MRD-105 (2.1.1) Return ≥15 g of bulk material for analysis in support of mission science objectives

MRD-106 (2.1.2) Return ≥45 g of bulk material to support NASA objectives

Overview

TAGSAM has proven its ability to ingest > 150 g of material under a variety of conditions. TAGSAM can ingest material 2 cm in diameter, and even material with long axes exceeding 2 cm. Collection has been demonstrated for a wide range of particle sizes, shapes, and densities. Satisfactory collection efficiency has also been demonstrated in the face of 5 cm stone obstacles. Testing in low gravity (with reduced atmospheric pressure) showed an improvement in collection efficiency over that observed in the laboratory.

Introduction

The basics of the TAGSAM design, using pressurized gas to mobilize regolith into a sample collection volume, started as an entry to an LM-internal competition for sampling methods

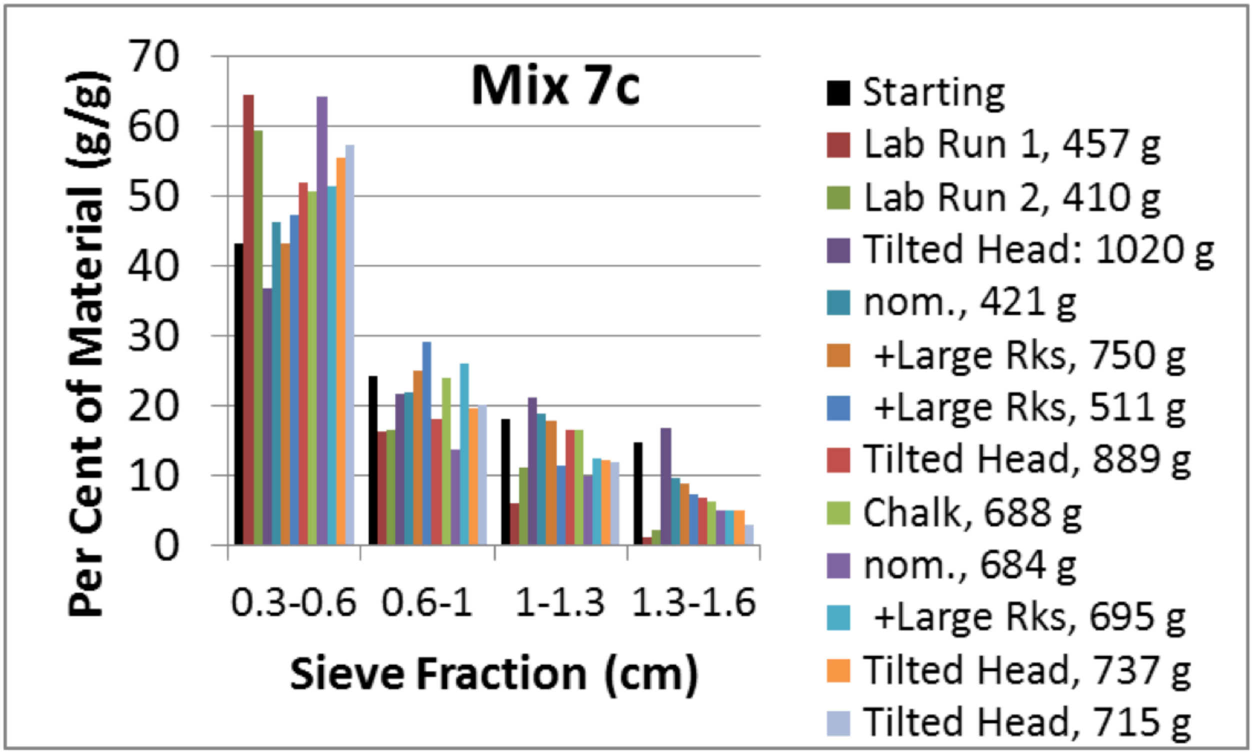
Prior to selection of OSIRIS-REx as the NF3 mission, LM IRAD activities advanced TAGSAM development from 2002 – 2011, including:

