ExoMars Airbag Piercing Tests with a Cutting Mole

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Fig. 1: ExoMars lander

1. ABSTRACT

The ExoMars mission will include on the lander platform the HP3 experiment – an Instrumented Mole System (IMS) with a soil penetrating mole trailing a soil measurement compartment. Nominally, a deployment device or robotic arm will bring the mole on the soil outside the deflated airbags. To avoid adding such devices, the mole should pierce the airbags under itself. The airbag is made of 4 Kevlar layers (2 abrasive and 2 bladders). A double fold of the airbag (a worst case) would represent a pile of 12 layers.

An exploratory study has examined the possibility of piercing airbag cloths by adding sharp cutting blades on the tip of a penetrating mole. Representative layers were laid over a Mars soil simulant. Initial tests used, as simplified mole model, a cutting tip, hammer-driven, and had moderate to poor results. Final tests used the IMS - the prototype of the HP3 Mole - and were fully successful: the 12 layers were pierced with 3000 strokes, within 3 hours. This better behaviour is attributed to the friction springs on the IMS 'box': this device assists the first egress of the Mole, preventing tip rebounds and maintaining the tip on a same spot after each shock. The feasibility of this alternative solution is demonstrated.

2. TEST OBJECTIVES

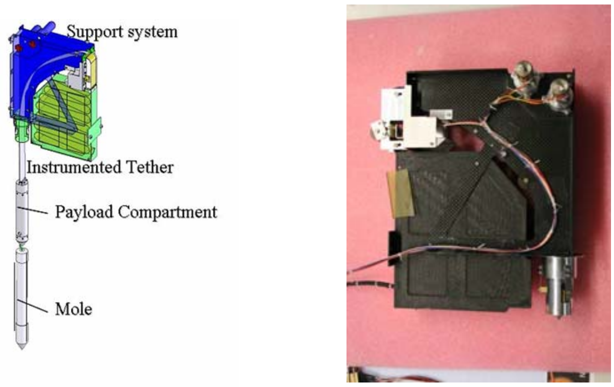

Fig. 2: IMS Mole with payload compartment and support system

The focus of the presented study is the piercing of airbag cloths by the sharp tip mounted on the penetrating instrumented mole (IMS). A sharp test tip has been developed for the mole to demonstrate the feasibility to cut the deflated airbags.

The tests were performed in three sections:

- ***needle tests:*** To perform a better penetrating action into the airbag the use of a needle can be considered. For these studies different shapes and diameters of needles have been tested.
- ***pre-tests:*** The focus of these pre-tests was to evaluate the general possibility to pierce airbag cloths with a sharp tip. The pre-test setup fulfilled the same requirements as the mole tests. Instead of the mole a drop tower was used which provided the items:
    - Reproducibility of the hammering strokes,
    - Adjustment of the strokes respective to the hammering energy of the mole.
- ***tests in a realistic environment with IMS:*** with original airbag cloths, Mars model soil and IMS. The tip was mounted on the nose of the mole. These are the most realistic and significant tests for a planetary application.

3. EXPERIMENTAL SETUP

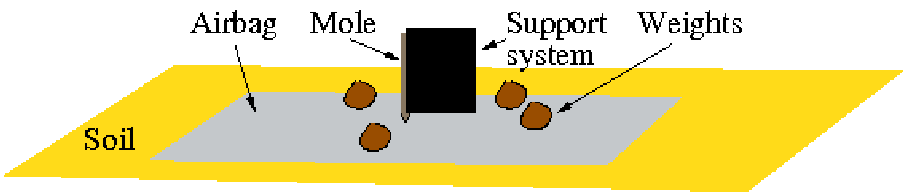

Fig. 4: Experimental setup for mole piercing tests

The test setup can be summarized as following:

- mole with a sharp tip
- cloths representing the deflated landing airbags
- Mars soil simulant
- weights representing the Mars Lander

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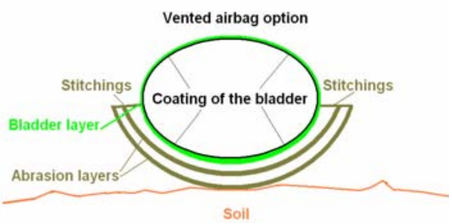

