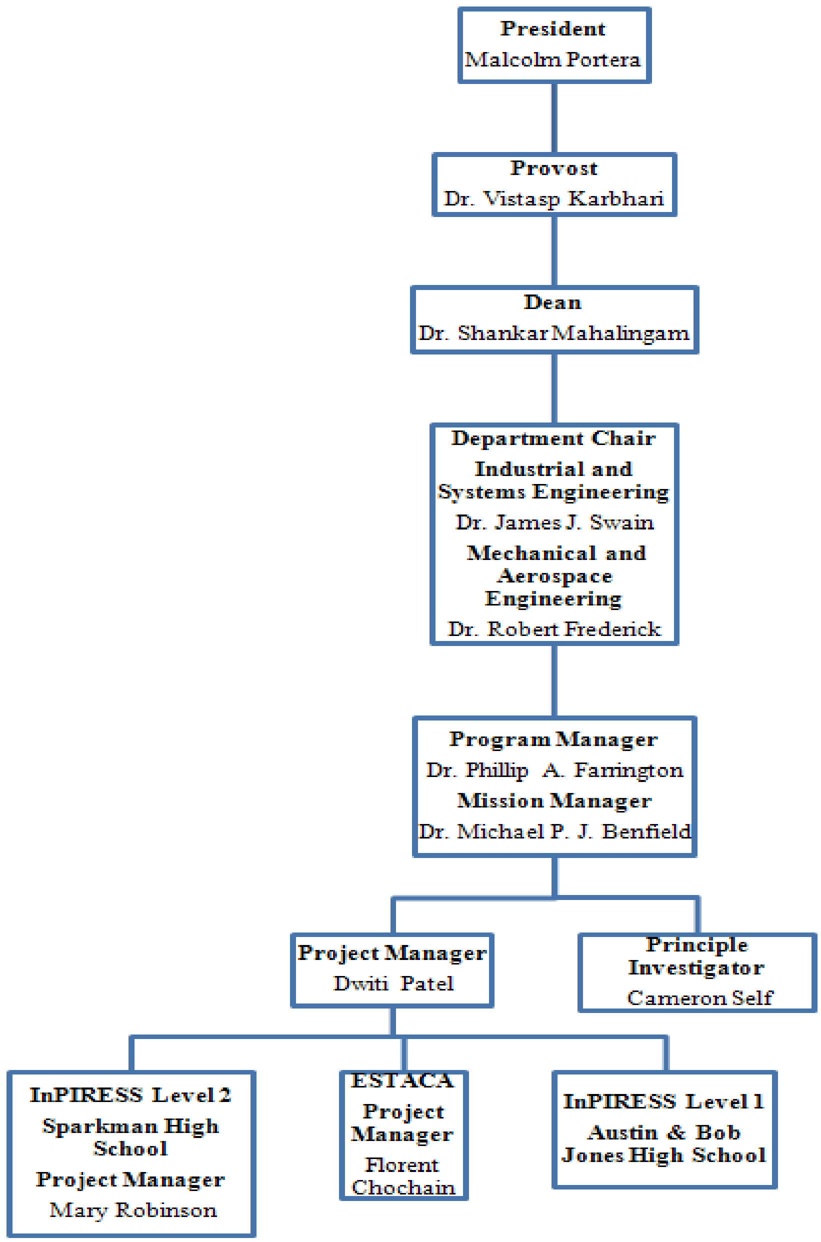

Figure G.1.1 Management Flowchart

The InSPIRESS Level 1 payload constraints defined by ESTACA are communicated to the PM, who then passes on the information to Level 1 Point of Contact, Sam Cauthen, who then communicates this information to InSPIRESS Level 1.

All the major decisions for the science related mission are made by the PI and CoPI. Engineering related decisions are made by the PM and UAH team. In case of urgency, the decision is made by the Project Manager, who then communicates this information to the entire CRETE mission.

G.2 Roles and Responsibilities

The mission participants on team CRETE are from universities ranging from various locations around the world. ESTACA Engineering School in Paris, France, shall be responsible for designing the interplanetary orbiter. The University of Alabama in Huntsville shall be responsible for designing the lander for this mission. The College of Charleston in Charleston, South Carolina shall be responsible for defining the science objectives and providing all science instrumentation requirements. Sparkman High School (InSPIRESS Level 2) in Harvest, Alabama shall be responsible for designing the Magnetometer boom. InSPIRESS Level 1 Team will be designing a payload that will be going on to the CRETE the spacecraft. Lead positions (discussed in sections G.2.1 – G.2.6) are required in order to insure proper integration of the mission.

G.2.1. Project Manager: Dwiti Patel (*Qualification and Experience*: Appendix J.3)

The PM is responsible for the overall Management of the CRETE Mission. The PM works closely with all the partners making sure the requirements imposed are met and that the work is accomplished in the given period of time. The PM also makes sure that all the requirements and the constraints are effectively communicated by the UAH team to all the partners on time. All the mass properties for this mission are handled by the PM. The PM also takes care of the supervision of the AO Proposal of CRETE Mission.

G.2.2. Principal Investigator: Cameron Self (*Qualification and Experience*: Appendix J.3)

The PI is responsible for defining the science for this mission. The instruments and its requirements are defined by the PI along with the team of CoPI. The PI works closely with the Mission PM and CE. The PI also is responsible for the Science Investigation and Science Implementation write up for the AO Proposal.

G.2.3. Chief Engineer: Brady Fitch (*Qualification and Experience*: Appendix J.3)

Lead contact between principal investigator and the engineering team. Co-lead contact to ESTACA. Development and definition of mission concept of operations manage mechanical and aerospace engineers to develop the engineering design. Lead structural and payload design/structural analysis engineer.

G.2.4. Lead Systems Engineer: Audrey Harmon (*Qualification and Experience*: Appendix J.3)

The lead systems engineer is responsible for directing systems engineers as well as determining the engineering processes necessary to make to the mission is a success for everyone. The lead systems engineer should make sure that all areas interface and communicate properly to lower risk and failure events.

G.2.5. Cost Lead: Sam Cauthen (*Qualification and Experience*: Appendix J.3)

The Cost Lead is responsible for estimating the total cost of the mission. The cost lead works closely with each subsystem to understand the materials and components of each subsystem. This information helps to estimate the cost of each subsystem more accurately based on previous missions with similar characteristics. The estimated cost of each subsystem along with launch services and margins allows the cost lead to estimate the total cost of the mission. Most importantly the cost lead is responsible for keeping the mission under the PI mission cost cap.

G.2.6. Primary Implementing Institution

The University of Alabama in Huntsville is a reputable university and has an *Accreditation Board for Engineering and Technology* (ABET) accredited program for Aerospace and Mechanical Engineering. The Integrated Product Team is a well-structured class conducted by Dr. Michael P.J. Benfield, who is the Deputy Center Director of Center for Modeling, Simulation, and Analysis at UAH and has conducted this class for past several years.

G.3 Risk Management

The primary challenges of the Europa mission include risks associated with trajectory, the harsh radioactive environment, and planetary protection. In addition, operational and technical risks must be considered to mitigate potential problems that could significantly impact mission costs, mission lifetime, meeting mass and power requirements as well as science objectives. Furthermore, the risk of landing on Europa produces even more complex challenges. Despite these challenges, the main goal of CRETE's mission is to demonstrate the feasibility of orbiting Europa, landing, and successfully collecting and communicating valuable scientific data on the surface of Europa back to Earth.

Table G.3.1 below details the critical risks associated with this mission and the implications of those risks if a mitigation plan was not implemented. The table also includes the mitigation plan necessary to reduce the likelihood of the risk occurring.

Table G.3.1 Risk Mitigation Matrix

Risk	Result	Mitigation Plan	Impact	Likelihood
Radiation	Effects on parts, materials and sensors, internal charging and instrument development. Furthermore, radiation effects can contribute to loss of science and adversely impact sensors and instruments used for navigation. In addition, the high levels of charged particles near Europa are a source of internal charging within flight system materials. The result of this charging is often an electrostatic discharge within the flight system that causes material damage and an electromagnetic pulse damaging to electronics. Internal Charging can result in mission degradation or failure.	Develop a Work Breakdown Structure to include elements for system reliability and failure modes to assess implications and ways to recognize the need for modifications. Radiation shielding should be used around the instruments and electronics in addition to parts evaluation and testing to account for radiation design of materials under various radiation dose rates to prevent internal charging through dissipating designs. An approved part and materials list (APML) should be included to mitigate the effects on sensors, detectors, and other instruments.	5	Original 5 Mitigated 2

Risk	Result	Mitigation Plan	Impact	Likelihood
Trajectory	CRETE has chosen to use a Venus Earth Earth Gravity Assist (VEEGA) to travel to Europa. Although the VEEGA approach reduces total mission ΔV as well as C3 launch allowing for more mass, the risk of radiation exposure due to a prolonged flight time is probable.	Implement a plan to reduce radiation exposure. While in addition designing to protect the system, subsystems, and instruments from radiation exposure by considering hardware and software designs to ensure problems regarding system functionality is communicated effectively to resolve issues quickly without degrading the mission.	5	Original 4 Mitigated 2
Planetary Protection	The concern is to meet all planetary protection requirements to reduce the probability of contaminating Europa's ocean as well as the other Jovian satellites.	As stated in the JEO, the approach to planetary protection compliance includes pre-launch sterilization to control bioburden for those areas not sterilized in-flight and in-flight sterilization via radiation prior to Europa orbit insertion (EOI). In addition, environmental guidelines from the National Environmental Policy Act (NEPA) will be used to protect, enhance, and preserve the environment.	5	Original 5 Mitigated 2
Operational	Operational risks include but are not limited to risks related to selection of instrumentation to operate in the harsh radioactive environment of Europa. In addition, risks associated with optimizing mass of the payload and power consumption required.	Develop a work plan through trade studies to meet mass and power requirements. In additon, include an approved parts and materials list during pre-phase to ensure selection of instrumentation is robust enough to withstand the radioactive environment.	4	Original 4 Mitigated 2
Technical	Degradation of total system and subsystem reliability is a risk that could fatally impact the mission. The inability to communicate problematic issues will also contribute to mission failure.	Establish failure modes to assess implications of technical problems as well as system redundancy to evaluate system reliability, effects on communication, subsystems and instruments.	4	Original 4 Mitigated 2
Landing	Europa's rugged terrain makes landing site selection difficult with a variety of rough textures that dominate the surface of Europa. In addition, Locating a safe landing site which will also support Europa science objectives is even more challenging. A landing site must be relatively smooth and flat and encompass an area large enough for a landing ellipse.	CRETE has chosen to use the honeycomb structure Lander. The honeycomb structure has been used in several previous missions; it absorbs impact by use of shock absorbers to produce a soft landing. Furthermore, the analysis of the landing gear incorporated a worst case scenario if there were only two legs that landed in the initial impact at 12° tilt.	5	Original 5 Mitigated 2

The impact assigned to each risk was based on the risk assessment scoring matrix shown in Table G.3.2 to the right. The matrix describes the impact and likelihood of a risk occurring and how a mitigation plan could lower the probability of the risk occurring and impacting the mission

Table G.3.2 Impact and Probability

Impact			Probability
5	Critical	Near Certain to Occur	80%-100%
4	High	Highly Likely to Occur	60%-80%
3	Medium	Likely to Occur	40%-60%
2	Low	Low Likelihood	20%-40%
1	Very Low	Extremely Improbable	0%-20%

significantly. The matrix includes assignable impact scores on a range of one to five. Five being critical meaning that there is an 80% - 100% probability of the risk occurring, while on the other hand the impact of one is very low meaning that the likelihood of occurrence is extremely improbable.

The risk assessment matrix below in Figure G.3.1 represents the scores assigned to each risk based on impact and the likelihood of occurrence. Radiation critically impacts the mission presenting a higher risk due to the highly radioactive environment on Europa in combination with the two year orbit. However, implementing the mitigation plan described in the table above and performing regular reviews reduces the probability of mission degradation. Trajectory, planetary protection and landing also critically impact the mission requiring regular review to ensure the effectiveness of the implemented risk mitigation plan. Operational and technical risks are not as critical but have a high impact on the mission. Although the mitigation plan reduces the likelihood of occurrence, these risks still fall in the yellow requiring regular review.

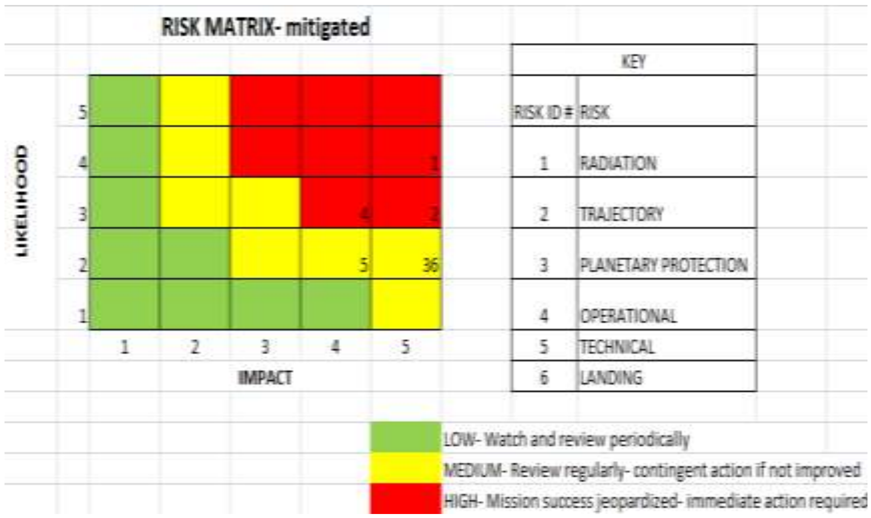

Figure G.3.1 Represents the scores assigned to each risk based on impact and the likelihood of occurrence

G.4. Contributions/Cooperative Agreements

The ESTACA Engineering School will be responsible for designing the orbiter. Sparkman High School will be designing the Magnetometer boom. Both of the contributed elements will be tested, verified and integrated according to section F.5. The cost will be considered by UAH in the PI cost CAP of $800M. In case they fail to meet the agreement UAH will be responsible for the manufacturing of the elements with the use of the already designed elements.

