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1. Abstract

Team IA-Nauts has created a tool designed to obtain a top layer sample of regolith from an asteroid. The tool can capture particles up to 1/8\textsuperscript{th} of an inch in diameter, is capable of one handed operation, and easily fits within an 8in x 8in x 18in volume. As the tool is based off the successful Contact Soil Sampling Device (CSSD) used in the Apollo missions, it has been christened the Improved Surface Sampling Device (ISSD).

The ISSD is constructed of aluminum-6061. It builds upon the CSSD by adding improved ergonomics and the ability to take two samples while minimizing the "organics and other materials" [Allton] that were present in the CSSD. The device is designed primarily for use with medium sized asteroids with a regolith surface layer. The ISSD satisfies all of the constraints and criteria provided by NASA.

2. Background

Jared Hall (our team lead) approached each of us with the idea of forming a team and participating in this challenge. We started by looking at previous surface sampling devices and the pros and cons each presented, we then progressed to what specifically we wanted to achieve with our ISSD. From the start our main goal was to keep it simple, minimizing malfunction possibilities. As we progressed we looked at tools that achieved what we had in mind for an individual component. Comparing the sample compartment to capturing the top layer of sand in a sandbox, we started the ideation process by looking at basic shovels and sand scoops. From there we progressed to how the door should close or rather how to keep the sample from moving. A trigger system with pneumatic power was briefly considered; and hastily discarded because it created a complex system for a simple task. When considering how the door would close one idea was that similar to a system of rock climbing cams; however, this yielded a device with several potential pinch points. We then started designing a tool with a bucket-like sample compartment and a simple handle that when released would slide closed over the sample compartment; entrapping a surface sample with up to 1/8 inch particles. We kept with the simple tool goal when it came to how to obtain multiple samples; just put another sample compartment and handle on the opposite side. The goal of keeping our tool simple was present throughout our design process, and we were able to design the following ISSD.
3. Hardware

3.1 Description of Design
Our tool design was modeled around the compartment that would secure the surface sample. We determined the simpler our tool would be the reduced risk to the operator. We designed a spring loaded, device that has a natural rest position of closed. Thus the only necessary operation would be to open and place on desired surface, release lever and device will automatically return to closed position. Our ISSD is made entirely manufactured from ABS plastic; however, an aluminum copy could be considered for practical use to reduce necessity of drilling holes, and overall tool structural integrity.

3.2 Mechanics of Design
The only mechanical component of our ISSD is a spring attachment that is compressed when the trigger is pulled, and returns to its equilibrium position when released. There are no mechanical operations other than the spring/door system. Our ISSD has no power system other than that provided by the astronaut hand operation.

3.3 Requirements

3.3.1 Functional
Our tool must be easily workable with EVA Gloves, with marked pinch points. All potential hazards to operator are addressed in the Hazard Analysis contained in Section 6.2. It will work both underwater and on dry land, with minimal modifications.

3.3.2 Technical
The ISSD has a tether loop. There are no holes or openings in which fingers could be caught, other than the opening to the sample compartment. The sample compartment opening is marked with high contrast colors, and divers will be instructed to keep fingers away from opening while operating the tool. The tool can be operated in a .5 to 3.5 ppm chlorine environment, and is capable of withstanding
hydrostatic pressure at depths in excess of 40 feet. The ISSD can operate in an ambient temperature range of +82 F to +88 F. It is composed mainly of Aluminum 60-61 and contains only materials approved for NBL use when entering the NBL. The dry-land version contains NBL approved materials with exception to velvet cloth within the sample compartment. Sharp edges, corners, and protrusions have been filed down in order to protect the handler, and the tool contains no parts which pose risk to the EVA suit. Mate/de-mate alignment marks and operation indicators have been added as needed. Pinch points, such as the opening to the sample compartment, have been marked with high contrast colors. The hardware can sustain loads likely to be encountered in normal operation.

### 3.3.3 Challenge

The ISSD has a tether loop. There are no holes or openings in which fingers could be caught, other than the opening to the sample compartment. The sample compartment opening is marked with high contrast colors, and divers will be instructed to keep fingers away from opening while operating the tool. The tool can be operated in a .5 to 3.5 ppm chlorine environment, and is capable of withstanding hydrostatic pressure at depths in excess of 40 feet. The ISSD can operate in an ambient temperature range of +82 F to +88 F. It is composed mainly of Aluminum-6061, and contains only materials approved for NBL use when entering the NBL. The dry-land version contains NBL approved materials with exception to velvet cloth within the sample compartment. Sharp edges, corners, and protrusions have been filed down in order to protect the handler, and the tool contains no parts which pose risk to the EVA suit. Mate/de-mate alignment marks and operation indicators have been added as needed. Pinch points, such as the opening to the sample compartment, have been marked with high contrast colors. The hardware can sustain loads likely to be encountered in normal operation.
4 Analysis and Testing

4.1 Analysis

4.1.1 Engineering Analysis

Main Structure:
Main Handle: The main handle length was designed so that an EVA glove could grip with the first two fingers on the trigger.
Tether Point: The tether point was strategically placed on the side bar of the main support so that entanglement would not be an issue when rotating the device for multiple samples.

