Project ELSA
Europa Lander for Science Acquisition

University of Colorado
Department of Aerospace Engineering Sciences
ASEN 4018

Project Definition Document (PDD)

Approvals

	Name	Affiliation	Approved	Date
Customer	Joe Hackel	Ball Aerospace	J Hackel	9/14/15
Course Coordinator	James Nabity	CU/AES		

Project Customers

Joe Hackel

Ball Aerospace and Technologies Corp.
1600 Commerce St
Boulder, CO 80301

Phone: 303-588-0260
Email: jhackel@ball.com

Team Members

Darren Combs darren.combs@colorado.edu 303-994-6057	Gabriel Frank gabriel.frank@colorado.edu 303-325-6045	Sara Grandone sara.grandone@colorado.edu 847-922-5233
Colton Hall colton.hall@colorado.edu 303-883-0586	Daniel Johnson daniel.e.johnson@colorado.edu 720-883-6607	Trevor Luke trevor.luke@colorado.edu 720-270-4532
Scott Mende scott.mende@colorado.edu 970-589-9668	Daniel Nowicki daniel.nowicki@colorado.edu 303-945-6268	Benjamin Stringer benjamin.stringer@colorado.edu 303-883-1913

Contents

1 Project Definition

Europa, one of Jupiter's four Galilean moons, is believed to have a sizable ocean up to 100 km below its icy surface.[1] NASA has identified Europa as a high priority target in the search for life within our solar system, because of this potential ocean. Spacecraft sent through the Jovian system have revealed that Europa has one of the smoothest surfaces in the Solar System and has few impact craters which indicates a "young" and geologically active surface.[2] Pictures of Europa show many large streaks along its surface called lineae. These lineae are suspected to be the result of tidal flexing on Europa's surface as it orbits Jupiter.[3] In 2013 the Hubble Space Telescope spotted significant plumes of water spouting from the surface, which further suggests that bodies of water exist under the ice. If an ocean does indeed exist, it would be one of the most hospitable places in our Solar System for simple extraterrestrial life.

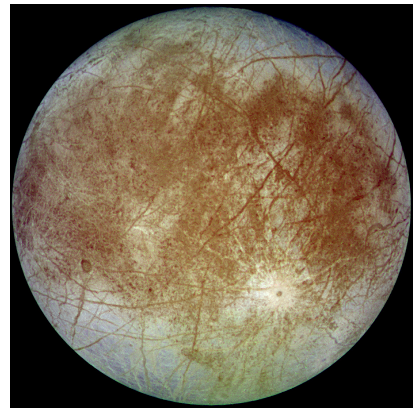

Figure 1: Europa imaged by Galileo Spacecraft

Project ELSA (Europa Lander for Science Acquisition) will provide a stepping stone for future missions exploring Europa by demonstrating the feasibility of collecting relevant data for 4 days from inside a relatively low cost, low mass, and low volume spherical landing probe. The 4 day timeframe accounts for more than one full orbit of Europa around Jupiter, which is approximately 3.5 days. The instrumental test suite shall provide data which is relevant to the currently uncertain conditions on the surface of Europa. Information such as temperature, pressure, magnetic field parameters, seismic activity, and surface features could prove helpful to scientists characterizing the surface. The ELSA team shall use a trade study to determine which two science instruments will be useful for future missions to Europa, while also keeping the probe within weight, size, and data generation requirements (10kg, 30cm sphere, and TBD data requirement respectively). The ELSA team will develop a data acquisition and data handling system which will collect and store a minimum of 4 days worth of data, from these sensors.

This project shall utilize hardware developed by previous student projects to create a probe which is capable of tabletop testing, and has flight grade avionics, or their equivalent. Ball Aerospace will provide the project team with an avionics board, communications hardware, the spherical housing system, and a CAD model of the existing probe and previous work. The ELSA team shall be responsible for creating functional communications, power, and data flow systems that will allow the data collected by the scientific instruments to be transmitted wirelessly to a ground station (developed by the team) set a TBD distance away over a 4 day period, at a maximum of 128 kbps, or be able to prove that the system is capable of doing so. The ELSA team will also provide a computer model of the probe structure which can withstand the harsh radiation environment that is expected on the surface of Europa. If Ball Aerospace is unable to provide an avionics board, the project team will be responsible for providing an alternative solution for the board and integrating it with the other system components. The ELSA team is expected to integrate the procured sensors with the avionics board and communications system, as well as provide a structural housing to fit all equipment within the spherical shell creating an autonomous system capable of collecting and transmitting data.