H Cost and Cost Estimating Methodology

H.1 Cost Model

The Hamaker Cost Model by Joseph W. Hamaker aided in the budget planning of CRETE's mission. The mass and power allocations for each subsystem were the main data entries used to estimate the cost for that subsystem. The lander and orbiter along with their margins, launch vehicle integration, launch services and launch vehicle upgrades were all factors in creating a cost estimate for CRETE's mission. The cost of each subsystem was estimated by a database of previous missions that were on the second sheet of the cost model.

H.2 Model Inputs and Outputs

Hamaker Cost Model uses historical data from previous missions to estimate the cost of a mission. The cost estimate of a mission is only accurate as the data used to create the estimate.

There is always risk in using estimating tools. This is a known risk and therefore can be anticipated. The total PI mission cost cap for this mission is $800M. CRETE used an estimating model to mitigate the risk of exceeding the PI mission cost cap of $800M as specified for this mission. Although the mission was planned to the best of CRETE's ability, alternate solutions also proved to exceed the cost cap.

The lander's dry mass was input into the cost model as 581 kg, even though the lander was designed to have a mass of 406 kg. The orbiter's mass was input into the cost model with a mass of 709 kg and the actual designed mass of 496 kg. These mass contingencies ensure that the spacecraft growth during production is included in the cost budget. The lander and the orbiter were both given a TRL of 5, further information on TRL can be found in section F.4. The life of the lander was input at 106 months and the orbiter life was input as 109 months. A more detailed model and schedule of the orbiter and lander can be found in section F.6.

The Hamaker Cost Model outputs an estimated mission cost in Y2004 US dollars. The Y2004 dollar amount was multiplied by 1.15 to convert to Y2010 dollars as required by the AO.

H.3 Cost Resources Allocation

H.3.1 Baseline Mission

As table H.3.1 shows, the cost for this mission is $1,370M. The dry mass, TRL, power, duration of mission, and the new design percent were the main inputs in the formulation of these models. The actual inputs and outputs are attached in the appendix. The power that went into the model is the actual power that the subsystem requires which is also the power that the ASRG provides. The total power is calculated into the cost model; however, the AO estimates the cost of two ASRGs at $54M and these will be provided free of charge. The new design percent was set at 70%. The reason for this is that a few of the systems have been used before or can be minimally developed from previous missions and some subsystems were in the prototype stage or needed to be tested further.

Table H.3.1 Baseline Mission

Cost in Millions	
Orbiter	$664
Lander	$616
Launch Vehicle Upgrades	$68
NEPA	$22
Total	$1,370
Total PI Mission Cost Cap	$800
Over Budget	$570
% Over Budget	71%

H.3.2 Threshold Mission

If additional funding is available the baseline mission should be performed. If additional funding is not available, a threshold mission was analyzed and can be performed adhering to the PI mission cost cap of $800M. The threshold mission was analyzed by the cost analysis using the Hamaker Cost Model. The threshold mission consists mainly of the baseline mission but with the lander subsystem removed. If the lander subsystem was removed from the baseline mission, the mission could be preformed for $800M. As table H.3B shows, the current mission's cost estimate is $711M. This leaves $89M or an 11% cost contingency. Removing the lander makes the launch load the wet mass of the orbiter, 3344 kg. This reduction of the launch mass allows for a smaller launch vehicle. The threshold mission can be completed with an Atlas V 531 or a Delta IVM+ (5,2). These two launch vehicles are considered medium performance and only cost $25M in upgrades. This is reflected in the threshold missions cost model, Table H.3.2. The threshold mission will take advantage of one free ASRG. The threshold mission will still utilize InSPIRESS level 1 science payload and InSPIRESS level 2 magnetometer boom.

Table H.3.2 Threshold Mission

Atlas V (531) or Delta IVM+ (5,2)

Cost in Millions	
Orbiter	$664
Launch Vehicle Upgrades	$25
NEPA	$22
Total	$711
Total PI Mission Cost Cap	$800
Under Budget	$89
% Under Budget	11%

I. Acknowledge of E/PO requirements and Student Collaboration

I.1 Education and Public Outreach

"The CRETE PI, Mr. Cameron Self, understands the NASA SMD requirements for E/PO and I am committed to carrying out a core E/PO program that meets the goals described in the *Explanatory Guide to the NASA Science Mission Directorate Educational and Public Outreach Evaluation Factors* document. Mr. Cameron Self will submit an E/PO plan with my Concept Study Report if this proposal is selected."(Discovery Announcement of Opportunity 2010)

I.2 Student Collaboration

Bob Jones and Austin/Decatur were the two InSPIRESS level 1 teams that were competing to be apart of CRETE's mission. Bob Jones's team, Engineering for Tomorrow (E4T) had a payload of sensors that would be deployed over the Great Red Spot as CRETE orbited Jupiter to get into Europa's orbit. Austin/Decatur had a payload of 10 seismometers that will be deployed on Europa's surface to measure the tremors/quakes.

I.2.1 Engineering for Tomorrow (E4T)

The following portion is the summary of team Engineering for Tomorrow's science payload N2 the EYE.

Science Question

What is the gravity, atmospheric pressure, temperature, and magnetism of Jupiter's Red Dot?

Instrumentation and Resources Required

All instruments will be powered by a battery.

Table I.2.1.1 MTi-G Instrument Objectives

Objective	**Instrument**
Measure the gravity of the red dot on Jupiter	Mti-G
Measure the atmospheric pressure of the red dot on Jupiter	Mti-G
Measure the temperature of the red dot on Jupiter	Mti-G
Measure the magnetism of the red dot on Jupiter	Mti-G

Payload design

The E4T team payload design consists of a capsule coated in an ablative material holding three spherical shells (called "softballs") which each contain a processor, antenna, MTI-G (MEMS-based Attitude and Heading Reference System (AHRS) and static pressure sensor), and battery. Each softball has a diameter of 17.78 cm and is constructed of carbon-fiber-reinforced-plastic, or CFRP. The capsule is 71.12 cm in length, 22.86 cm in diameter, and is constructed of aluminium.

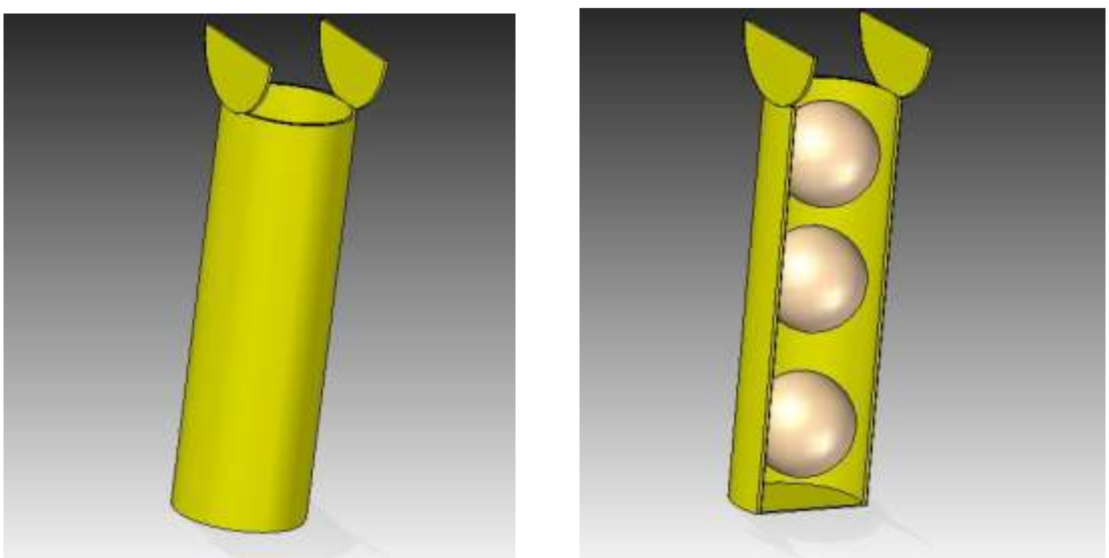

Figure I.2.1.1 Payload

Table I.2.1.2 Mass Summary-Per Softball

Instrument	**Mass (kg)**
Mti-G	0.068
Processor	0.550
"Softball" shell	2.000
Ni Cadmium Battery	0.091
Total	**2.709**

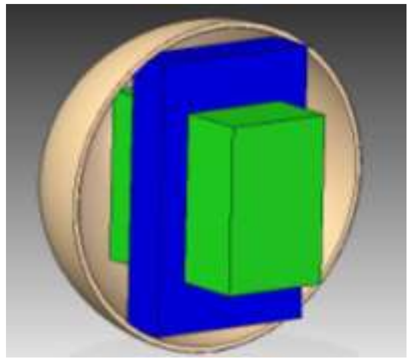

Figure I.2.1.2 Sensor CAD

Table I.2.1.3 Mass Summary-per Capsule

Item	**Mass (kg)**
Softball 1	2.709
Softball 2	2.709
Softball 3	2.709
"Capsule" shell	5.500
Parachute	0.017
Total	**13.644**

Concept of Operations

Our mission to collect data from Jupiter's Red Spot will consist of 3 phases: Capsule Launch, Parachute and Softball Deployment, and Data Collection and Transfer. There will be a window of approximately 5 hours in which the Red Spot will be in range of the orbiter during each orbit around Jupiter. This should allow for ample time to carry out all 3 phases of the mission.

Phase 1 will begin with the deployment of the capsule from the orbiter once the orbiter is in the correct position and trajectory to the Red Spot. The capsule will be shot out from the orbiter using pressurized Helium from the orbiter. The capsule will continue towards Jupiter's atmosphere.

The second Phase begins when the capsule reaches Jupiter's atmosphere. The capsule, protected by its ablative thermal shielding, will begin to slow down to its terminal velocity. After a predetermined time, the capsule's parachute will deploy. After approximately 10-15 seconds, once the parachute has slowed the capsule further, the bottom of the capsule will open and the softballs will drop.

The "third phase" actually occurs throughout the mission beginning with the capsule's deployment from the orbiter. However, the significant data will be collected after the softballs are deployed from the capsule. During the mission, the softballs will be constantly sending data back to the orbiter. The mission will conclude either when the softballs are destroyed, the batteries run out, or the orbiter is no longer in range.

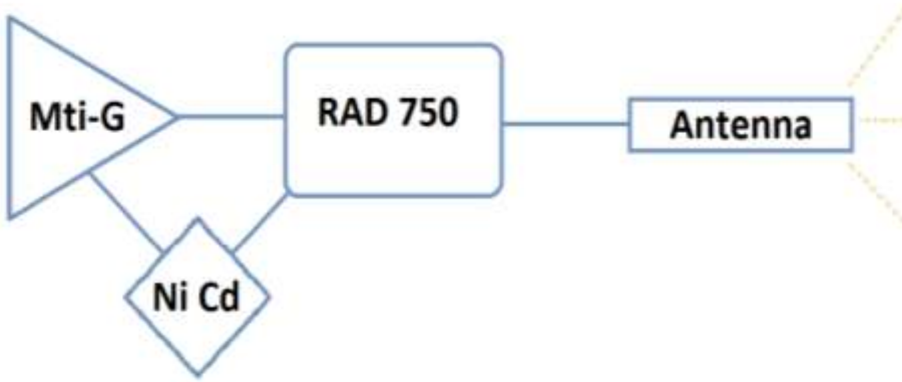

Figure I.2.1.3 System Integration

Summary

The overall mission of the E4T team payload includes accompanying the University of Alabama in Huntsville's Europa Mission to Jupiter and deploying our payload over the red dot. The main goal of the mission consists of taking temperature, pressure, acceleration/gravity, magnetism measurements of the Red Dot of Jupiter. To accomplish this mission, the payload will launch spherical shells, or softballs, containing various sensors into the red dot. As the softballs enter into the atmosphere of Jupiter, the sensors will take measurements and report this data back to the main orbiter. The data received from "N 2 The Eye" will provide many useful applications to people living on planet Earth. Not only will scientists know more information about Jupiter, but meteorologists will also find much use in this information in trying to predict and analyze severe storms.

I.2.2 Measuring the Magnitude of the Europan Tremors (M2ET)

The following is the Engineering Proposal of team Measuring the Magnitude of the Europan Tremors (M2ET) from the Decatur City School's Engineering Academy. The payload Quake, Rattle, and Roll (QRR) is designed as part of the CRETE mission to Europa.

The QRR will be deployed from the ESTACA designed Europa Orbiter. M2ET's mission is to determine the inner structure of Europa. This will be accomplished by measuring the magnitude of the tremors. This is significant because some scientists think that there might be a large warm ocean flowing underneath the thick ice layer conducive to the support of life forms. These scientists believe that the warm ocean underneath the ice is causing the top ice layer to thaw and then refreeze causing the rough surface on the moon. Other scientists believe that the tremors might be strong enough to be moving the ice and causing it then to have a rough surface. M2ET 's mission will reinforce the theory that the seismic activity is strong enough to move the ice. The shape of the waveforms recorded will provide important information about the nature of the ice and the inner structure of Europa.

The QRR will be placed on the bottom of the Europa Orbiter. The QRR will consist of a deployment mechanism, the Europa Dual Inhaler Devices (EDID) that shoots the spherical Seismometer Measurement Mechanisms (SMMs) at different times. The SMMs are stacked inside the EDID. The EDID is shaped like dual inhalers connected to each other (see Figure 1). It will be made of Aluminum 60-61. There will be a total of ten SMMs deployed. There are five SMMs in each EDID. The SMMs (See Figure 2) will be fired out of the EDID at different times to vary the locations at which each lands so that different tremor readings can be measured to enhance the science of the mission. M2ET has calculated where and how we will land and worst case scenarios. Once settled, the SMMs will begin to take measurements of the tremors through internal instrumentation.

The EDID will fire ten balls from the orbiter using the helium from the orbiter. The SMMs will each contain a seismometer, antenna, computer chip and a battery. The computer chip will control the seismometer and the antenna as well as store data collected for transmission. The battery will power the devices. The seismometer chosen will be able to undergo 10,000 Gs and was designed for the Japanese Lunar A mission. It will be mounted with a static connection to the inner wall of the SMM. The SMM will be filled with spray foam or epoxy to ensure equipment safety. The total weight of the EDID with ten SMMs is approximately 11 kg. The volumetric envelope is 4019 cm3.