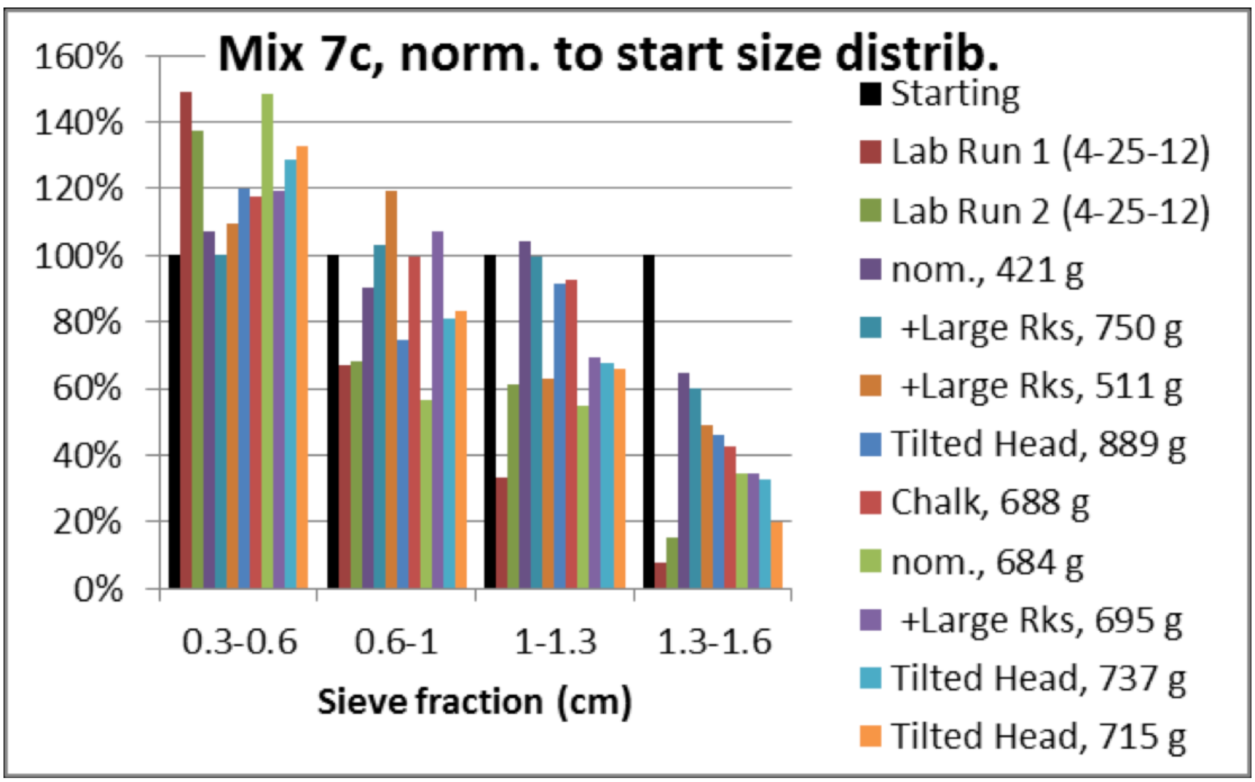
- Over 100 ground tests
- Two reduced gravity campaigns before selection
- 13 different material types as well as combinations of materials and different size-frequency distributions

Phase B Testing

- Ground tests (~70) focused on balancing TAGSAM collection optimization with updates of spacecraft capability
- Two additional reduced gravity campaigns that evaluated performance against larger particle sizes (which are immobile in 1g), orifice size, and contact time

The following two Figures demonstrate collection results for ground-based and reduced-gravity testing





Collection Performance with Obstacles

Some testing has evaluated TAGSAM performance in the face of obstacles

Photo is from an October 2012 reduced gravity flight

5 multi-cm rocks placed in TAGSAM contact area

Test collected 325.4 g, photo is collected material Initial contact slightly presses large rocks into the regolith. Gas firing excavates smaller material at depth, and larger rocks are pushed further down, allowing TAGSAM access to more of the bulk regolith.

