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PICMET '97
Portland State University
Engineering Management Program
P.O. Box 751
Portland, OR 97207-0751 USA

Phone: 1-503-725-3525
Fax: 1-503-725-4667
E-Mail: picmet@emp.pdx.edu
URL: http://www.emp.pdx.edu

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TRIZ & INNOVATIVE TECHNOLOGY OF DESIGN™ USED IN THE DEVELOPMENT OF A TECHNOLOGY ROADMAP FOR SPACE SOIL PENETRATOR PROBES INCLUDING A MINI AIR BAG CONCEPT

JULIAN O. BLOSIU
FRANK DELIGIANNIS

JET PROPULSION LABORATORY/
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA
(818) 354-1686

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ABSTRACT

Many future NASA missions will be designed to robotically explore planets, moons and asteroids by collecting soil samples and conducting in-situ analyses to establish ground composition and look for the presence of specific components.

The currently designed ground penetrator probes are made of two components. The first component is the ground penetrator, also called the forebody. The second component is designed to stay at surface level and is called the aftbody. A flexible data power cable interconnects the two components.

The forebody is designed to penetrate the ground up to two meters, collect soil samples and perform an in-situ soil analysis. The aftbody contains the batteries, transceiver, antenna, and other instruments. For deep ground penetration, the probe's acceleration at ground impact is 80,000 g which is equivalent to 200 meters per second. This high speed provides the forebody a high inertia to penetrate Martian soil. However, high speed at impact damages the aftbody components (including the battery). Therefore, there is a sound technical reason to have the Martian probe crash onto the Martian surface at 200 meters per second to allow the forebody to penetrate deep into the Martian soil, and to have the probe land softly on the Martian soil so that the aftbody's components aren't damaged.

ABSTRACT
(continued)

TRIZ and Innovative Technology of Design knowledge base and techniques were applied to systematically perform a detailed functional analysis to state problems to be solved and to generate ideas in order to establish an inventive technology concept roadmap that will solve the stated problems.

Ten concepts were generated. The mini air bag concept is emphasized. This concept is also the subject of a NASA new technology report.

ACKNOWLEDGMENT

The work described here was performed at the Jet Propulsion Laboratory/California Institute of Technology under a contract with the National Aeronautics and Space Administration.

BACKGROUND

- Several future NASA missions will be designed to robotically explore planets, moons and asteroids.
- Deep soil penetrators are designed to collect soil samples and conduct in-situ analyses to establish soil composition and detect the presence of vital life supporting components such as water.
- Water presence on Mars is thought to exist deep beneath the surface.
- A penetrator probe dropped at 80,000 g is one method used to punch deep into the planet's soil (forebody).
- Power sources, instrumentation, radio transceiver, and antenna (aftbody) are kept at ground surface to communicate with the forebody and an orbiting satellite.

DESIRED NEED

- **The forebody of the soil probe should penetrate the soil to the desired maximum of two meters deep, collect soil samples, perform in-situ water detection, communicate the results to the aftbody's electronic transceiver.**
- **The aftbody should land safely on the surface of Mars, provide power to the forebody components, receive soil analyses' results from the forebody, transmit results via the antenna to an orbiting satellite, and perform other science measurements.**

PROBLEM

- A large bullet-like penetrator (forebody) is designed to perform deep soil penetration and in-situ soil collection and analyses.
- High velocity to the surface enables deep soil penetration by the forebody.
- High velocity to the surface damages the components of the aftbody, including vital power sources (batteries), thus potentially ending the mission.

CONFLICTING ENVIRONMENT

- **Management Conflict:**

  Deep soil analysis of planets, moons and asteroids should be performed at minimum cost by a multitude of independent soil probes.

- **Technical Conflict:**

  Soil penetrators need to strike the soil at high velocity in order to punch deep into the soil. Components are damaged at high striking speeds.