Fig. 3: Configuration of landing airbag

Table 1: Airbag characteristics

Airbag	Bladder	Vectran fabric 280 dtex plain weave (silicone coated)
	Abrasion layer	Vectran fabric 220 dtex rip-stop

Fig. 5: Sharp tip

Table 2: Tip and soil simulant characteristics

Tip	Length of single blade	36 mm
	Diameter of tip	26 mm
	Tip angle	60 °
Soil	Material	Olivine
	Grain size	< 30 µm
	Bulk Density	1.2 g/cm3

4. PRE-TESTS

Fig. 6: Pre-test setup with ‘drop tower’, schematically (left) and actual (right)

In the drop tower a ram falls on the plunger with the mounted tip, which will penetrate the airbag cloths. The drop tower is positioned above a chamber filled with the Mars model soil and the airbag cloths lying on the soil surface. The stroke energy of 0.16 J and a drop weight of 246 g results in a drop height of about 6.5 cm. The ram was lifted by hand, then released. Note that the tip was loosely guided and could rebound and move during successive shocks, which was identified later as a drawback.

Pre-tests results

6 different tests were carried out, differing in layer sizes, fixation weights on the layers and the presence of stitches. The different layer sizes and fixation weights result in a variation of the cloth retention force on the ground. Test cases 4 and 6 contained two layers with stitches.

Table 3: Results pre-tests

Test case	# Layer	Layer size [cm]	Tension	Piercing
1	4	95 x 50	Unfixed	Success
2	4	40 x 30	Unfixed	No
3	4	40 x 30	Unfixed	Almost
4	4	30 x 17	Unfixed	No
5	4	40 x 17	2 x 13.5 kg	Success
6	4	30 x 17	2 x 13.5 kg	No

5. MOLE TESTS

In the test setup the mole was positioned upright on the airbag cloths. The airbag cloths were laid on the same Mars model soil as in the pre-tests. The sharp tip was fixed with an adapter ring on the breadboard model of the IMS mole. Four sacks of sand, each with a weight of 10 N (mass of 1 kg), were positioned on the airbag cloths, giving a low retention force. These weights were small against the lander mass, but simulate a part of the lander mass laying on the cloths and a certain friction of the cloths to the ground. The mole was inserted in its IMS support system, which is designed to give it the upright position and the necessary friction for its forward motion.

4-layer configuration

The 4-layer test setup consists of 2 bladders and 2 abrasion layers – which represents the default configuration of a deflated ExoMars airbag. The mole penetrated through the airbag cloths with less than 900 strokes and than further into the soil.

Fig. 7: Experimental 4-layer setup, mole has pierced the airbag cloths

12-layer configuration

Worst case scenarios have to be considered in which a fold occurs by means of the tangential (w.r.t. the soil surface) component of the velocity in the airbag cloths underneath the lander in front of the mole. In this situation the mole has to pierce through 3 full airbags, i.e. 12 layers (6 bladders and 6 abrasion layers) instead of 4 as in the default configuration.

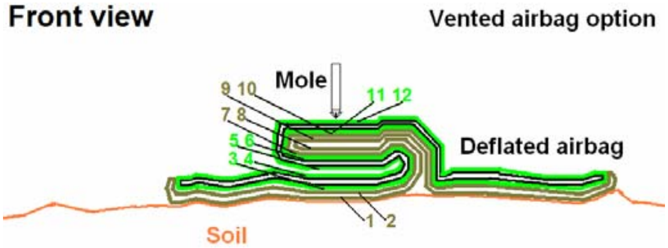

Fig. 8: Deflated airbag with fault, worse case scenario


Fig. 9: 12-layer setup, with fault


Fig. 10: After 2h 40 min, tip completely penetrates in the material

In the 12-layer test, the additional weights (40 N) were positioned beside the fold. A weight on top of the fold would damp its vibration after the strokes which should simplify the piercing.

The piercing of the airbag took between 2650 and 3100 strokes. The cuts were also precise and had the length in the range of the tip diameter. After the test, the blades of the test tip were shifted but not loose. The blades could not be moved by hand.