Simulants Used in Phase B

Extensive testing demonstrated that TAGSAM collects well with fine-grained materials (e.g. sand, lunar simulant, plastic beads). Detailed analysis of high-resolution images from asteroid Itokawa, especially in the "smooth" Muses-C region (where the Hayabusa spacecraft collected its sample) suggests fined-grained material is not abundant, and may even be absent. Because collection of fine-grained material is not in doubt, but because this material may not be present, regolith simulant testing has focused on coarse-grained material. Using the size-frequency distribution (SFD) observed at Itokawa, and extrapolating to slightly smaller sizes than confidently resolved in the images, this regolith SFD named "7c". Use of two different materials, basalt and a clay mixture specifically engineered for similarity to a carbonaceous meteorite (Tagish Lake) for testing collection performance against size-frequency distribution and inertia. See table below for grain densities and bulk densities. Note these are representative values, and there is variability between grains and the bulk density collected with each test fire.

Material	Grain Density [g/cm3]	Bulk Density [g/cm3]
Basalt regolith simulant	3.0	1.5
Tagish Lake simulant	1.6	1.0

Ground Testing Overview

Because previous testing has illustrated collection efficiency trends associated with different types of regolith, Phase B testing has emphasized refining the TAGSAM design, and its performance against different encounter conditions

Design Tests

Filter

The “wall” of TAGSAM sample volume consists of two layers:

(1) fine-mesh screen

(2) perimeter support brace

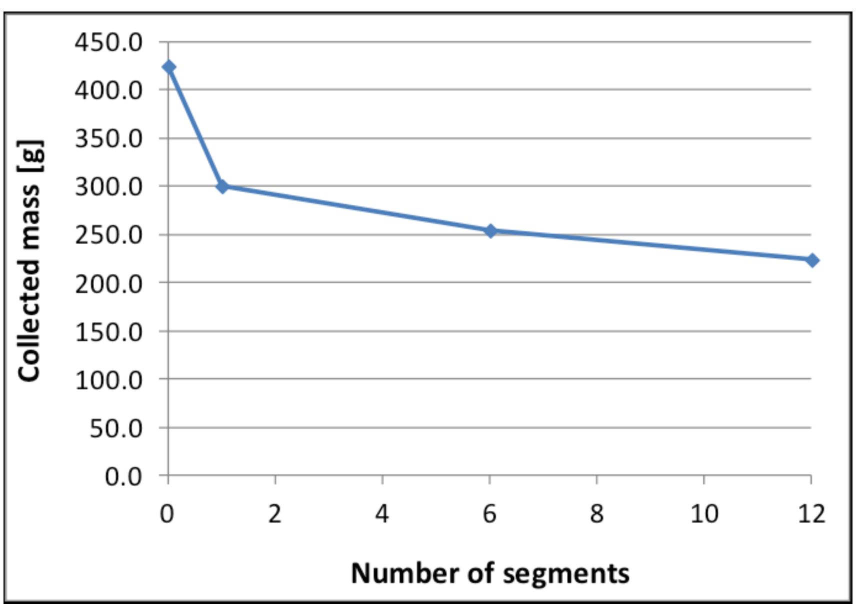
Hypothesized that increasing the open area in (2) enables more gas flow

Pre-Phase B design typically collected 300-350 g of basalt 7c

Preserving the configuration, changing only the perimeter support brace, results in collection of ~400 g

Conclusion: utilize revised design

Check-valve (mylar flap) for sample volume



Mylar “flap” acts as a check valve for sample material: allows entrance into collection volume, but prevents escape

Hypothesized that segmenting flap would enabled “optimized local flow” of gas and regolith, improving collection

Plot demonstrates collection decreases with increasing flap segments

Conclusion: maintain single-flap design

Gas volume

Regolith mobilization a function of gas pressure and gas volume

Hypothesis: increased high-pressure gas volume will improve sample collection

Doubling the gas volume improved sample collection of basalt 7c to an average of ~600 g

However, the contact time (> 5 sec) necessary to realize the increased collection is incompatible with modeling of contact dynamics (contact time < 3 sec)

Conclusion: maintain single-bottle design

Orifice size

Gas velocity and mass flow rate of gas set by orifice diameter of volume holding high-pressure gas: larger orifice leads to higher exit velocity, higher mass flow rate, and higher peak pressure

Hypothesis: increasing orifice size will improve sample collection

This was confirmed during Phase A testing

However, increasing velocity and mass flow rates leads to an increase in “jet force” of TAGSAM head, increasing dynamics of TAGSAM at the end of the sample arm

Status: Ongoing testing and analysis will determine the flight orifice size

Encounter Conditions

Tilt

Possible that a rock will prevent the TAGSAM head from achieving full contact and “seal” against asteroid surface

Test tilt of the head relative to the plane of the regolith surface

Collection exceeds requirement for tilts less than ~ 10 deg in ambient conditions; collection improves in reduced gravity

Contact Time

Preliminary analysis indicates collection not sensitive to contact times between 2-5 sec in ambient conditions, because most of the collection occurs in the first < 2 sec (and likely faster). However, collection in reduced gravity conditions is more sensitive to contact time.