M2ET has calculated the G forces that the SMM equipment would be subjected to. Calculations show that the velocity of the SMM when it hits Europa would be approximately 1700 m/s. Using the penetrator equations for ice and frozen soil, the maximum penetration depth was found to be 59 m. The acceleration of the SMM was found to be 24204 m/s^2. By dividing this number by 9.8 m/s^2 the G forces were found to be 2500. However, the calculated angle of entry for the SMM is 28°. It is believed that the SMM will skip across the surface rather than embed immediately into the ice reducing the G forces significantly. Table I.2.2.1 shows the masses and volumes of the elements.

Table I.2.2.1Austin/Decatur Payload Breakdown.

Instrumentation Specifications						
	mass (kg)	power (w)	Frequency (Hz)	Noise (ms^{-2}/Hz)	Sample Rate	Max G-Load
Seismometer	0.4	0.2	0.8 – 10	$5x10^{-10}$	16 samples /s	10,000
QRR Data						
		Weight				
EDID with 10 SMMs		~11 kg				
SMM		0.5 kg				
EDID		5 kg				
Dimensions						
	Length	Width	Height			
EDID	28.9cm	18 cm	46 cm			
Dimensions						
	Inner Radius	Outer Radius				
SMM	3.5 cm	4 cm				

The computer chip on the SMMs will include time stamping capability. Before the SMMs are fired from the EDID, the timers of each SMM will be synchronized and started simultaneously through a signal from the orbiter. While embedded in the ice, the seismometers on the SMMs will continuously record and log data. Data will be transmitted when the orbiter is overhead (approximately every three earth days). Each seismometer samples 16 times per second (12 bit data resolution). Since each is a three-axis seismometer the number of bits per second can be approximated to 720 (allowing an additional 25% for overhead, error correction and time stamping data). If each SMM is able to collect data for a two week period, each would accumulate 871 megabits (approximately 100 megabytes) of data. Since battery life is not expected to exceed two weeks, M^2ET would require 1000 megabytes of storage on the orbiter's hard drive.

Outstanding issues include the mass of the EDID. Each SMM has an approximate mass of .5 kg. The number of SMMs may have to be reduced to accommodate weight restrictions. M^2ET estimates that a minimum of five functioning SMMs is required for an optimum reading. Anticipating an SMM survival rate of 50%, M^2ET requires ten SMM devices. In addition, while a lithium battery is called for, M^2ET has not been able to find a battery that will withstand the temperatures on Europa.

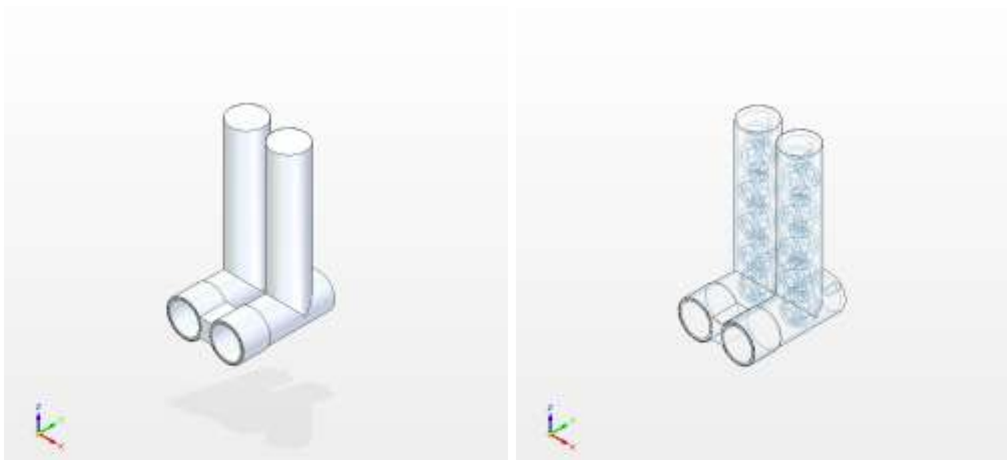

Figure I.2.2.1 EDID

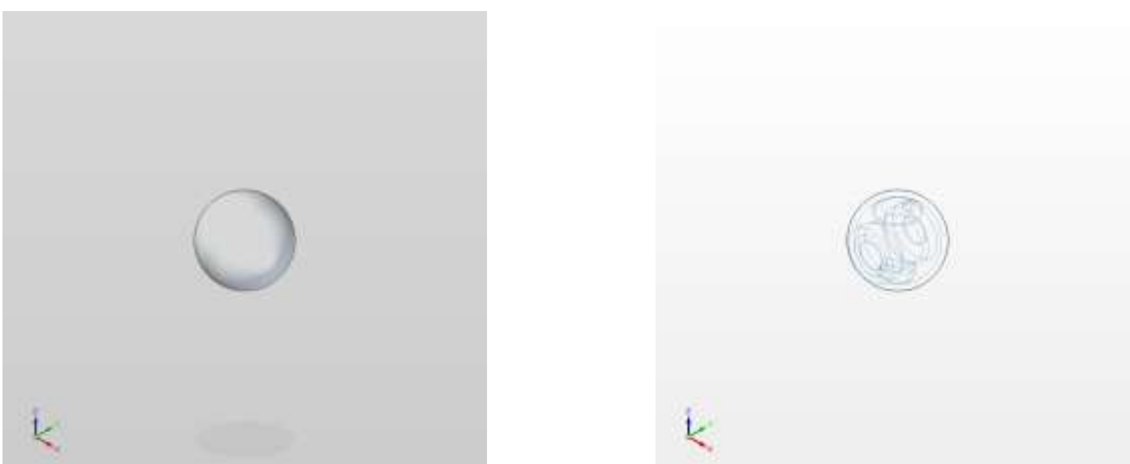

Figure I.2.2.2 SMM

Austin/Decatur was chosen as the InSPIRESS level 1 high school team to accompany CRETE on its Europa Mission. Austin/Decatur was chosen because CRETE originally wanted to do similar seismic measuring from the lander. CRETE ultimately decided on other science methods and instruments. Austin/Decatur provided a way to still get the seismic data as well as all of the other science objectives needed to be accomplished by the PI.

J. Appendix

J.1 Proposal Participants

Proposal Team Members Commitment through InSPIRESS

"I acknowledge that I have been identified by name as a team member for the proposed project entitled "CRETE", which is being submitted in response to the Announcement of Opportunity, Discovery 2010, NNH10ZDA007O, and I intend to carry out all responsibilities identified for me in this proposal. I understand that the extent and justification of my participation as stated in this proposal will be considered during peer review in determining in part the merits of this proposal. If you have any questions, please feel free to contact me at any time."

Table J.1.1 of Proposal Participants.

Particitaion	Name	Email	Organization
Science Team: Science Goals and Instruments	Cameron Self	ckself87@gmail.com	College of Charleston
	Mary Bronaugh	mbronaugh@gmail.com	College of Charleston
	Stephanie Vogtman	stvogtman@edisto.cofc.edu	College of Charleston
Engineering Team: Lander Design	Dwiti Patel	dap0006@uah.edu	Univeristy of Alabama in Huntsville
	Brady Fitch	bjf0001@uah.edu	Univeristy of Alabama in Huntsville
	Audrey Harmon	aharmon@carinatek.com	Univeristy of Alabama in Huntsville
	Shane Jackson	ane.jackson@amrdec.army.m	Univeristy of Alabama in Huntsville
	Sam Cauthen	sbc0001@uah.edu	Univeristy of Alabama in Huntsville
	Mimi King	mnk0001@uah.edu	Univeristy of Alabama in Huntsville
	Justin Wilson	jkw0002@uah.edu	Univeristy of Alabama in Huntsville
	Angela Mitchell	abm0002@uah.edu	Univeristy of Alabama in Huntsville
	Amber Wise	afw0002@uah.edu	Univeristy of Alabama in Huntsville
	Jonathan Nelson	kewljw@comcast.net	Univeristy of Alabama in Huntsville
	Destiny Hicks	ddh0008@uah.edu	Univeristy of Alabama in Huntsville
	Terasha Burrell	burreltn@uah.edu	Univeristy of Alabama in Huntsville
Engineering Team: Orbiter Design	Florent Cochin	florent.cochain@estaca.eu	ESTACA
	Guillaume Coutinho	guillaume.coutinho@estaca.eu	ESTACA
	Quentin Piat	quentin.piat@estaca.eu	ESTACA
	Antoine Oger	antoine.oger@estaca.eu	ESTACA
	Cyril Prieux	cyril.prieux@estaca.eu	ESTACA
InSPIRESS Level 2: Magnatometer Boom Design	Mary Robinson	lizrobinson@mchsi.com	Sparkman High School
	Baticia Johnson	baticia.johnson@yahoo.com	Sparkman High School
	Michael Mayhall	shademourne@knology.net	Sparkman High School
	Jacob Stover	stoverjb@yahoo.com	Sparkman High School
	Jacob Owensby	64lespaul@gmail.com	Sparkman High School
	Brandon Lowrey	randon_lowrey_8@yahoo.co	Sparkman High School
InSPIRESS LEVEL 1 Payload			

J.2 Letters of Commitment

UAHuntsville
THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

April 6, 2011

Dwiti Patel
Project Manager
University of Alabama in Huntsville
Mechanical and Aerospace Engineering Dept.
N274 Technology Hall
Huntsville, AL 35899

Dear Ms. Patel,

The University of Alabama in Huntsville is pleased to formally acknowledge your team's design for an Europa Extraterrestrial Life Survey (EELS) mission as part of NASA's Discovery Program. We believe, should your design be selected, the science gained from this mission will not only provide a greater understanding of our solar system, but will help to distinguish our institution as a premier center for engineering education, research, and technological development. With this said, The University of Alabama in Huntsville is fully committed to support your team in its current and future endeavors. Best wishes on being selected!

Sincerely,

Michael P.J. Benfield, Ph.D.
Europa Extraterrestrial Life Survey Mission Manager
The University of Alabama in Huntsville

ENGINEER PROGRAM OFFICE
Shelby Center 157 301 Sparkman Drive Huntsville, AL 35899
T 256.824.2976 F 256.824.6970 http://ipt.uah.edu

J.3 Resumes

Dwiti A. Patel

(517) 648-7506
dap0006@uah.edu
616 Gooch Ln
Madison AL 35758

CITIZENSHIP India

TECHNICAL SKILLS CAD (Solid Edge, NX), Microsoft Office, MathCAD, Matlab, Patran, Nastran.

EDUCATION

University of Alabama in Huntsville **Huntsville, Al**

Bachelor of Science in Engineering (BSE) with a concentration in Mechanical Engineering

GPA: 3.89/4.0 Expected graduation: May 2011

WORK EXPERIENCE

Aug 2008- Present **UAHuntsville** **Huntsville, AL.**

Student Specialist V

Tutor Math and Engineering Subjects

May 2010 –Aug 2010 **UAHuntsville** **Huntsville,AL.**

Robotic and Controls Research:

Undergraduate Research Assistant (May 2010-August 2010)

- Work included: Setup of Track Robots; make RS232 Connections for HOKUYO Laser Range Finder; CAD models for Robotic Arm and Bioloid; use Simulink and XPC Target to run the Robots; Responsible for Quality Control of the Manuals.

HONORS AND AWARDS Dean's List, Honors Scholar Standing

AFFILIATIONS

Society of Women Engineers (SWE)
Phi Kappa Phi Honor Society
National Scholar Honor Society
Sigma Gamma Tau, National Honor Society in Aerospace Engineering
American Institute for Aeronautics and Astronautics (AIAA)
American Society for Mechanical Engineering (ASME)

Audrey P. Harmon

Phone: (256) 881-8274; Cell: (256) 698-3390

aharmon@carinatek.com

9013 Shereton Rd

Huntsville, AL 35802

CITIZENSHIP: United States Citizen

TECHNICAL SKILLS: Matlab software, C++ Programming, Minitab software, TORA software, Electronics Workbench, Altera Software, CAD, Lean Training, Arena

EDUCATION:

The University of Alabama in Huntsville — **Huntsville, AL**
Bachelor of Science with a concentration in Industrial and Systems Engineering
Minor/Cluster: Electrical Engineering GPA: 3.01/4.00
Expected Date of Graduation: May 2011

Calhoun Community College — **Huntsville, AL**
Transfer Student GPA: 3.89/4.00

WORK EXPERIENCE:

March 2006 to Current — **Carina Technology Inc.** — **Huntsville, AL**
Purchasing / Production Manager

- Perform all purchasing and procurement of all materials and/or services needed for production.
- Determine scheduling and maintenance for pipeline production.
- Receive all inventory to kit up parts for production plant.
- Negotiating costs and contracts with vendors to achieve best pricing.
- Setup and maintain inventory module (ERP) to manage inventory on parts and products.
- Provide proposals and cost analysis reports to CFO for board meetings.
- Track sales and costs within accounting system to produce reports pertaining to margins, profit/loss and budgets.
- Forecast project timelines necessary to meet client needs.
- Project manager to production plant.
- Liaison between engineering and plant for all products from design stage, through prototyping and finally into production.
- Assist engineering with redlining schematics and bill of materials when released to get accurate. information into document control and maintain document control as needed.
- Determine ways to reduce cost and become lean by time of production release.
- Create all purchase orders, work orders and sales orders.
- Assist engineering to cross parts when necessary.
- Consulted directly with CFO, COO and sales manager to determine cost effective ways to improve production and improve forecasting.
- Assisted with contracts to determine product pricing, develop warranties, negotiate sales price, and schedule timelines according to deadline.
- Worked on request for proposal and request for quote with staff when bid received.
- Market research to compare costs between parts and services.
- Handled return merchandise authorization process for all repair/warranty work
- Report directly to Chief Financial Officer.

CLEARANCE: Secret security clearance granted in 2000 through Teledyne Brown Engineering (inactive as of 01/2005)

HONORS:
Phi Theta Kappa National Junior Honor Society
Who's Who Among American Junior Colleges
UAH Scholar's List

Samuel Cauthen

(256) 457-9234
samuel.cauthen@gmail.com

Current Address	Permanent Address
364 Jack Coleman Drive	8310 Forest Home Road
Huntsville, Alabama 35805	Forest Home, Alabama 36030

CITIZENSHIP

U.S.