2 Previous Work

Project ELSA is a continuation and adaptation of two separate senior projects completed in previous years at the University of Colorado at Boulder. A CU mechanical engineering senior design project developed a novel approach to landing a small probe on the surface of another celestial body. Historically, the preferred methods for interplanetary landers have involved large, complicated, or expensive systems to protect the delicate hardware onboard. Small probes like those used in the CU project did not have the ability to have a controlled descent (such as a parachute[4]), vastly reducing the likelihood of survival upon impact. The team's design solution was to cover the spherical probe in foam panels, cushioning the impact significantly. Their concept was tested and verified in a trade study with 9 other options. By using foam panels, the probe impact velocity was reduced by approximately 50% proving that an impact could be survived from a fall at the required height.

Building on this idea, the student-lead TIRESIAS (2013-2014) team developed a fully integrated pod as a building block for the Binary Asteroid in-Situ Explorer (BASiX) mission[5]. The concept for the BASiX mission was to deploy multiple pods to the surface of an asteroid from an orbiter. Once on the surface, one probe carrying an explosive payload would be detonated while other probes measured the vibrational effect. TIRESIAS demonstrated that vibrational data could be collected and transmitted through their communications system with a standalone pod.

Although many aspects of ELSA mirror that of TIRESIAS, this project is novel in a few key ways. First and foremost, this project will choose and implement which scientific data is most useful to be taken on the surface of Europa. This decision will be derived in part from the findings of other missions. Voyager 1 and 2 detected volcanic activity on Io which supports the theory of tidal heating. Galileo detected frequent fluctuations in Europa's magnetic field which could be caused by a large subsurface ocean. Based on these findings, important scientific objectives include characterizing the composition of the ocean and icy crust, as well as the forces that shape them. Because of their similarities, multiple parts of the TIRESIAS project will be repurposed and integrated into the NeoPod design. The NeoPod will contain the same outer structure consisting of the aluminum sphere outer casing and impact foam core coating. The previously developed communications system will also be reused in the NeoPod design. However, much of the data collection and flow of information will be significantly different from previous projects. In the TIRESIAS project, avionics was handled using a simple arduino microcontroller. This year, Ball Aerospace intends to use a flight-ready avionics board, which is potentially capable of supporting the data transfer and data processing from scientific instruments through the communications system. In addition, a new power system must be designed to support 4 days of data collection. A new internal mounting structure must also be developed to support internal components. With the completion of this project, science data will be collected, processed, and transmitted from the probe, which is a critical step forward to eventually sending multiple probes to Europa.

3 Specific Objectives

In order to meet a higher level of success, all previous levels of success for a given section must be met. However, in the case of Avionics, the level 1 requirement is in place as a contingency in the event the flight grade avionics board supplied by Ball is not available. Consequently, Avionics levels 3 and 4 can be reached by first accomplishing level 1 or 2, with level 2 being the more preferred goal.

Criteria	Payload	Communication (Post Avionics)	Avionics	Power	Ground Station	Structure
Level 1	Identify relevant instrument suite (minimum of 2 instr.) with total TBD data rate Simulate data stream at instrument suite TBD data rate	Transmit and validate a known data packet of TBD size from avionics	COTS computer handles data input and sends to communications system in real-time	External power supplied to all sub-systems at TBD V and TBD A	Record and validate a known data packet of TBD size over wireless connection	Modify existing internal structure CAD design to integrate new hardware within 30 cm sphere Design external sphere to withstand TBD radiation dosage
Level 2	Acquire and verify instrument functionality (minimum of 2 instr.)	Transmits at average data rate of 128 kbps	Ball provided avionics board handles data input and sends to communications system in real-time	Regulated on-board power system at TBD V and TBD A within TBD tolerance	Sends commands over wireless connection	Manufacture internal structure to TBD (derived) tolerances
Level 3	Sends collected data from instrument to avionics at TBD data collection rate	Receives commands over wireless connection	Capability to store TBD amount of data for transmission at later time	4 day lifespan with TBD hour data collection and TBD hour transmission cycles	Records 128 kbps data stream and saves to file	Mount subsystem hardware to internal structure with maximum mass of 10 kg
Level 4	Verify instrument accuracy and calibration to TBD accuracy	Transmits across TBD distance (or estimated losses)	Transmits data upon command and ceases transmission independently		Automated commanding at TBD contact periods	Internal structure integration within 25 cm spherical shell

4 Functional Requirements and Mission Conops

The figures shown below aim to provide context and clarity on details of operation of the components developed in this project. The Concept of Operations (CONOPS) documents will provide context of this project as it relates to its larger mission, as well as show how the final product will be operated and tested. The Functional Block Diagram will show a top level view of interactions between the hardware components used in this project.