Trigger Support:
The trigger support was designed so two springs could be compressed in each hole. We decided to connect the support holes with a bar in the center to eliminate a potential pinch point.
Main Support Bar: The main support bar length was created from the compression length of the door added to an ergonomic benefit of squeezing two fingers.

Sample Compartment:
The sample compartment was designed to collect and store dust sized to 1/8th inch diameter particulate. It is made of aluminum alloy 6061, and is CNC machined.

Main compartment:
Stores regolith. It is 3.8”x0.675”x0.3”. A piece of velvet is adhered to the bottom of the compartment to trap the topmost layer of regolith and to apply positive pressure to the sample, maintaining particle orientation.

Door supports:
Door support 1 serves as both a support for the door and as a wall of the main compartment. The top of door support 1 is polished to provide a low friction sliding surface for the door. Door support 2 acts as a support for the door while in the open position. The top is polished to provide a low friction sliding surface for the door. Door support 2 has a slot in it for the door support, allowing the sample compartment to sit higher than the top of the main structure. This minimizes contact between the operator's hand and the asteroid surface.

Connecting hole:
The bottom of the sample compartment has a four sided connecting hole. It is the female end of the connecting structure between the main structure and the sample compartment. The four sided connector was decided on for ease of manufacturing. The sample compartment will be TIG welded to the main structure. The connecting structure is in place to keep the main structure and the sample compartment aligned while welding.

Door/ Trigger System:
The length of the trigger was measured using the distance of the trigger support hole, in combination to the necessary. The door depth was generated by adding the length of the track in the back facing sample compartment to the width of the sample compartment plus an additional 0.05 inches of overhang. The distance that the support and trigger are dropped from the height of the door was given by maintain a safe distance for a hand to easily squeeze the trigger but yet minimizing the surface area of the tool that would be in contact with the regolith.

4.1.1 Structural Analysis

The ISSD’s structural integrity was tested using finite element analysis software. The tool was evaluated at a hydrostatic pressure of 17.341 psi (the pressure at a depth of 40 feet). The Von Mises stress test results showed that the tool was well below its elastic limit, and should have no problems operating within the NBL environment.

Tests were also done to simulate forces applied during normal operations. The tool performed as expected, and should have no problems during normal use. A spring pressure of 15 lbs, the calculated spring pressure when the door is completely closed, was used for this.

4.1.1 Analysis Summary

The tool should perform well in the NBL environment. In a vacuum environment, various coatings would need to be applied to the aluminum to mitigate temperature and cold welding concerns. The team does not have any experience with these coatings, but this shouldn’t pose any problems in a chlorinated water environment. The team also lacks experience in drafting engineering and structural analyses, and most of what we knew was self taught or found using tutorial videos. Finite element analysis software was used for structural analysis because of a lack of experience with structural analysis reports. Von mises stress tests were recommended by internet sources, but other stress tests may provide more insight. Since the tool is made of aluminum and contains no powered or hydraulic components (and only one moving part), it shouldn’t encounter any forces that can damage it.

4.2 Testing

4.2.1 Test Description

We originally developed a foam-core prototype of our device to test its ergonomics and functionality. We tested the foam-core prototype while
wearing ski gloves to simulate an astronaut wearing a pressurized glove as closely as possible. We tested that we were able to fully open the door while wearing the gloves and how much grip we had on the device. After testing the foam-core prototype we made some adjustments to our design and began to 3-D print components of our device. Once we had the main body component, a sample compartment, and a door attachment printed we tested our device again. We tested ergonomics and usability again and decide that it its ergonomics were sufficient. We also tested the structural integrity of the 3-D printed prototype and it was clear that it was not structurally sufficient to use in the NBL. We also made two changes to the sample compartment and the door to better trap particles and keep particle orientation. We decided our best option was to put a Teflon coating on the back wall of the sample compartment. We took our 3-D printed prototype outside and attempted to collect a sample of dirt using approximately the amount of force that would be applied to the device while being officially tested, and it broke. We decided that our final design will be milled by a CNC machine and be made out of aluminum alloy 6061.