TECHNICAL SKILLS

CFD-ACE+, CFD-GEOM, CFD-VIEW, LaTeX, Solid Edge (CAD program), MatLab, Mathcad, Microsoft Office Suite, Windows OS, Linux OS

EDUCATION

The University of Alabama in Huntsville — **Huntsville, Alabama**

Bachelor of Science in Engineering

GPA: 2.9/4.0 (3.1/4.0 in major), Expected graduation August 2011

- Mechanical Engineering with an Aerospace concentration

WORK EXPERIENCE

Dec 2007 – Apr 2011 — **ESI-Group R&D** — **Huntsville, Alabama**

Solver Group Co-Op

- Bug testing/code validation
- Simple mesh generation/problem set up
- Test battery test case updating
- Flowchart generation
- Test case summery database

PROJECT EXPERIENCE

- Integrated Product Team 2010 - Europa Mission (Announcement of Opportunity DISCOVERY 2010 - NNH10ZDA007O)

Brady Fitch

(931) 993-9546
Brady.Fitch@uah.edu
65 Old Carmargo Rd
Fayetteville, TN 37334

:

CITIZENSHIP U.S.

TECHNICAL SKILLS

- Teamwork, problem solving, and effective communication skills.
- Software: Experienced with Pro/ENGINEER (Wildfire 4.0), CATIA V5, Patran/Nastran, Microsoft Office, Mathcad , NX and Solid Edge.

EDUCATION

University of Alabama Huntsville **Huntsville, AL**

Bachelor of Science in Engineering with a concentration in Mechanical

GPA: 2.90/4.0 (3.17/4.0 in major), Expected graduation: May 2011

WORK EXPERIENCE

June 2010 – Present **UAH RESC** **Huntsville, AL**

Contracted to Boeing: Huntsville Design Center.

Structural Design Engineer Intern

- Detail design for Boeing 787-9 program using CATIA V5
    - Develop and update interface control models
    - Develop spreadsheets as engineering aids and how-to's for new hires.
- Collaborating with a large design team and meeting deadlines

Feb. 2008 – Feb. 2010 **Northrop Grumman Corporation** **Huntsville, Al**

Manufacturing/Design Engineering Co-op

- Developed and integrated new manufacturing methods.
- Designed flight hardware using Pro/ENGINEER and collaborated with analysis and manufacturing teams.
- Provided hands-on fabrication of composite hardware.
- Managed procurement of flight hardware.

Jan. 2006 – Jan. 2008 **UAH: AMST** **Huntsville, Al**

Student Specialist

- Refurbished science modules for public schools in North Alabama.

Summers 2004 – 2006 **Bekins: Karr Relocations** **Huntsville, Al**

- Provided moving services for residential and commercial customers.

HONORS AND AWARDS NASA NESC Group Achievement Award: Max Launch Abort System Team.

Mimi N. King

Home: (256) 864-0853; Cell: (256) 617-1443
cedlatin@aol.com
113 Rain Oak Dr
Harvest, AL 35749

CITIZENSHIP

U.S.

TECHNICAL SKILLS

Microsoft Office Suite

EDUCATION

The University of Alabama in Huntsville — **Huntsville, AL**

Bachelor of Science in Engineering with a concentration in Industrial and Systems Engineering

Expected graduation: December 2011

WORK EXPERIENCE

May 2009 – Present — **Tennessee Valley Authority** — **Decatur, AL**

Intern

- Perform Apparent Cause Analysis to determine corrective actions for Performance Improvement Department
- Develop and manage database to trend instructor training evaluations and observations
- Perform analysis for quarterly Integrated Trend Reports
- Generate monthly reports for performance indicators for Training Center
- Create and publish monthly student feedback newsletter for Training Center
- Manage instructor qualification and certification database

Dec 2007 – May 2009 — **The University of Alabama in Huntsville** — **Huntsville, AL**

Student-Aid for Biological Sciences

- Managed student databases
- Managed UAH faculty and staff bi-weekly timesheets
- Processed program of study worksheets for students
- Managed office files

AFFILIATIONS

North American Young Generation in Nuclear Society

Shane Jackson

(256) 426-1182
shane.jackson@amrdec.army.mil

Current Address
101 Stone River Road
Huntsville, Alabama, 35811

CITIZENSHIP U.S.

TECHNICAL SKILLS

FCC License, General Radiotelephone Operator License with Radar Endorsement

Weather Radar/Color Radar (05/22/1996): Allied Signal

PCT-200 Universal Repair for Electronics (07/12/1996): PACE, INC.

PCT-300 Multilayer and Flexible Circuit Repair (07/19/1996): PACE, INC.

PCT-400 Surface Mount Assembly and Rework (07/26/1996): PACE, INC.

AN/AAR-47 Missile Warning System Level I Maintenance (Certificate 01/27/1998)

EDUCATION

Embry-Riddle Aeronautical University **Daytona Beach, Florida**

Bachelor of Science in Professional Aeronautics

GPA: 3.5 in major

The University of Alabama in Huntsville **Huntsville, Alabama**

Bachelor of Science in Industrial and Systems Engineering

Current GPA: 3.0 in major (currently attending, 9 classes remaining); Expected Graduation:

WORK EXPERIENCE

Mar 2007 – Nov 2010 **U.S. Government** **Redstone Arsenal, Alabama**

Project Manager

- Currently serving as product lead for six different programs including Apache Survivability Product Improvement (ASPI) Kit, ASPI Modernization, Bulkheads, Intermediates, Second Generation ASPI, ARC-231 Trainers, and Kiowa Common Missile Warning System (CMWS).
- Responsibilities include: customer interface, contractor management, and engineering support.
- Specific duties involve: the evaluation of contractor progress towards meeting requisite cost and schedule objectives by conferring with contractor management personnel, analyzing contractor records, production plans, and physically inspecting facilities; the evaluation of material lead times, process sequence intervals, and design change probabilities to identify the current program status in meeting customer demands; preparing reports of cost and schedule status with detailed recommendations to either mitigate or preclude schedule delays and cost over-runs thereby reducing risk.

Angela Mitchell

(615) 342-9210
abm0002@uah.edu

Current Address
601 John Wright Drive
Huntsville, AL 35805

Permanent Address
458 Bradshaw Road
Lebanon, TN 37087

CITIZENSHIP

U.S.

TECHNICAL SKILLS

Microsoft Office, AutoCAD, Solid Edge, Solid Works, NX, Patran/Nastran, MATLAB, Mathcad, Simulink

EDUCATION

The University of Alabama in Huntsville **Huntsville, Alabama**

Bachelor of Science in Engineering with a concentration in Aerospace Engineering

GPA: 3.758/4.0 (3.813/4.0 in major), Expected Graduation Date: May 2011

WORK EXPERIENCE

Jun 2010 – Aug 2010 NASA MSFC Huntsville, Alabama

Undergraduate Student Research Program (USRP) Summer Intern

- Produced an attitude control simulation in Simulink of a Warm Gas Test Article, a lunar lander testbed vehicle
- Verified simulation properties with a comparison to theoretical values
- Performed the initial phases of the test article's system analysis

May 2009 – Aug 2009 DHS Technologies, LLC Tanner, Alabama

DC2E Engineering Support Summer Intern

- Assisted in the design of a bracket for a large projector screen
- Improved the quality of drawings and Bills of Materials (BOMs)
- Organized hundreds of drawings and specifications into Product Data Management (PDM) within a month
- Assisted in the assembling and disassembling of a large screen projector

HONORS AND AWARDS

Tau Beta Pi Engineering Honor Society, Sigma Gamma Tau Aerospace Engineering Honor Society, UAHuntsville Dean's List, UAHuntsville Presidential Scholarship

AFFILIATIONS

National Defense Industrial Association, American Society of Mechanical Engineers (ASME) UAH chapter, ASME Moon Buggy Team, Charger Chasers: UAHuntsville Engineering Ambassadors, UAHuntsville Charger Pep Band

Amber F Wise

(256) 206-0255
afw0002@gmail.com

Current Address	Permanent Address
1303 Ben Graves Drive Rm. 325S	9 Slaughter Pen Rd
Huntsville, AL 35816	Ardmore, TN 38449

CITIZENSHIP U.S.

EDUCATION
The University of Alabama in Huntsville — **Huntsville, AL**
Bachelors of Science in Engineering
Concentration: Aerospace Engineering, GPA: 3.3/4.0, May 2011

WORK EXPERIENCE
May 2006 – Present — **U.S. Army AMRDEC** — **Redstone Arsenal, AL**
STEP Employee/ Engineering Co-op

CLEARANCE U.S. Government Security Clearance: SECRET, Granted: May 2006

HONORS AND AWARDS
2009-2010 Dean's List
2008-2009 Dean's List
Valedictorian Scholarship
Noojin Family Scholarship
Aerojet Propulsion Scholarship
UAH Academic Excellence Scholarship
STIL Shiner Award
American Society of Civil Engineers
2007 Valedictorian of Ardmore High School
DAR Good Citizenship Award Recipient
Who's Who Among American High School Students 2004-2007
National Honor Roll Honor Society 2003-2007
Ardmore High School Senior Class Secretary, Favorite, and Beauty

AFFILIATIONS
American Society of Civil Engineers
Member of the 2009 UAH Concrete Canoe Team- Placed 9th Nationally
Volunteer for Boys and Girls Club
Volunteer for Special Olympics
Active Member in Decatur Christian Fellowship

Justin Wilson

(615) 504-2435
justin.wilson@uah.edu

Current Address	Permanent Address
604-F John Wright Dr.	1100 Lewis Jones Blvd.
Huntsville, AL 35806	Gallatin.TN 37066

CITIZENSHIP U.S.

TECHNICAL SKILLS Microsoft Office, Microsoft Visio, Microsoft Visual Studio, Adobe Photoshop/Premier Pro/After effects, AutoCAD, Autodesk Inventor, Solid Edge, NX, Solid Works, MathCAD, LabVIEW, Visual Basic, C++

EDUCATION

University of Alabama in Huntsville **Huntsville, AL**

Bachelor of Science in Engineering with a concentration in Aerospace Engineering

GPA: 3.6/4.0 (3.7/4.0 in major), Expected graduation: May 2012

WORK EXPERIENCE

Sept. 2010 – Dec. 2010 **Jacobs ESCG** **Houston, TX**

Staff Engineer

Worked with Senior management in discrepancy report tracking

Refined new chief engineer metric database

Assisted in developing simulations for the CEV Parachute Assembly System

HONORS AND AWARDS

Tau Beta Pi Engineering Honor Society Member, January 2011 – Present

Sigma Gamma Tau Aerospace Engineering Honor Society Member, March 2009 – Present

National Society of Leadership and Success Member, November 2009 – Present

Charger Chaser, Ambassador of the College of Engineering, August 2009 – May 2010

AFFILIATIONS

American Society of Mechanical Engineers Member, August 2008 – Present

UAH Math Club Member, January 2011 – Present

UAH Moonbuggy Team, September 2008 – May 2010

Jonathan Nelson

(256)508-1906
jwn0003@uah.edu
826 Harrisburg Dr
Huntsville, AL 35802

CITIZENSHIP U.S

TECHNICAL SKILLS Solid Edge, Siemens NX, Mathcad, MatLab, Nastran, Patran, Microsoft Office Suite

EDUCATION **The University of Alabama in Huntsville** **Huntsville, AL**
Bachelor of Science in Engineering with a concentration in Mechanical Engineering
GPA: 3.9/4.0, Expected to graduate in August 2011

WORK EXPERIENCE **January 2011- Present** **The University of Alabama in Huntsville** **Huntsville, AL**
UAH Grader

HONORS AND AWARDS
Dean's List
Tau Beta Pi Committee Member

AFFILIATIONS
Tau Beta Pi
Pi Tau Sigma
Phi Kappa Phi
National Society of Leadership and Success
Alpha Lambda Delta
Habitat for Humanity
Red Cross Blood Drive
Volunteer work at United Methodist Church

Quentin PIAT

Phone: +33 683517773
Email: quentin.piat@gmail.com

128 rue Victor Hugo
Levallois-Perret
92300 France

CITIZENSHIP French

TECHNICAL SKILLS

Aerospace engineering

CATIA, Solid Works, Matlab Simulink

Word Excel

EDUCATION

ESTACA **Paris France**

Master of Aerospace engineering expected on 2012

WORK EXPERIENCE

Month Year – Month Year		Name of Company	City, State
• July – August 2010	Internship	Snecma	Vernon France
• April-June 2009	Internship	CNES	Kourou French Guyana

Florent COCHAIN

+33(0)620830208
florent.cochain@estaca.eu

25 rue des Ormeaux
33160 Saint Médard en Jalles
France

CITIZENSHIP French

TECHNICAL SKILLS Fluid Mechanics, Aerodynamics, Propulsion, Mission / Design / Architecture Launchers, Space Mechanics, Mechanical Systems, Thermal, Mechanical Design of connections, Analysis Modeling and Control Systems

EDUCATION

Now **4th year at ESTACA** (Engineering School specialised in aeronautics and space www.estaca.fr)
Major : Space

2009 **Universitary Institute of Technology in Bordeaux-Physical Measurment Department**
Technical Diploma in Physical Measurment
Option : Instrumentations Technicals

2007 **Lycée Sud Médoc La Boétie – Le Haillan**
Baccalauréat S

WORK EXPERIENCE

2009 **SNECMA PROPULSION SOLIDE – Groupe SAFRAN – Le Haillan (France)**
3 months **Training period/Upper technician**
From the costs of the unquality of an independent production unit (scrap, retouching, anomalies), development of Pareto by reference taking into account production rates, with operations and recommendations

2008 **KEOLIS LITTORAL – Rochefort (France)– Seasonal worker**
1 month *Management of the bus station in Rochefort, Creation of magnetic cards, phone and direct contacts with clients, Master Terminal Point Deventer, frequent use of english with tourists*

2007 **KEOLIS LITTORAL – Rochefort (France)– Seasonal worker**
1 month *Idem*

LANGUAGES

French : Native Language
English : Advanced Level (**TOEIC : 915 - TOEFL :94**)
Spanish : Basics

IT SKILLS Nastran/Patran, Catia V5, Matlab, knowledges C/C#, LabView, Pspice, Lattice, SolidWorks3D

Cyril Prieux

Cell: 06 33 76 36 99
Email: cyril.prieux@estaca.eu

11 allée de la futaie
53970 L'Huisserie
France

Citizenship French

Technical Skills

Software: **MS Office**, **Catia V5**, **Matlab**, **Solidworks**, **Nastran/Patran,C/C++**.