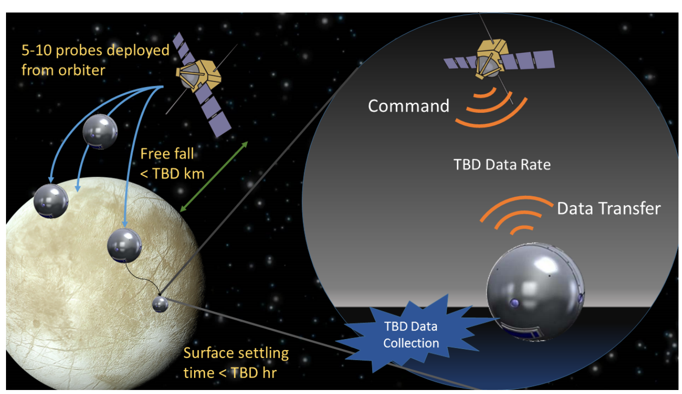

Figure 2: Europa Mission Background CONOPS

The Concept of Operations for project ELSA is derived from the need to test the transmission of data in an Earth environment that can be scaled to a Europa like environment. A model for the atmospheric and space losses incurred on Europa will be developed and scaled to a model of the losses on Earth. The NeoPod will then be tested under these scaled conditions.

The Figure 4 illustrates the plan for the system being developed by the project team. The avionics board will store data from the instrument suite until it receives a command from the ground station.

The data will then be sent to the communication system to be transmitted to the ground station. The avionics board, transceiver, antenna, as well as the external structure of the probe will be provided. All other components will either be purchased or designed if necessary. Additionally, the internal structure of the probe will be designed in order to mount the internal hardware. An important distinction that should be made is that the Avionics board will have no software provided by Ball. While the board itself is provided, the software needed for all command and data handling will need to be developed by the Project team.