4.2.1 Unexpected Results

We did not expect the parts to be so small when we made the foam-core prototype. The ergonomics were also off, as the astronaut would not have enough room to wrap his fingers around the trigger of the door. We made adjustments in our CAD model to fix these issues.

The 3-D printed model was less structurally sound than expected and was not as precise as we had originally anticipated. We made a few structural changes to the device and made two changes to better maintain particle orientation and prevent cross contamination between samples.

4.2.1 Test Summary

The original prototype we created was made out of foam core; its main function was to test ergonomic practicalities. We quickly discovered that the allowable room for two fingers from an EVA glove to easily squeeze the trigger was too small. We needed to expand the total height of our model. This test also forced us to question the ability of the door to seal in the sample collected. We quickly decided that we needed to add a track to the back to allow the door to continue past the distance of the collection pod instead of coming to a flush surface; modifying the model in this way allowed us to ensure that no tiny particles would be allowed to escape. The next prototype was made from 3D printed plastic. The first thing we noticed was that the 3D printed plastic would no longer be
a feasible option to use in space. There was too much cracking involved with the combination of the three components (main support, door/trigger system, and sample compartment) and the plastic was not providing the necessary stability. With this prototype we noticed that the back face of the sample compartment would need a sealant as well. We agreed that our best option would be a Teflon coating along the top face of the back support. Still using this prototype we ventured outside and attempted to scoop up some surface dirt. It was a unanimous decision that the final version would be made of aluminum. The outside test proved that the 3D printing was not going to be a viable option with respect to the force that would be needed to be applied to close the door. The final version will be an aluminum structure with the sample compartment being tig-welded to the main support. There will be a Teflon tape applied to the back face to completely seal in the sample.

4.3 Pictures

4.3.1 Analysis

Below: Spring pressure of 15 lbs when door closed, analyzed in finite analysis software.
Below: Pressure on system at a water depth of 40ft.

4.3.2 Testing

The Foam-core prototype
3D Printed prototypes

Left: The main support and trigger system components.

Bottom: Sample compartment and door system.

Mockup of what Aluminum-6061 final design will look like.
4.3.3 Associated Data

We quickly discovered that the trigger/door support connection needed to be thicker.

5. Operations Plan

5.1. Hardware Configuration

- **In Pool**
  
  When testing inside the pool, the device will be fitted with sample compartments optimized for underwater use. The sample compartments will have drain holes, and the velvet cloth will be removed.

- **Out of Pool**
When testing on dry land, the device will be fitted with sample compartments optimized for out of water sample collection. The sample compartments will not have drain holes, and will contain velvet cloth.

- Check-Out, Diver Training, and Inspection
  For Check-Out, Diver Training, and Inspection, the device will be fitted with both underwater and out of water sample compartments.

### 5.2 Test Objectives

We hope to accomplish the following through testing:

1. Confirm that the device is ergonomic and comfortable for an astronaut in a pressurized EVA suit to use
2. Confirm that an astronaut is able to easily collect two samples with the device
3. Confirm that the device successfully collects particles up to 1/8 in diameter
4. Confirm that the device successfully maintains orientation of the sample
5. Confirm that the device prevents cross-contamination between samples
6. Confirm that the device meets all of NASA’s criteria

### 5.3 Test Plan

We will run two different tests with our Improved Surface sampling Device. One test will be run in the Neutral Buoyancy Lab Pool and will be testing the ergonomics and usability of the device. This test will tell us how easy our device is to operate and if it’s reasonable to use in zero gravity. The second test will be conducted outside of the NBL Pool and will test the device’s ability to gather maximum sized particles and maintain the orientation of the particles after sampling.

### 5.4 Test Procedure

**Test 1:** Underwater Sample

*Procedure:* For this test, the ISSD will be submerged in the NBL pool and operated with one hand by a test subject in a pressurized EVA suit. The test subject shall perform any necessary preparation with both gloved hands, but will be limited to one hand during the testing operation. Two samples of simulant regolith will be collected by the astronaut test-subject while under water. This
tests the ergonomics and usability of the device and its ability to collect two samples. We will use more than one test subject if able.

**Goals:** The test subject will be able to easily operate the device and take both samples without having to use more than one hand.

**Expected Results:** We expect it will take three attempts at operating the device for the test subject to become comfortable with using the device. Once the test subject is comfortable with the operation of the ISSD, they will be able to comfortably collect both samples only using one hand.

**Data Collection:** We will observe the test subject performing the operations and then ask them (in real time and after the subject exits the water) a series of questions related to the operation of the device before and after the test.