Programme includes: Mechanics system, aerodynamics, Fluid Mechanics, Propulsion, Thermal, Power integration, Mechanical Design of connections, Analysis Modeling and Control Systems, FEA

Education

Now **4th year at ESTACA** (*one of leading French engineering universities specialised in the transport sector*) –Laval. 5 year programme (MSc) in Aeronautical, Automotive, Aerospace & Railway Engineering.
Major : Aeronautical engineering.

2007 Bac calauréat S, A. Paré Secondary School, Laval.
Majors: Maths & Physics (equivalent to A Levels). Graduated with distinction.

Work experience

2010 –1 month
SABENA TECHNICS DNR, St-Malo, France
Receptionist
-Checked reception of aeronautical equipment.

2008 –1 month
SALMSON, Laval, France
Operator on assembly line
- Assembled and tested water pumps

Languages

French: native speaker | **English:** TOEIC score 685
German: Basics | **Chinese:** Basics

Honors and awards

Gained leadership skills as class spokesman in last year of high school for 1 year.
Certification training in first aid.

Guillaume COUTINHO

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guillaume.coutinho@estaca.eu

132 rue du Président Wilson
Levallois-Perret, 92300
France

CITIZENSHIP French

TECHNICAL SKILLS Software used: Matlab Simulink Simscape, CATIA V5, NASTRAN/PATRAN, Word, Excel, Power Point, Initiation of programming with C and C++.

EDUCATION

4th year in Space engineering major of ESTACA *(French Engineering School specialized in Aeronautical, Automotive, Space and Railway)* *(2009-2012)*
Levallois-Perret, FRANCE

Engineering diploma expected in October 2012.

Classes Préparatoires aux Grandes Ecoles *(Preparatory Classes for Postgraduate Schools).* *(2006-2009)* **Paris, FRANCE**

Baccalauréat in scientific section with honors *(2006)* **Paris, FRANCE**

PROFILE

- Quick learner
- Logical
- Working as a team
- Using a computer and the internet

LANGUAGE:

French (native speaker)

English (Toeic score = 815, IELTS score = 6.5) written and spoken

Spanish (basic)

AFFILIATIONS

- Member of ESTACA Space Odyssey (ESO), the spatial association of ESTACA.
- Member and current secretary of the European Guild of Role-playing Games (GEJR).

Antoine OGER

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Current Address
16 Avenue du Marechal Leclerc
Laval, France

Permanent Address
10 rue des rosiers
Vaiges, France

CITIZENSHIP French

TECHNICAL SKILLS Use of CATIA V5, Solidworks, Word, Excel, PowerPoint, Matlab and frequent use of internet.

Programme includes : Aerodynamic, Fluid's Mechanic, Aeronautics

EDUCATION

Immaculée Conception School **Laval, France**

BAC S. Majors: Maths & Physics (equivalent to A levels). Graduated with honours

WORK EXPERIENCE

July 2008 – August 2008 **Gevelot Extrusion** **Laval, France**

- Think about how to automate a manual press
- Presentation of solution
- Introduction to CATIA

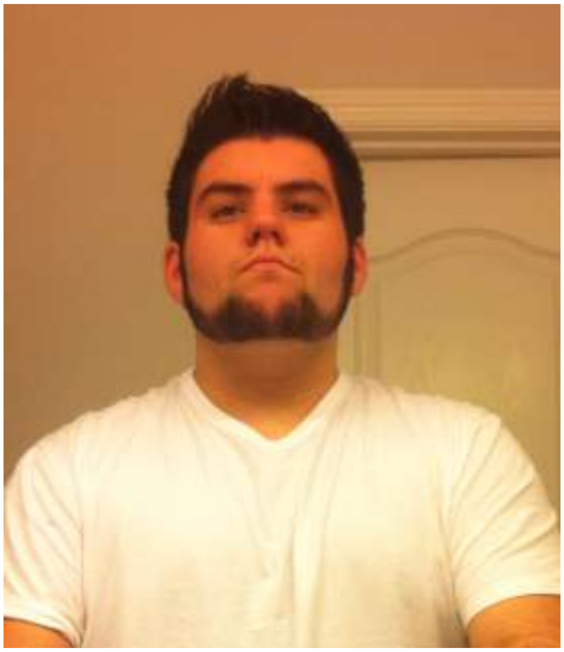
July 2009 – August 2009 **SIRAL SNC** **Evron, France**

- Establishment of instruction sheet

LANGUAGES French: native speaker

English: intermediate level (TOEIC 810)

German: elementary level



Michael Mayhall

(SHS Senior) Class of 2011

Senior, Sparkman High School

President, Sparkman Engineering Academy

Personal and Scholastic:

Born: 12/01/1992

Age: 18

Sex: Male

Race: White

Height: 6’0

Weight: 270lbs

Hair: Black

Eyes: Hazel

GPA: 3.5

Extra-Curricular; Classes:

- Sparkman Engineering Academy (President) – Three years
- National Beta Club – One Year
- NHS (National Honors Society) – One Year
- NSHSS (National Society of High School Scholars) – Two Years
- NYLF (National Youth Leadership Forum) National Security – One Year
- NYLF (National Youth Leadership Forum) Alumni – Two Years
- Monrovia Volunteer Firefighter (Senior Member)
- GUMC (Grace United Methodist Church) Casa and Volunteer Work
- Taekwondo and American Freestyle (Black Belt Rank) – Alexander’s Martial Arts
- ACE Program (First Grade through Sixth Grade)
- Football (Middle School 5-6th)
- Real Estate Assistant (Jeff Benton Homes)
- Sparkman Engineering Team
- BEST Robotics (1st Place, District Winner)
- BEST Robotics (4th Place, Regional)

Classes:

- AP Computer Science (11)
- Java Programming (Calhoun)
- C++ Programming (Calhoun)
- AP English (11-12)
- Solid-Works CAD (Calhoun)
- AP World History (11)
- AP Chemistry II (12)
- Pre-AP Pre-Cal for Engineers (10)
- Pre-AP Pre-Cal (12)
- Honors: English (6-10); History (6-10);

Mary E. Robinson

Sparkman High School

Birthdate: 4 Nov 1992

Class of 2011

Classes of Note:

Advanced Core Classes Throughout Middle School

Honors English 9-10

Honors History 9-10

Honors Biology

Honors Geometry

Honors Chemistry 1

Honors Algebra II with Trigonometry

Pre-AP Anatomy and Physiology

Engineering 1

Pre-AP Calculus for Engineers

C++ Programing

AP Calculus

Pre-AP Physics

Engineering Research and Design

Extra-Curricular Activities:

Optimist Club (9,Vice President-10,President)

National Honors Society (11-12 requires 50 hours of volunteer work per year)

Theater (Drama) Club (9-10)

Advanced Acting/Musical Theater (11)

Yearbook Design (9-10)

Toney United Methodist Youth Foundation (11,President)

Band (6-8)

Honors Band (8)

Vision Team Toney United Methodist Church (11-12)

Sparkman Engineering Team (12)

Anime Club (12)

Sparkman Engineering Academy (11-12)

J.4 Summary of Proposed Program Cooperative Contributions

Not Applicable.

J.5 Draft International Participation Plan

Not Applicable.

J.6A Planetary Protection Plan

Not Applicable.

J.6B Sample and Space-Exposed Hardware Curation Plan

Not Applicable.

J.7 Discussion of End-of-Mission Spacecraft Disposal Requirements

Not Applicable.

J.8 Compliance with Procurement Regulations by NASA PI Proposals

Not Applicable.

J.9: Master Equipment List

Table J.9 Mass Equipment List

Orbiter		
Subsystem	Equipments	Mass
Payload	Ice Penetrating Radar, Laser Altimeter, Thermal Emission Spectrometer, Nephelometer, Magnetometer, UV Spectrometer, IR Spectrometer, Narrow Angle Camera	90
Structure	Chassis and trusses	150
Power	ASRG	30
Cabling	Wires, cable	12
CD&H	2 Solid State Recorder	24
Telecommunication	3m Gimbaled Antenna (HGA)	24
Propulsion	HiPAT Bi Propellant Engine, 2 propellant tank (Hydrazine and NTO),	143
ACS	16 Aerojet MR-111 4N monopropellant thrusters, 3 reaction wheels	11
Thermal	MLI, RHU, louvers, FWPF	12
Lander		
Subsystem	Equipments	Mass
Payload	RAMAN, Panoramic Camera, Thermal Emission Spectrometer, Mass Spectrometer	10
Structure	Refer to Appendix J.15.1	99
Power	ASRG	39
Cabling	Wires, cable	25
CD&H	RAD750, SSDR	32
Telecommunication		35
Propulsion	2 MR-80B,	68
ACS	9 MR-111E, 3 MR-106E	8
Thermal	MLI, Titanium Chassis, Tungsten-Copper Component Shielding, RHU	90

J.10 Heritage

Table J.10.1 Heritage

Subsystem	Element	Heritage Level	Heritage Examples
Science Instruments	Raman	In Progress	In Progress
	Panoramic Camera	In Progress	In Progress
	Thermal Emission Spectrometer	In Progress	In Progress
	Mass Spectrometer	In Progress	In Progress
ACS	In Progress	In Progress	In Progress
Command and Data Handling	In Progress	In Progress	In Progress
Power	ASRG	Low	In Progress
Propulsion	Atlas V 551	High	New Horizons
	Aerojet MR-80B Engine	Low	In Progress
	Aerojet MR-111C Engine	High	In Progress
Structures	In Progress	In Progress	In Progress
Thermal	Bi-Metallic Passive Actuated Louvers	High	Magellan
	Titanium Chassis Shielding	Medium	Juno
	Layer Kapton MLI	High	Cassini
	Layer Aluminum MLI	High	Cassini
	Layer Silk MLI	In Progress	In Progress

J.11 List of Abbreviations and Acronyms

ACS	Attitude Control System
AHRS	Attitude and Heading Reference System
ALTO	Assembly Test and Launch Operation
AO	Announcement of Opportunity
ASRG	Advanced Stirling Radioisotope Generator
CD&H	Command Data & Handling
CE	Chief Engineer
CG	Center of Gravity
CRETE	Collaborative Research of Europa Through Exploration
CoPI	Co Principle Investigator
COPV	Composite Overwrapped Pressure Vessels
DDD	Displacement Damage Dose
DOE	Department of Energy
DSN	Deep Space Network
DTM	Development Test Model
E4T	Engineering for Tomorrow
EAR	Export Administration Regulations
EDID	Europa Dual Inhaler Devices
EM	Engineering Model
EMC/EMI	Electromagnetic Compatibility/Interference
EOL	End of Life
FWPF	Fine Weave Pierced Fabric
GPHS-RTG	General Purpose Heat Supply Radioisotope Thermoelectric Generator
GPS	Global Positioning System

HGA	High Gain Antenna
IMU	Inertial Measurement Unit
ISP	Specific Impulse
ITAR	International Traffic in Arms Regulations
JEO	Jupiter Europa Orbiter Report
M^2ET	Measuring the Magnitude of the Europan Trimmers
MGA	Middle Gain Antenna
MLI	Multilayer Insulation
MMH	Mono Methyl Hydrozine
MMRTG	Multi-Mission Radioisotope Thermoelectric Generator
NEPA	National Environmental Protection Agency
NTO	Nitrogen Tetroxide
ORT	Operational Readiness Test
PI	Principle Investigator
PM	Project Manager
PMF	Propellant Mass Fraction
PMSR	Preliminary Mission and System Review
POC	Point of Contact
QRR	Quake, Rattle, and Roll
RHU	Radioisotope Heating Unit
RTG	Radioisotope Thermoelectric Generator
SEE	Single Event Effects
SEO	Science Enhancement Option
SMM	Seismometer Measurement Mechanisms
SSDR	Solid State Data Recorder

TID Total Ionizing Dose

TRL Technology Readiness Level

UAH University of Alabama in Huntsville

VEEGA Venus Earth, Earth Gravity Assist

J.12 List of References

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"Design, Verification/Validation and Operations Principles for Flight Systems, Rev.1," *JPL Guidelines Official,* DMIE Document ID: DMIE-4391,Document Reference Number: D-17868

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Larson, Wiley L., and James R. Wertz., *Spacecraft Mission Analysis and Design,* 3rd ed., Microcosm Press, El Segundo, CA, 1999

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NASA General Safety Programs Requirements, NASA Systems Engineering Handbook, NASA/SP-2007-6105Rev 1 NPR 8715.3

"NASA Research and Technology Program and Project Management Requirements (w/ change 1 dated 11/24/10), [online], http://www.nasa.gov/mission_pages/juno/news/juno20100712.html0[retrieved 4 March 2011]

J.13 NASA-Developed Technology Infusion Plan
Not Applicable

J.14 Description of Enabling Nature of ASRG
A trade study was performed to determine the need for the Advanced Stirling Radioisotope Generator (ASRG) in this mission. It was found that the most recent commonly used radioisotope thermoelectric generator (RTG), the General Purpose Heat Source Radioisotope Thermoelectric Generator (GPHS-RTG), was discontinued after the Cassini mission. According to the information found the most recent use of this RTG in the New Horizon mission was a used spare GPHS-RTG unit from the Cassini program, and the cost of restarting the assembly line was one of the reasons for not sending another New Horizon spacecraft. The cost of this was too great, $65-$95 million, for this mission's budget as well. The other developing RTG, the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) was researched as well. This power supply was found to be not only less cost effective, being $15 million more expensive for an RTG that supplies around 30 watts less, 110 watts, but was also a less efficient use of our mass, since it is roughly 1.5 times the mass of the ASRG. Thus, the ASRG was found to be not only the most efficient means or powering the spacecraft/lander because two would be given to the mission for free, but would be the best choice for purchasing additional RTG's in the case more power was needed than could be supplied by the two given ASRG's. The actual decision analysis can be seen in Table J.14.1.