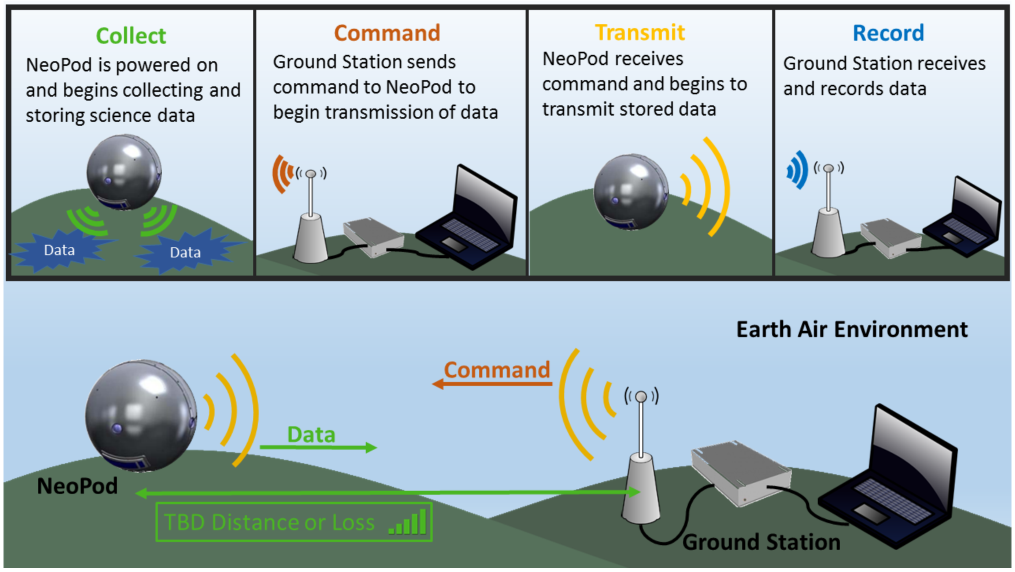

Figure 3: Team ELSA CONOPS

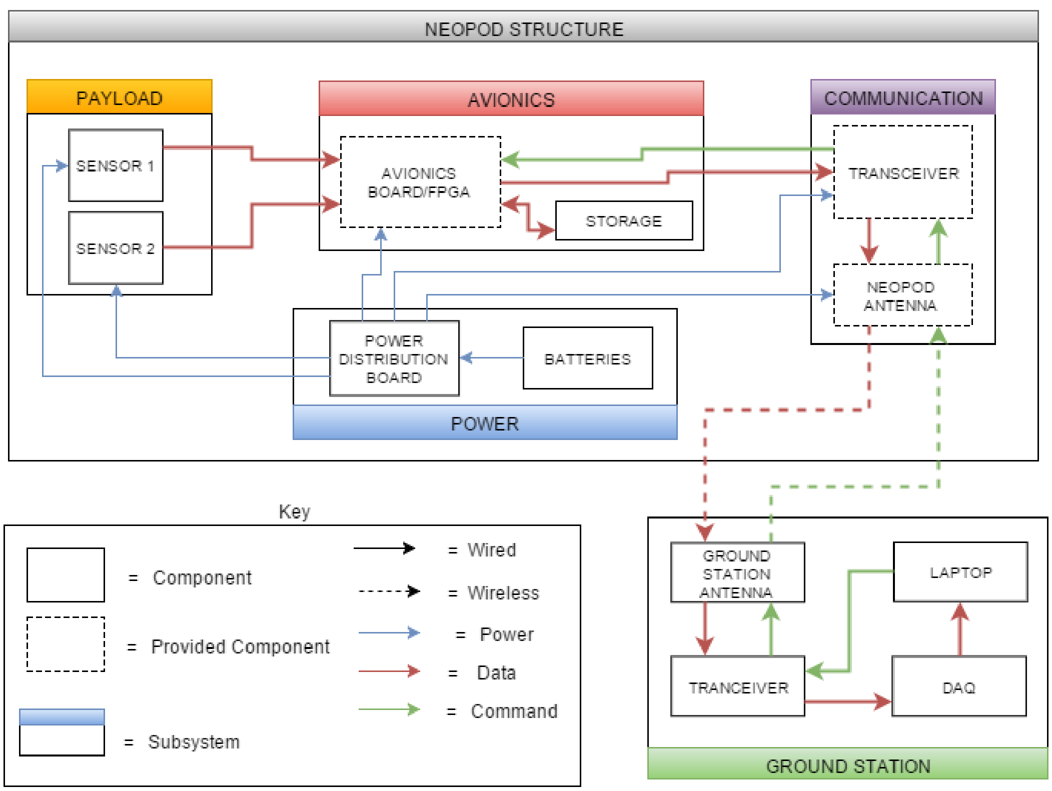

Figure 4: Functional Block Diagram

5 Critical Project Elements

Technical		
T1	Avionics FPGA Software	Critical for comm. system and payload command and data handling. No software provided. Must fully program FPGA. Extensive work required.
T2	Payload Mechanical Integration	Payload design must fit in 30 cm sphere along with all other hardware and interface with internal structure. Instruments may need to interface with external structure. High design and manufacturing precision necessary for stringent size and weight requirements.
T3	Avionics Hardware Integration	Avionics board must interface with internal structure, payload, power, and comm. system. Involves advanced electronics knowledge and will require extensive safety procedures to avoid hardware damage.
T4	Ground Station System	Must wirelessly command and receive data from NeoPod. Necessary for validation of all levels of success. Will need to gain knowledge of TNC, packet transmission, and communication protocols.
T5	Power System Integration	Must determine overall power dissipation and find batteries capable of meeting lifespan requirements. Must fit in 30 cm sphere along with all other hardware. Largest impact on meeting weight and size requirement.
T6	Power and Comm. Modeling	Must develop accurate model for power usage based on hardware specs and develop link budget for wireless communication system. Crucial for power system and data transmission validation . Extensive research required.
Logistic		
L1	Avionics Board Procurement	Supplied by Ball. Projected availability > 3 months. Critical to C&DH system. Must have COTS avionics contingency plan.
L2	Structural Hardware and Schematics Procurement	Supplied by Ball. Necessary for proper structural integration and size requirements. Includes SolidWorks models. Critical to beginning design process.
L3	Test System Environment and Setup	Test system will require long distances and extended durations. Long distance radio tests will require proper frequency and location approval. Crucial for scaling transmission to Europa-like conditions.
L4	Scientific Instrument Selection and Procurement	Instruments will not be provided. Must perform trade study and select appropriate sensors to satisfy science objectives. Comm. system limitations will influence instrument selection, while instrument selection will also influence comm. system design.
Financial		
F1	Payload Components	Hardware that satisfies the stringent size requirements will be more costly. Necessary for science acquisition.
F2	COTS Power System	Hardware must satisfy lifespan, mass and size requirements. Larger power capacity at reduced size will be more costly. Needed for all sub-system functionality.
F3	Ground Station Hardware	Wireless transmitters, receivers, and data acquisition system for ground station could be costly. Critical for comm. and payload verification.