Reduced-gravity Tests

May 2012 Reduced Gravity Flights

This reduced gravity campaign conducted as part of the FAST program

Nominal reduced gravity parabolas have the following requirements:

- 0.0 ± 0.05 g for 17 sec
- 0.0 ± 0.02 g for 10 sec

Negative-g accelerates material off chamber floor; coupled with lateral accelerations the material flows during test

Tests verify that reduced gravity enhances collection

Flight	Chamber	Regolith	Test Condition	Collected Mass [g]
1	100	7c	nominal	420.9
1	200	7c	nominal	683.5
1	300	7d	nominal	457.6
1	400	7e	nominal	412.9
1	500	7c	Head at fixed tilt	715.3
2	100	7c	large rocks on surface	511
2	200	7c	with chalk	688.3
2	300	7d	no fire	0.9
2	400	7e	nominal	393.7
2	500	7c	Head at fixed tilt	889.1
3	100	7c	large rocks on surface	695.1
3	200	single size	1.59 cm to 1.91 cm	104.5
3	300	7d	nominal	618.4
3	400	7f	nominal	458.9
3	500	7c	nominal	736.7
4	100	7c	nominal	750.1
4	200	single size	1.59 cm to 1.91 cm	147
4	300	7d	nominal	396.8
4	400	7f	nominal	333.1
4	500	7c	nominal	1020.4

October 2012 Reduced Gravity Flights

Test Objectives

Maintain positive-g throughout the entire flight

Evaluate collection with 5 cm gap

Evaluate collection performance for different orifice sizes

Evaluate collection performance for different contact times

Observations / Results

Beds stable throughout all parabolas

Some compliance of regolith bed at TAGSAM head contact

For longer contact times, head penetrates somewhat into regolith as bed is excavated

As expected, smaller orifice size and shorter contact time leads to less collection

5 cm gap tests indicate that collection under this condition is much more efficient in reduced gravity than in 1 g

Flight	Chamber	Regolith	Planned Contact Time	Collected Mass [g]
1	100	7c	3 sec	1277 g
	200	Tag Lake (TL)	3 sec	578 g
	300	7c	3 sec	1173 g
	400	7c	3 sec	709 g
	500	7c w/5cm rock	3 sec	327 g
2	100	7c	1 sec	870.0 g
	200	TL	1 sec	760.8 g
	300	7c	3 sec	183. 0 g
	400	7c	3 sec	224.8 g
	500	7c w/5cm rock	1 sec	177.8 g
3	100	7c	3 sec	1174.7 g
	200	TL	3 sec	489.5 g
	300	7c	1 sec	116.3
	400	7c	1 sec	221.5
	500	7c w/5cm rock	3 sec	447 g

4	100	7c	2 sec	308.9 g
	200	TL w/5cm rock	3 sec	510.4 g
	300	7c	2 sec	76.69 g
	400	7c	1 sec	603.02 g
	500	7c w/5cm rock**	1 sec	408.84 g
5	100	7c	1 sec	325.4 g
	200	TL	1 sec	383.3 g
	300	7e*	3 sec	1089.3 g
	400	7d + rocks	3 sec	768.0 g
	500	7c w/5cm rock**	1 sec	277.73 g

Summary Of Tests To Date

To date, TAGSAM has systematically tested the following regolith and environmental variables as part of its scientific investigations into collection efficiency:

- Absolute grain size
- Various size mixtures (different SFDs)
- Grain density
- Grain shape
- Inclusion of cobbles on surface
- Ambient pressure
- Gravitational acceleration
- Regolith volume (to test boundary effects)

TAGSAM head collects > 150 g for a broad range of regolith types and collection conditions

- Collection improves as grain size decreases
- Collection improves in vacuum relative to ambient pressure
- Collection improves in reduced gravity relative to 1 g
- Longer contact times lead to increased collection
- Still exploring the lower-limit to contact time