Table J.14.1

RATING AND WEIGHTING METHOD									
Decision Analysis- Power System									
		Power Systems							
Attributes	Types of RTG's	Free ASRG	Additional ASRG	MMRTG	GPHS-RTG	Free ASRG	Additional ASRG	MMRTG	GPHS-RTG
Cost	9	10	7	5	1	90	63	45	9
Mass	1	10	7	7	5	10	7	7	5
Power Output	3	6	9	3	10	18	27	9	30
Heat Output	3	5	7	8	10	15	21	24	30
Total						133	118	85	74

J.15 Calculations

J.15.1 Structures

Table J.15.1.1

RATING AND WEIGHTING METHOD							
Decision Analysis- Landing Gear							
		Landing Gear					
Attributes	Weight Factor	Structured	Airbags (Orion)	Airbags (Mars Path Finder)	Structured	Airbags (Orion)	Airbags (Mars Pathfinder)
Cost	9	6	2	2	54	18	18
Mass	9	6	7	5	54	63	45
Diameter Conservation	3	6	10	10	18	30	30
Risk	3	8	5	3	24	15	9
Total					150	126	102

Table J.15.1.2

RATING AND WEIGHTING METHOD											
Decision Analysis- Design Arrangement											
		Design Arrangement									
Attributes	Weight Factor	Circular	4 Sided	5 Sided	6 Sided	8 Sided	Circular	4 Sided	5 Sided	6 Sided	8 Sided
Cost	9	1	10	8	7	4	9	90	72	63	36
Mass	9	8	10	8	7	4	72	90	72	63	36
Diameter Conservation	9	10	1	6	9	10	90	9	54	81	90
Symmetry	1	10	8	1	6	8	10	8	1	6	8
Rigidity	3	10	2	6	8	9	30	6	18	24	27
Total							211	203	217	237	197

J.15.1.3 Calculations

Pressure for Lander

$d := 3.5in$ $mass := 400kg$

$370kg = 815.71lb$ $a := 9 \cdot g = 88.26\frac{m}{s^2}$

$Area := \pi \cdot \frac{d^2}{4}$

$eF := mass \cdot a = 3.53 \times 10^4 N$

$P := \frac{eF}{Area \cdot 3} = 275 psi$

Force on Honeycomb

$\theta := 25deg$

$b := 55.13in$

$h := 6in$

$r := h + b$

$eL := \tan(\theta) \cdot (b + h)$

$w := \sqrt{r^2 + eL^2}$

$M_B = eF \cdot eL - A_x \cdot b$

$A_x := \frac{eF \cdot eL}{b} = 1.825 \times 10^4 \cdot N$ **Ax acts to the left**

$M_A = eF \cdot eL - B_x \cdot b$

$B_x := \frac{eF \cdot eL}{b} = 1.825 \times 10^4 N$ **Bx acts to the right**

$M_{eF} = B_x \cdot r + A_x \cdot h - B_y \cdot eL$

$B_y := \frac{B_x \cdot r - A_x \cdot h}{eL} = 3.53 \times 10^4 N$ **By acts down**

$F_x := B_x = 1.825 \times 10^4 N$

$F_y := B_y = 3.53 \times 10^4 N$

$F_{member} := \frac{F_x \cdot w}{r} = 2.014 \times 10^4 N$ **Force in member**

$$P_{member} := \frac{F_{member}}{Area \cdot 3} = 156.875 psi$$

Stress in member

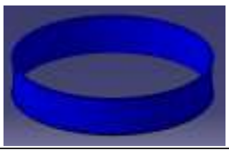
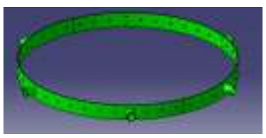
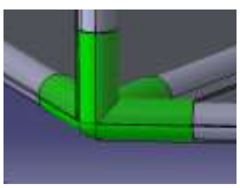
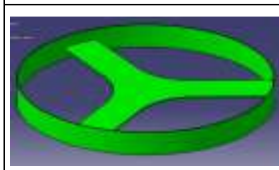
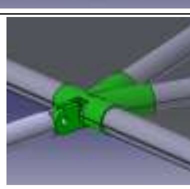
$$F_{crossmember} := A_x = 1.825 \times 10^4 N$$

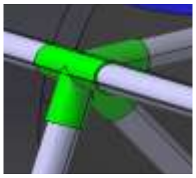
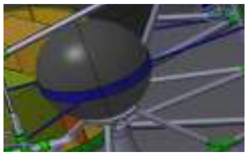
Force in cross-member

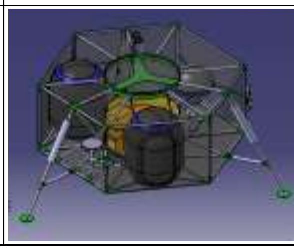
$$P_{crossmember} := \frac{F_{crossmember}}{Area \cdot 3} = 142.177 psi$$

Stress in cross-membe

Table J.15.1.4 – Structures/ Mass Summary

Part	Description	Function	Mass (kg)
	Orbiter to Lander Adapter	Adapter that interfaces between orbiter and lander. Supports the structure for the lander and the thermal chassis.	5.8
	Lander Structure Mounting Bracket	Mounts to the orbiter to lander adapter and supports all the lander structure	3.2
	Truss Srtucture	Withstands and transfers the impact forces of the landing and withstands the thrust from the engines. The engine supports, landing gear leg, tank supports and outside covering mount to it	34.8
	Corner Fittings	Used at every corner of the hexangonal assembly or the truss structure.	4.5
	Top Center Fitting	Withstants the remainder of the loads given from the impact landing of the threee legs into the three memers into the middle	4.3
	Landing Gear to Lander Fitting	Tranfers impact load to the lander and is pinned so that when the honecomb absorbs the impact the bar that it connects to can travel	1.1
	Lower Landing Gear Struts	Tranfers impact load to the lander and is pinned so that when the honecomb absorbs the impact the bar that it connects to can travel	1

	**Main Landing Gear Strut**	**Holds the honeycomb core tube withstants the blunt of the impact**	**5.8**
	**Landing Gear Feet**	**Transfers the load to the landing gear and adjusts to the surface angle/conditions when peforming landings**	**2**
	**Main to lower landing gear fitting**	**Tranfers impact load to the lander and is pinned so that when the honecomb absorbs the impact the bar that it connects to can travel**	**0.4**
	**Honeycomb core cylinder**	**Absorbs an estimated 1/3 of the impact force in each leg.**	**0.1**
	**Impact strut to lander fittings**	**Tranfers impact load to the lander**	**1.2**
	**MR-80B Supports**	**Supports the MR-80B Engines and withstands the thrust**	**10.4**
	**Tank Supports**	**Supports the propellent and the pressurant tanks**	**7.3**

	Composite Siding	**Holds insulation that is to be applied on the outside**	**15.6**
	**ACS Supports**	**Supports the ACS**	**1.8**
		**Total**	**99.3**

J.15.2 Propulsion

J.15.2.1 Orbiter Propulsion

Considering the thrust and the performance needed, only monopropellant and bi-propellant engines can be used. Six Aerojet engines have been analyzed. The following chart contains the main characteristics of these engines:

Table J.15.2.1.1

Engine	MR-104D	MR-80B	R-42	R-4D	HiPAT	HiPAT DM
Manufacturer	Aerojet	Aerojet	Aerojet	Aerojet	Aerojet	Aerojet
Propellant type	Mono-propellant	Mono-propellant	Bi-propellant	Bi-propellant	Bi-propellant	Bi-propellant
Propellant	Hydrazine	Hydrazine	MMH/NTO (MON-3)	MMH/NTO (MON-3)	MMH/NTO (MON-3)	Hydrazine/NTO (MON-3)
Catalyst	S405/LCH-202	S405				
Thrust (N)	506.2	3184	890	490	445	445
Feed pressure (bar)	24.8 - 6.9	369	29.3 - 6.9	29.3 - 4.1	27.6 - 6.9	21.4 - 15.2
Chamber pressure (bar)	9.4 - 3.8	171 - 0.14	7.1	7.45	9.4	9.4
Expansion ratio	53/1	16.7/1	160/1	44/1 - 164/1 - 300/1	300/1 - 375/1	300/1 - 375/1
Flow rate (g/s)	217.9 - 90.8		300	158	141	141
Power consumpsion (W)	74.4	183	46	46	46	46
Height (inches)	21	16.16	31	35 - 45 - 52	25 - 28.5	25- 28.5
Nozzel diameter (inches)	5.55	6	15.34	6 - 11 - 14.84	12.8 - 14.25	12.8 - 14.25
Weight (kg)	2.22	7.94	4.53	3.4 - 3.76 - 4.31	5.2 - 5.44	5.2 - 5.44
Isp (s)	237 - 223	231 - 200	303	300 - 311 - 315.5	320 - 323	326 - 329
Total impulse (N.s)	693.9		24271000	200160000	20016500	9.55E6
Total pulses	1742		134	20781	500	672
Status	Flight ready	In development	In Production	Flight proven	Flight proven	Qualified

Table J.15.2.1.2

Attributes	Weight	MR-104D	MR-80B	R-42	R-4D	HiPAT	HiPAT DM
Cost	5	10	10	5	5	3	3
Total Mass	10	10	3	8	8	7	7
Risk	8	7	3	1	10	10	10
Isp	10	4	1	7	8	10	10
Length	3	8	10	4	3	7	7
Nozzle diameter	3	10	9	3	6	5	5
Power consumption	5	6	1	10	10	10	10
Thrust	8	8	4	10	7	6	6
Total		394	208	334	[illegible]	[illegible]	[illegible]

Table J.15.2.1.3

Engine	ISP	Mi (kg)	M propellant (kg)	M propellant (kg) with a total mass of 5300kg	M propellant (kg) with a total mass of 4790kg
MR-104D	237	2174	1374	3349	3027
MR-80B	231	2231	1431	3399	3072
R-42	303	1748	948	2875	2598
R-4D	315,5	1695	895	2799	2529
HiPAT	320	1677	877	2772	2505
HiPAT DM	326	1655	855	2737	2474

Table J.15.2.1.4

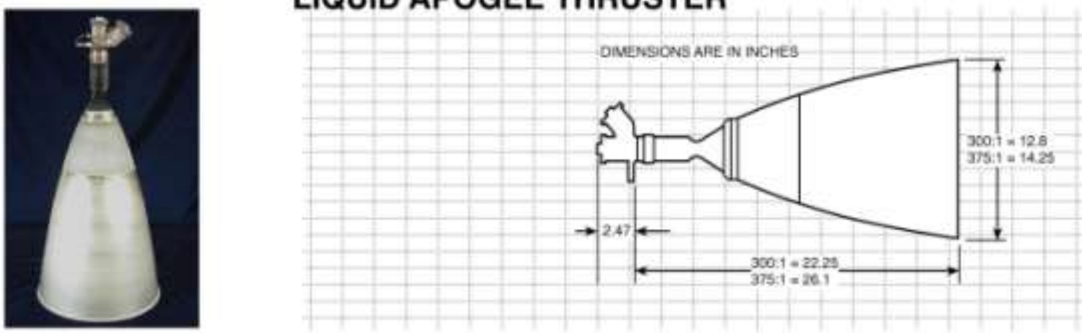
Propellant tank volume considering a total mass of 4790kg									
Engine	M usable (kg)	M margin (kg)	M propellant (kg)	Mhydrazine (kg)	MNTO (kg)	NTO volume(m3)	NTO tank volume (m3)	MMH volume (m3)	MMH tank volume (m3)
MR-104D	3027	651	3678	1636	x	x	x	1,63	1,76
MR-80B	3072	614	3686	1661	x	x	x	1,65	1,79
R-42	2598	689	3287	1404	1194	0,83	0,90	1,40	1,51
R-4D	2529	670	3200	1367	1162	0,81	0,89	1,36	1,47
HiPAT	2505	664	3169	1354	1151	0,80	0,87	1,35	1,46
HiPAT DM	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

DATA	
MMH/hydrazine density(kg/m3)	1004
NTO density (kg/m3)	1434
Melange ratio	0,85

Table J.15.2.1.5

	MMH	NTO
Pp (psia)	310	
Vp (m3)	1,42	0,84
R (J/kg.K)	2077,3	
Ti (K)	275	
k	1,67	
Pg (psia)	400	
Pi (psia)	5000	
mgi (kg)	9,634	5,734
Vgi (m3)	0,160	0,095

HiPAT™ 445N (100-lbf) DUAL MODE HIGH PERFORMANCE LIQUID APOGEE THRUSTER



Design Characteristics

- Propellant . . . . Hydrazine/NTO(MON-3)
- Thrust/Steady State . . . . 445 N (100-lbf)
- Inlet Pressure Range . . . . . 21.4 – 15.2 bar (310 – 220 psia)
- Chamber Pressure* . . . . 9.4 bar (137 psia)
- Expansion Ratio 300:1, 375:1
- Oxidizer/Fuel Ratio 0.85
- Flow Rate* . . . . 141 g/sec (0.31 lbm/sec)
- Valve . . . . Aerojet Solenoid, Dual Coil, Single Seat
- Valve Power . . . . Various (46 Watts @ 28 Vdc Typical)
- Mass . . . . 300:1, 5.2 kg (11.5 lbm)
  . . . . 375:1, 5.44 kg (12 lbm)

**At rated thrust*

Performance

- Specific Impulse* . . . . 300:1 = 326 sec (lbf-sec/lbm)
  . . . . 375:1 = 329 sec (lbf-sec/lbm)
- Total Impulse Demonstrated . . . . In Excess of 9.55×10^6 N-sec
  . . . . (2.15×10^6 N-sec)
- Total Pulses 672
- Total Thermal Cycles 345
- Minimum Impulse Bit . . . . 35.6 N-sec (8 lbf-sec)
- Demonstrated Steady State Firing . . . . 1800 sec

Status

- Qualified

Reference

- AIAA - 2003 - 4775

Figure J.15.2.1.1

J.15.2.2 Orbiter Calculations

Atlas V 551

Mass of payload it can carry

$$M_{availiable} := 4790\,kg$$

C3 of Launch Vehicle

$$C3 := 12.8\frac{km^3}{s^2}$$

Delta V of VEEGA

$$\Delta V := 2324\frac{m}{s}$$

Orbiter:

Specific Impulse

$ISP := 329s$

Propellant Mass Fraction

$PMF := 0.8$

Orbiter Propellant Mass

$$M_{pO} := M_{availiable} \cdot \left(1 - e^{\frac{-\Delta V}{g \cdot ISP}}\right) = 2459.179771 kg$$

Wet mass of Orbiter

$$PMF = \frac{M_p}{M_{wet}}$$

therefore

$$M_{wetOrbiter} := \frac{M_{pO}}{PMF} = 3073.974713 kg$$

$$M_{dryObiter} := M_{wetOrbiter} - M_{pO} = 614.794943 kg$$

Mass after 30% Reserve

$$Mass_1 := M_{dryObiter} - M_{dryObiter} \cdot 0.3 = 430.35646 kg$$

Mass after another 5% Reserve

$$Mass_1 - Mass_1 \cdot 0.05 = 408.838637 kg$$

Mass Calculations:

J.15.2.3 Lander Propulsion

Lander

Assumptions

Europa Gravity

$$g := 1.3 \frac{m}{s^2}$$

Earth's Gravity

$ge := 9.81 \frac{m}{s^2}$

$\Delta V_l := 1528 \frac{m}{s}$

Mass of the lander:

$M_L := M_{availiable} - M_{wetOrbiter} = 1716.025287 kg$

Specific Impulse

$ISP_l := 223 s$

Propellant Mass Fraction

$PMF_l := 0.6$

Lander Propellant Mass

$$M_{pL} := M_L \cdot \left(1 - e^{\frac{-\Delta V_l}{ge\, ISP_l}}\right) = 862.569926 kg$$

Wet mass of Lander

$$PMF_1 = \frac{M_p}{M_{wet}}$$

therefore

$$M_{wetLander} := \frac{M_{pL}}{PMF_l} = 1437.616544 kg$$

Dry mass of lander

$M_{dryLander} := M_{wetLander} - M_{pL} = 575.046617 kg$

Dry mass after 30% reserve

$Mass_1 := M_{dryLander} - M_{dryLander} \cdot 0.3 = 402.532632 kg$

Dry mass after another 5% reserve

$$Mass_1 - Mass_1 \cdot 0.05 = 382.406001\,kg$$

Margin available for the whole mission:

$$M_{wetOrbiter} + M_{wetLander} = 4511.591257\,kg$$

$$Mass_{left} := M_{availiable} - M_{wetOrbiter} - M_{wetLander} = 278.408743\,kg$$

$$\frac{Mass_{left}}{M_{availiable}} \cdot 100 = 5.812291$$

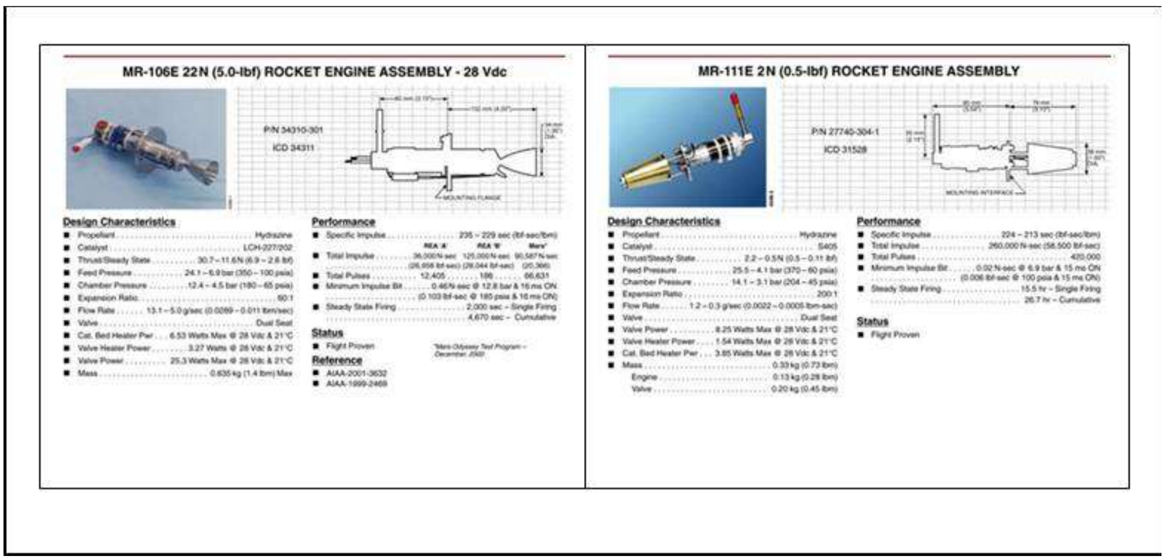


Figure J.15.2.3.1 ACS Engines

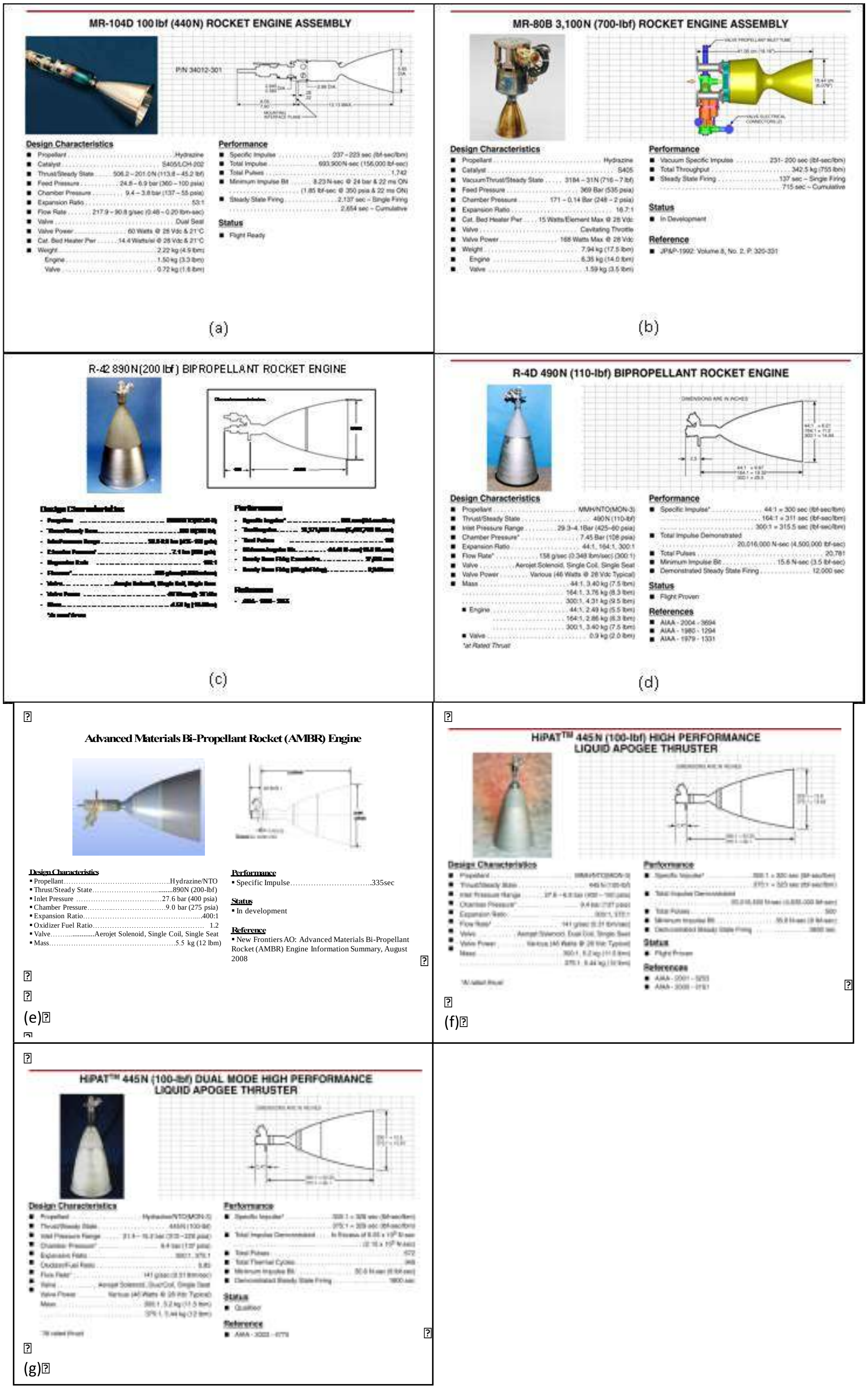


Figure J.15.2.3.2 Propulsion Engines

Table J.15.2.1.6

Decision Analysis-Monopropellant Engines					
Monopropellant Engines					
Attributes	Weight	MR-104D	MR-80B	MR-104D	MR-80B
Cost	3	8	7	24	21
Mass	9	10	4	90	36
Thrust Range	9	5	10	45	90
Efficiency	3	10	9	30	27
Performance	9	8	10	72	90
Length	1	7	10	7	10
Nozzle Diameter	1	10	9	10	9
			Total	278	283

Table J.15.2.1.7

Element	Quantity	Mass (kg)	Total Mass (kg)
Hydrazine		862	862
Tank	2	4	8
Helium		5	5
Tank	1	35	35
MR-80B Engines	2	8	16
Lines and Valves		4	4
Propulsion Mass (excluding propellant)			68

J.15.3 Thermal

J.15.3.1 Orbiter Thermal/Radiation Protection

There are several ways to reduce the impact of radiations on electronic systems of the spacecraft.

Firstly it is necessary to choose an appropriate trajectory based on mission goals to minimize exposure to radiation.

The second way is to physically separate the different electronic components in order to reduce the probability of being hit by a particle and ionization by heavy ions or protons; and redundant electronic systems to ensure that even in case of failure of a loop, the equipment will act as if it was functional. This is a way to fight against probable single event effects.

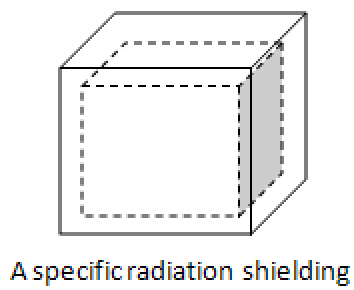


Figure J.15.3.1.1

The third way consists of protections against radiations for electronic equipment. Aluminum protections are effective to stop the electrons even at high energies and the low energy protons but not the high energy protons. Moreover, the addition of a tantalum layer provides better reduction of radiation.

These protections aluminum-tantalum can be set up in two different ways, either at the spacecraft thereby protecting all electronic equipment, either individually as a box around equipment. As we have strong mass constraints, it is better to use specific shielding for electronic equipment and particularly shielding with copper-tungsten or tantalum, whose properties and high density will allow us to lighten the radiation shielding. Indeed for the same protection, using one of these two elements can save about 20% on the mass balance (A/ 1). In addition, tantalum and tungsten-copper have both a low thermal expansion and high thermal resistance. Their main differences are their density (16.6g.cm^{-3} for tantalum against 15.9g.cm^{-3} for copper-tungsten) and their thermal conductivity (about 160 W.K^{-1}.m^{-1} for copper-tungsten, 58 W.K^{-1}.m^{-1} for tantalum and 237 W.K^{-1}.m^{-1} for aluminum at 300K). So depending on the case, we choose the most suitable material based on these two criteria.

The most critical or sensitive equipment will naturally be better protected and the distribution of the equipment in the satellite can also help to influence their exposure to radiations.

We choose to use two thicknesses for radiation shielding, a first thickness of aluminum and a second of tantalum.

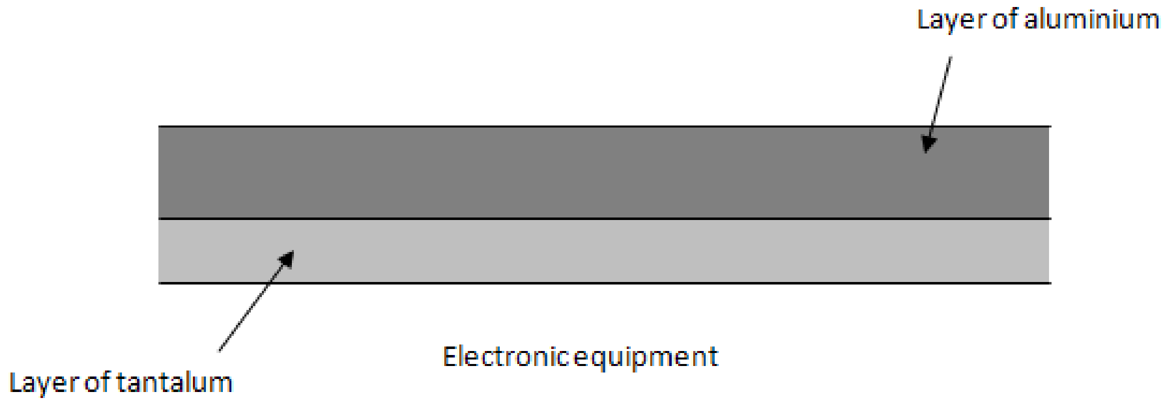


Figure J.15.3.1.2

The thickness of aluminum is 0.04 to 0.1 inches and the thickness of tantalum is 0.04 to 0.25 inches. The two thicknesses depend on the equipment sensitivity.