**Data Analysis:** We will make an evaluation of the functionality of the device based on the test subject’s opinion as well as our observations from watching the device in use.

**Conclusion:** After analyzing the data we will suggest design improvements, if necessary, and make changes to our device to meet NASA criteria.

**Test 2: Dry Sample**

**Procedure:** The device shall take two samples of simulated asteroid material. The operator for this test does not need to be in full astronaut attire, but will be wearing gloves (pressurized if at all possible). After the samples are taken the device will be shaken to test its ability to maintain orientation. This will test the device’s ability to gather particles up to 0.125in, and its ability to maintain the orientation of particulate in each sample.

**Goals:** The ISSD shall successfully gather maximum sized particles and maintain the orientation of the particles after sampling.

**Expected Results:** We expect that the ISSD will be able to easily collect the maximum sized particles on the first try.

**Data Collection:** We will be able to observe whether or not our device collects the largest sized particles. We will also be able to observe if the device maintains the particle’s orientation. In order to accurately record this we will have a set of benchmarks the sample has to meet in regards to its orientation and the difference in the sample right after collection, and after shaking the
device. These benchmarks will be set by asking NASA engineers/scientists how to properly assess if the orientation of particles has been maintained.

**Data Analysis:** By analyzing how well the device maintains orientation of the particles, we will be able to assess if there is too much, or not enough pressure put on the sample while being stored inside the device.

**Conclusion:** After analyzing the data we will suggest design improvements, if necessary, and make changes to our device to meet NASA criteria.

6. Hazard Analysis
6.1 Hazard Analysis Table

<table>
<thead>
<tr>
<th>Hazard</th>
<th>Cause / Scenario</th>
<th>Consequence / Effect</th>
<th>Controls and Verification</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sharp Corners</td>
<td>Operator touches sharp corner</td>
<td>Cause tear in EVA Gloves or harm to operator</td>
<td>All corners are filed down reducing risk.</td>
<td>Controls in Place</td>
</tr>
</tbody>
</table>
| Pinch Points    | Finger or equipment caught within opening to sample compartment | Pinched/damaged finger or equipment | 1) Diver training, keep hands away from pinch points.  
2) All potential pinch points were 3D printed in high contrasting colors | Controls in Place |

6.2 Hazard & Risk Analysis
The main hazard in our design would be sharp corners and pinch points. We have adequately filed down all sharp edges. The potential pinch points are a maximum of 0.2 inches deep and in high contrasting colors; in addition with proper diver training there is no reason a hand or anything else should be near a pinch point during operation. Although the tool does present hazards to a diver we have recognized and put in place controls to reduce risk.

6.3 Hazard & Risk Mitigation
Controls have been established to mitigate risks to a diver operating our ISSD. The first hazard associated with our tool was sharp corners. Because
our tool will be solely manufactured using Aluminum-6061 the corners were not sharp in a substantial manner; however we file them down so now all corners will be round and pose no danger to a diver. We have eliminated the most substantial hazard associated with our tool. The second hazard we came across with our design were potential pinch points at the doors to the sample compartments. The compartments are only 0.2 inches deep so no substantial body part or tool could potentially be damaged.

7. Forward Plan

7.1 What is next for IA-Nauts?

We have an ABS plastic 3D printed prototype fully made. We have done several tests with the plastic model, and have incorporated the lessons learned into the final model shown in the TEDP. We will now move into manufacturing the aluminum model, but will keep the design to what is shown in the TEDP. We will create two models, one for water testing and one for land testing. Funding for manufacturing and travel is next on the agenda, and we plan to continue outreach activities.

7.1.1 Schedule

Left: A sample design of the body using the honeycomb style 3D printing. Right: The first 3 components completed 3D printing and awaiting assembly

6/22/15 Submit TEDP
6/22/15 Submit Project Status Report #2
6/24/15 NEEMO
6/24/15 Finish 3D printing components
6/27/15 Complete Pressure Test
6/30/15 Finalize 3D printing style

July any additional changes that may need to be adapted would take place during this month.

8/1/15 Drive down to Houston, TX
8/3/15-8/7/15 Test tool at Johnson Space Center
8/8/15 Return drive
8/28/15 Submit Micro-g NExT Final Report & Outreach Log

7.2 Hardware Transportation

We are driving down to JSC and thus hardware transportation will not be an issue. We will be taking our ISSD down with us in the car.

7.3 Accompanying Tools

- Dremel
- Safety glasses
- Hearing protection
- Exacto knife
- Latex gloves for adhesive application
- NBL approved adhesive