6 Team Skills and Interests

Name	Skills/Insterests	CPE
D. Combs	Currently working for a communications company doing Drive-test post processing. Experience analyzing Electromagnetic Emissions from antenna systems. Experience in process automation. Leadership experience as high school baseball captain and varsity Assistant Coach. Co-founder of NPO. Microavionics Course.	T4, T6, L3, L4, F2
G. Frank	Spent the summer of 2015 writing testing procedure for Orion Capsule avionics. Gained knowledge of requirements, systems, and testing. Worked for Jeppesen the 2014 summer with the IT team, helping to manage and streamline work tracking system. Took Aerospace Software class. Eagle Scout.	T4, T5, T6, L3, L4, F3
S. Grandone	Currently working in software verification at Lockheed Martin. Taken upper division E&M classes. Double majoring in Astrophysics, with special interest in exploration of Galilean moons. Has contacts in Astrophysics department.	T1, T4, T6, L3, L4, F1
C. Hall	Two years working with procurement at University of Colorado Boulder. Certified in Systems Tool Kit (STK). Experience with Space Grant as the Ground Station Team Lead, specifically doing RF communications with ground based repeaters and orbiting cubesats.Licensed HAM radio operator. Experience with Lockheed Martin working with software requirement verification and testing.	T4, T6, L3, F1, F3

D. Johnson	Software and leadership background. Last one and a half years as Lockheed Martin software intern. Led freshman projects group. Certified in SolidWorks. Some experience with Altium circuit design tool. Licensed HAM radio operator. Project experience working at Space Grant.	T1, T2, T4, L3, T6, F3
T. Luke	Materials background, optimizing material choices and design parameters. Milling machine experience. Proficient in SolidWorks and Autodesk Inventor. Leadership experience with Gateway to Space class. Eagle Scout.	T4, T5, L3, L4, F1, F2
S. Mende	Current position at LASP developing operations software and tools. Experience with electronics hardware, as well as management skills, managing a Jeppesen software test lab. Some manufacturing experience as well (woodworking). Led freshman projects group.	T1, T3, T6, L1, L4, F2
D. Nowicki	Extensive experience developing SolidWorks drawings. Took Aerospace Machining course. Experience with CNC mills and other machining equipment. Electronics experience with Lockheed Martin internship this summer working on server racks. Eagle Scout. Microavionics Class.	T1, T2, T3, T5, L2
B. Stringer	Interned at biochemistry lab working with mass spectrometers and gas chromatographs. Aerospace Software class, working with C, and Bash code. Laser Cutting experience. Eagle Scout.	T2, T5, L4

7 Resources

CPE	Resources
	Technical
T1	Trudy Schwartz, Scott Palo
T2	Dan Scheeres[5] (BASIX P.I.), Matt Rhode, Scott Palo
T3	Trudy Schwartz, Bobby Hodgkinson
T4	Brian Sanders
T5	Scott Palo, Trudy Schwartz
T6	Trudy Schwartz, Xinzhao Chu, Zoltan Sternovsky
	Logistical
L1	Joe Hackel (Ball Contact)
L2	Joe Hackel (Ball Contact)
L3	Lee Ciereszko (First RF)
L4	Dan Scheeres, Fran Bagenal, Sascha Kempf[6]
	Financial
F1	Joan Wiesman, PAB, Joe Hackel
F2	Joan Wiesman, PAB, Joe Hackel
F3	Joan Wiesman, ITLL, PAB, Joe Hackel

8 References

[1] "Europa: Facts About Jupiter's Icy Moon and Its Ocean." Weblog post. Ed. Space.com. N.p., 9 Feb. 2015. Web. 12 Sept. 2015. <http://www.space.com/15498-europa-sdcmp.html.>.

[2] Greenberg, Richard J., *Europa–the Ocean Moon: Search for an Alien Biosphere.* Berlin: Springer, 2005. Print.

[3] Pappalardo, Robert T., William B. McKinnon, and K. Khurana, *Europa.* Tucson: U of Arizona, 2009. Print.

[4] Frequently Asked Questions - Huygens Probe. (n.d.). Retrieved September 14, 2015, from http://saturn.jpl.nasa.gov/faq/FAQHuygens/

[5] Anderson, Robert C., Daniel Scheeres, and Steven Chesley. "Binary Asteroid In-situ Explorer Mission (BASiX): A Mission Concept to Explore a Binary Near Earth Asteroid System." *45th Lunar and Planetary Science Conference* (2014): n. pag. Web, 01 Sept 2015.

[6] "NASA's Europa Mission Begins with Selection of Science Instruments." NASA. Ed. Karen Northon. NASA, 26 May 2015. Web. 12 Sept. 2015. <https://www.nasa.gov/press-release/nasa-s-europa-mission-begins-with-selection-of-science-instruments/>.