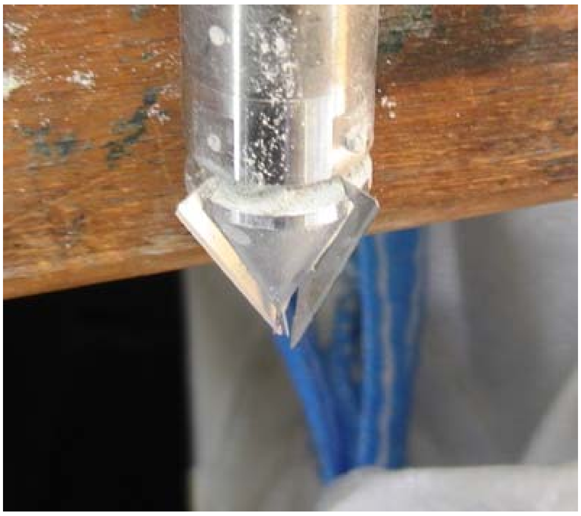

Fig. 11: Test tip after 12-layer penetration. Notes: Blades were shifted (to be corrected)

Table 4: Results 12- layer test

# Test scenario	# Layers			Load	Test Duration [h]	Total number of strokes	Estimated number for piercing
	Absolute	Bladder	Abrasion				
1	4	2	2	40 N	1.1	1100	< 900
2	12	6	6	40 N (beside fault)	3.5	3500	2650 - 3100

6. NEEDLE TESTS

Fig. 12: Concept of sharp tip with needle in front

The test has been performed by pressing the needle with a force gauge till the needle pierced the airbag (configuration with 4 layers, 2 bladders + 2 abrasion layers) and a base plate. A reference experiment has been performed piercing the base material only. The difference of the two recorded force values (with airbag + base and with only the base) has been estimated as the force needed to pierce the airbag. 4 different needle diameters were tested. Only the smaller needle was especially sharp.

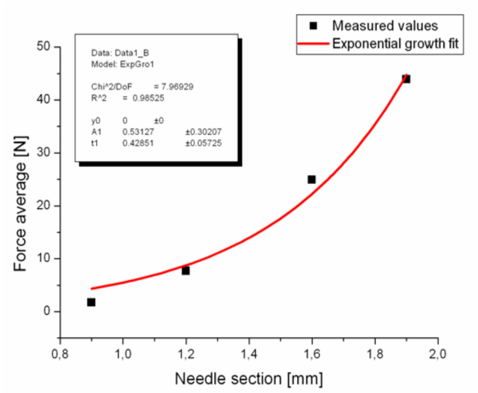

Fig. 13: Mean force of airbag cloth piercing vs. needle section

7. DISCUSSION

The mole tests were successful, showing the feasibility to pierce the airbag cloths.
Note that a full airbag was pierced with 900 strokes, and that a folded airbag – equivalent to 3 full airbags - was pierced with approximately 3 times as many strokes.

The poor initial results in the pre-tests are attributed to the missing friction, which is implemented by design in the mole tests by the IMS support system. This missing friction and the loose guidance of the tip in the pre-tests can lead to jumps of the tip on the airbag cloths. This reduces its efficiency. A needle in front of the tip can assist the piercing by an initial piercing and may keep the cutting tip on the same position on the cloths.

The applied configuration was a test setup leaving various options for improvements:

- **Sharpness of the blades:** commercial blades were used; sharper blades could be specified for the airbag material
- **Solid cone of the tip**, the test tip was manufactured of 4 quarters, for a simplified blade change. In flight applications the tip would consist of a solid cone preventing any shifting of the blades.
- A **needle in front of the tip** may assist the piercing of the airbag. Its diameter should not exceed 1 mm, because the required force grows exponential.
- The **support system of the mole** has to be adapted to the sharp tip and can support not only the moles forward motion, but also the piercing of the cloths.
- The correct Mole penetration performance in deeper soil has to be verified; it is expected to remain similar to the original one with a simple cone.

8. CONCLUSION

A prototype of the ExoMars HP3 Mole, with 4 cutting blades added to its tip, could pierce and penetrate a total of 12 Kevlar layers - modelling an ExoMars airbag in its a worst case of folding - with 3000 strokes, within 3 hours. The feasibility of this alternative solution is demonstrated.