This radiation shielding weighs between 19.7 kg and 112.5 kg per square meter of surface to protect for a maximum total thickness of 0.35 inches (about 0.89 centimeters)

J.15.3.2 Lander Thermal/ Radiation Protection

Table J.15.3.2.1 MLI Decision Analysis

RATING AND WEIGHTING METHOD																			
Decision Anaylysis - Thermal Control System																			
		MLI																	
		Plastics						Metals						Spacers					
Attributes	Weight Factor	Kapton	Mylar	Teflon	Kapton	Mylar	Teflon	Aluminum	Gold	Silver	Aluminum	Gold	Silver	Dacron	Nylon	Silk	Dacron	Nylon	Silk
Cost	9	5	5	5	45	45	45	9	1	2	81	9	18	9	9	7	81	81	63
Shielding/Thermal Efficiency	9	10	7	7	90	63	63	7	9	9	63	81	81	8	6	10	72	54	90
Mass	1	5	5	5	5	5	5	8	2	4	8	2	4	10	10	10	10	10	10
Risk	1	10	10	10	10	10	10	10	7	7	10	7	7	10	10	10	10	10	10
TOTAL					150	123	123				162	99	110				173	155	173

Table J.15.3.2.2 Chassis and Component Shielding Decision Analysis

RATING AND WEIGHTING METHOD							
Decision Analysis - Thermal Control System							
	Chassis Radiation Shielding						
Attributes	Weight Factor	Titanium	Tungsten-Copper	RXF-1	Titanium	Tungsten-Copper	RXF-1
Shielding/Thermal Efficiency	9	8	9	9	72	81	81
Cost	3	5	6	1	15	18	3
Mass	3	8	4	10	24	12	30
Risk	1	9	8	1	9	8	1
TOTAL					120	119	115

Lander Thermal Calculations:

The following calculations assume that heat is dissipated evenly. During the flight to Europa, the ASRG will output 640 Watts of power because of the radiator attached. This yields the following temperatures for the titanium chassis.

$$q_{ASRG} = 640\ W$$

$$q_{RHU} = 65\ W$$

$$A_{titanium} = 1.59m^2$$

$$\varepsilon = 0.513$$

$$\sigma = 5.67051x10^{-8}\frac{W}{m^2K^4}$$

$$T_{titanium} = \sqrt[4]{\frac{q_{total}}{A_{titanium}\varepsilon\sigma}} = 296K = 23\,^{\circ}C$$

When the lander breaks-away from the orbiter, the ASRG power for the radiator is transferred to other components. Therefore the temperature in the titanium chassis is as follows:

$$q_{ASRG} = 500\ W$$

$$q_{RHU} = 65\ W$$

$$A_{titanium} = 1.59m^2$$

$$\varepsilon = 0.513$$

$$\sigma = 5.67051x10^{-8}\frac{W}{m^2K^4}$$

$$T_{titanium} = \sqrt[4]{\frac{q_{total}}{A_{titanium}\varepsilon\sigma}} = 280.3K = 7.3\,^{\circ}C$$

Fortunately, this value is in the optimal range for every component of the system that is included in the titanium vault with a 3 degree margin. Knowing this, further calculations can be performed. Since the outer layer of the lander is made of carbon fiber, epsilon changes.

$$A_{outer\_lander} = 22.0m^2$$

$$T = \sqrt[4]{\frac{q}{A_{outer_{lander}}\varepsilon_{outer_{lander}}\sigma}}$$

Using trial and error and the following equation, one finds that the optimal number of layers, N, of MLI equals 15. Beyond this value each additional layer becomes much less efficient.

$$q_{out} = \varepsilon_{outer\_lander}\sigma A_{outer\_lander}(T^4 - T_{Europa}{}^4)/N$$

$$q_{radiated\ out\ of\ spacecraft} = 66\ W$$

The propellant needs to be between 6 and 55 degrees C. The simplest calculation to find the heat radiated from the titanium vault to the tanks is to find the area that the heat will come from and the heat that it will be radiated onto.

$$A_{q\_out} = \frac{3}{12}A_{titanium}$$

$$A_{q\_in} = \frac{1}{2}A_{tank}$$

$$q_{out} = \frac{3}{12}q$$

The previous equations plus the assumption that approximately 1/2 of the radiation that is not dissipated through the inside walls or the MLI on the spacecraft will be reflected toward a single tank. The propellant is only required before the spacecraft lands on Europa, so the propellant only needs to be calculated while in space. This yields the following:

$$T_{tank} = 282K = 9.4^{\circ}$$

Schedule

The schedule and the following information was summarized out of the JEO Final Report 2008.

Phase A/B: Primary purpose is to select instruments in response to AO and accelerate instruments to PDR level of maturity. Each instrument will have its own Instrument Concept Design Review (ICDR). After this is complete, the program will review the ICDRs and move into an overall Instrument Confirmation Review (ICR) which will assess results and update the mission concept as may be required depending on ICR results. A Planetary Protection decisions will be conducted in Phase B as well.

Phase C/D: Primarily deals with Flight System achieving Launch Readiness. Phase C will be consumed with implementing the radiation and planetary protection risk mitigation measures for the system. Phase D will be primarily focused on Integration and Test (I&T) to ensure that the spacecraft design is compatible with the launch vehicle.

Phase E/F: This is the actual mission phase. Phase E is primarily comprised of the travel and science of the spacecraft and associated instruments for the entire mission. Phase F is reserved for end of mission activities as well as final data analysis and archival.

Critical Path: This path includes the release of the AO, the instrument solicitation, and the instrument development and delivery. There are 161 days of schedule reserve for instrument delivery and Assembly, Launch, and Test Operations (ATLO). A secondary critical path includes the design of the primary structure through delivery and integration of the propulsion system. This critical path has a schedule reserve of 175 days.

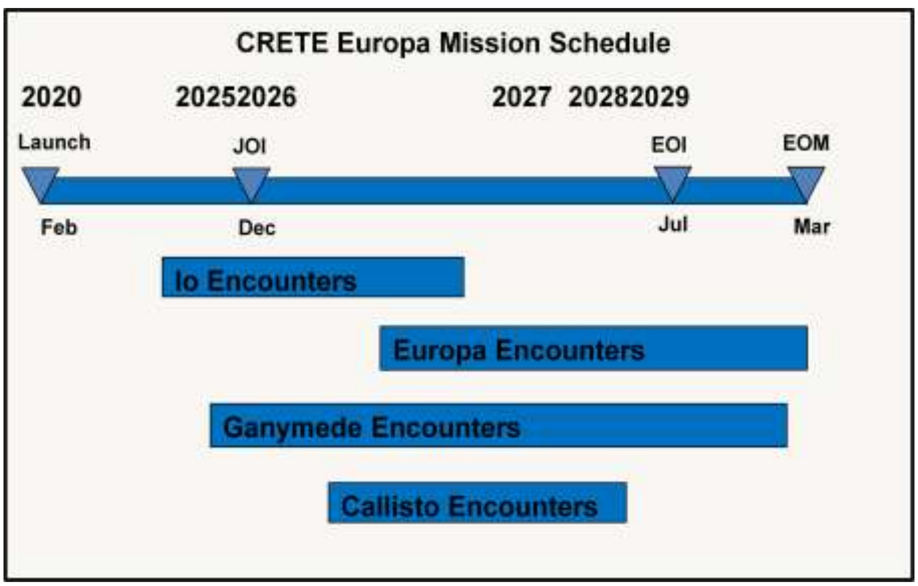


Figure J.15.3.1.3

J.15.4 Power

Table J.15.4.1 ASRG Degradation

ASRG 850°C		ASRG 850°C	
Years	ASRGs power (W)	Years	ASRGs power (W)
0	160	0	160
1	158,72	1	158,72
2	157,45024	2	157,45024
3	156,1906381	3	156,1906381
4	154,941113	4	154,941113
5	153,7015841	5	153,7015841
6	152,4719714	6	152,4719714
7	151,2521956	7	151,2521956
8	150,0421781	8	150,0421781
9	148,8418406	9	148,8418406
10	147,6511059	10	147,6511059

Position	Mission	Power Needed
	<u>Phase 1 : Trip</u> - Communication with Earth (High Gain Antenna only)	≈ 55 W
	<u>Phase 2 : Scanning Europa (no visibility with Earth)</u> - Perform Science Analysis (IPR+TES+Magno+UVS) - Data stocked on the Onboard Computer	≈ 90 W
	<u>Phase 2 : Scanning Europa (no visibility with Earth)</u> - Perform Science Analysis (LA+IRS+NAC) - Data stocked on the Onboard Computer	≈ 90 W
	<u>Phase 2 : Scanning Europa (visibility with Earth)</u> - Transfer/Receive information to Earth (High Gain Antenna Only)	≈ 55 W
	<u>Phase 2 : Scanning Europa (before separation)</u> - Separation only during visibility with Earth	≈100W
	<u>Phase 3 : Lander on Europa (visibility with Lander)</u> - Receive information from Lander (Medium Gain Antenna only) - Stock Data on the Onboard Computer	≈100 W
	<u>Phase 3 : Lander on Europa (visibility with Earth)</u> - Transfer/Receive Information to/from Earth	≈ 55 W
	<u>Phase 3 : Lander on Europa (no visibility with Earth or Lander)</u> - Stock data on the Onboard Computer	≈ 35 W

Figure J.15.4.1 Mission Power Budget

J.15.5 Instruments

Table J.15.5.1

Instrument	Watts
Ice Penetrating Radar	45
Laser Altimeter	15
Thermal Emission Spectrometer	6
Magnometer	4
UV Spectrometer	5
IR Spectrometer	25
Narrow Angle Camera	14
Nephelometer	3
total power instrument	117

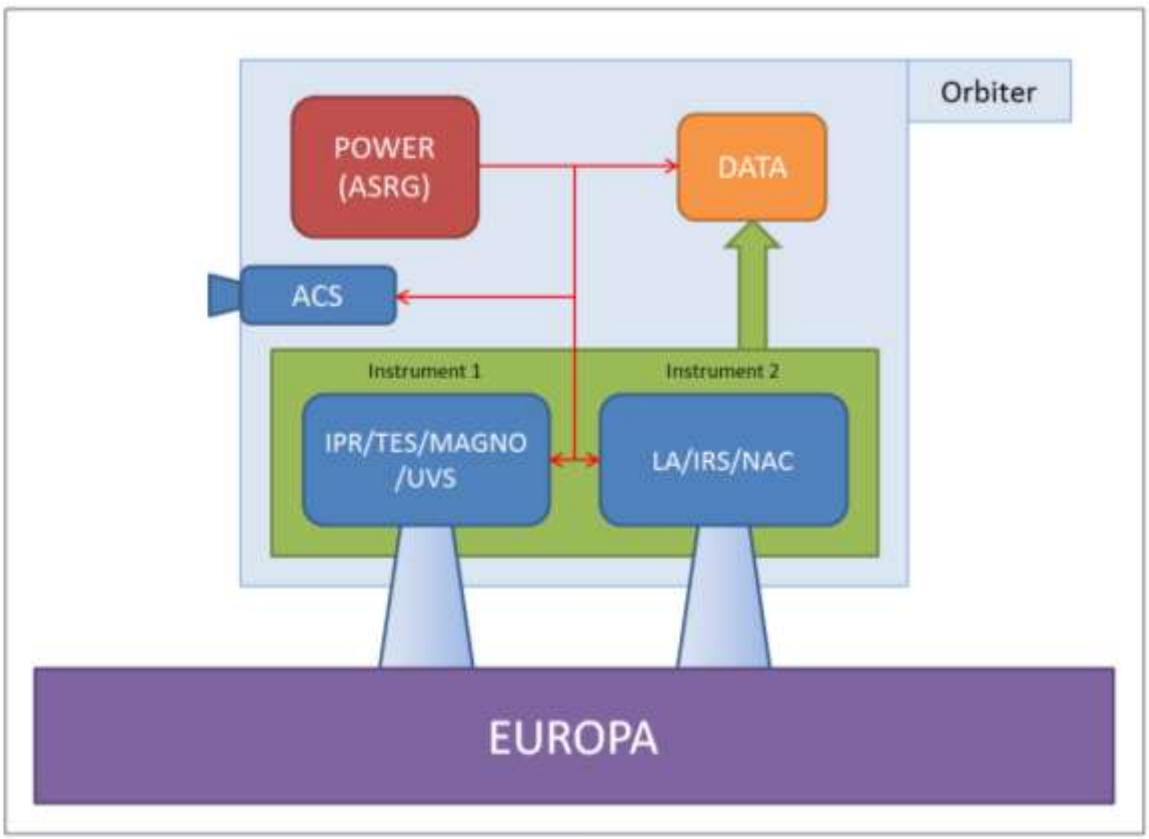


Figure J15.5.1 Instrument diagram

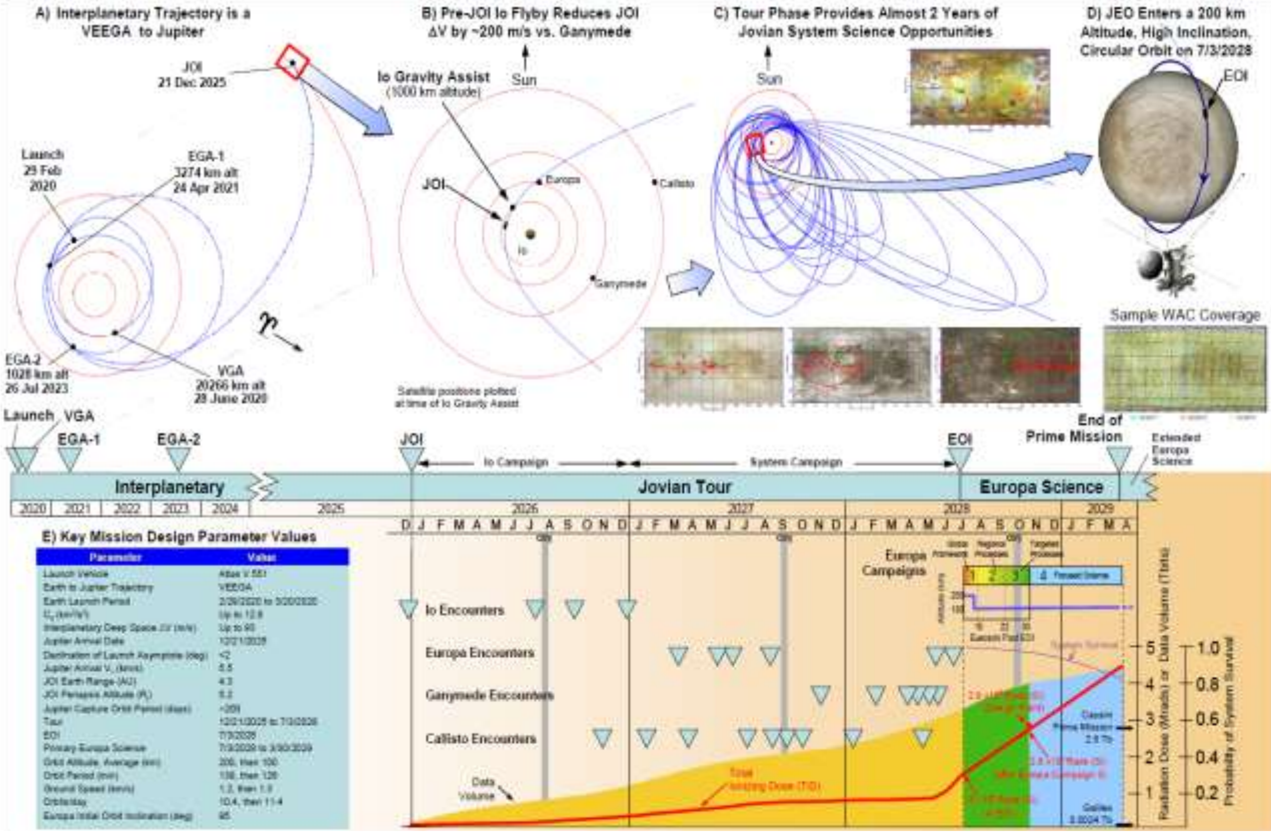


Figure J.15.6 JEO Trajectory representation

(JEO Report 2008). CRETE Mission shall follow this trajectory