- **Physical Conflict:**

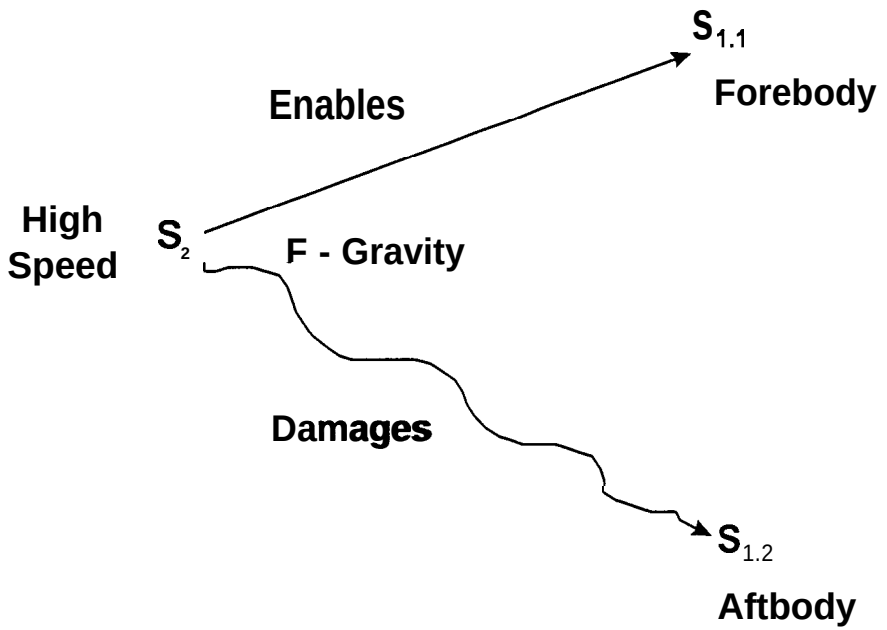
  In order for the forebody to enter soil deeply, the soil striking speed has to be high.

  In order for the aftbody components to stay intact, the soil striking speed has to be low.

CONTRADICTION

HIGH SPEED AND LOW SPEED

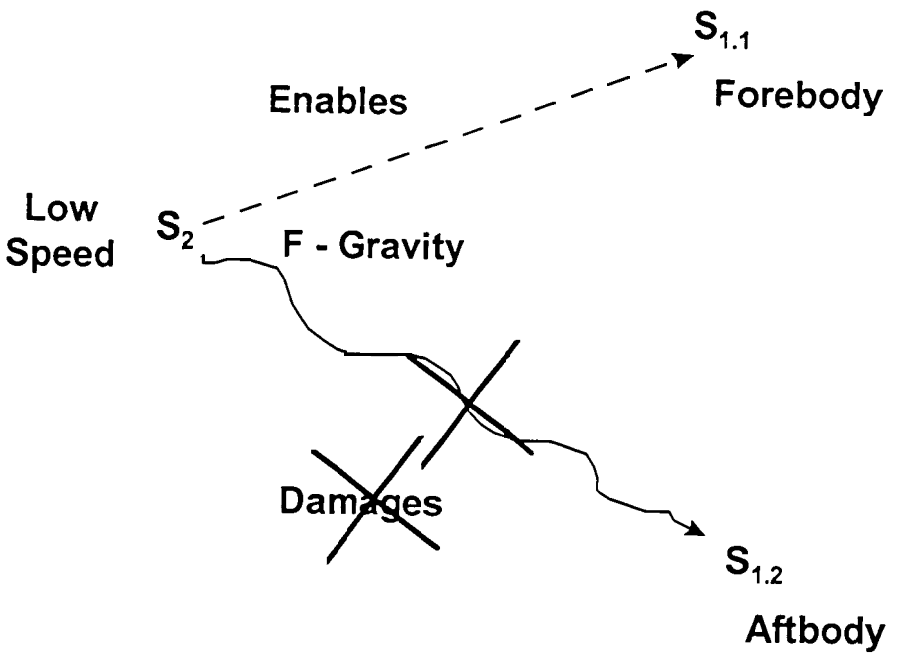
PROBLEM ANALYSIS USING "S' FIELD



Note: 1) Useful function: Forebody penetrates soil

2) Harmful function: Aftbody components are damaged

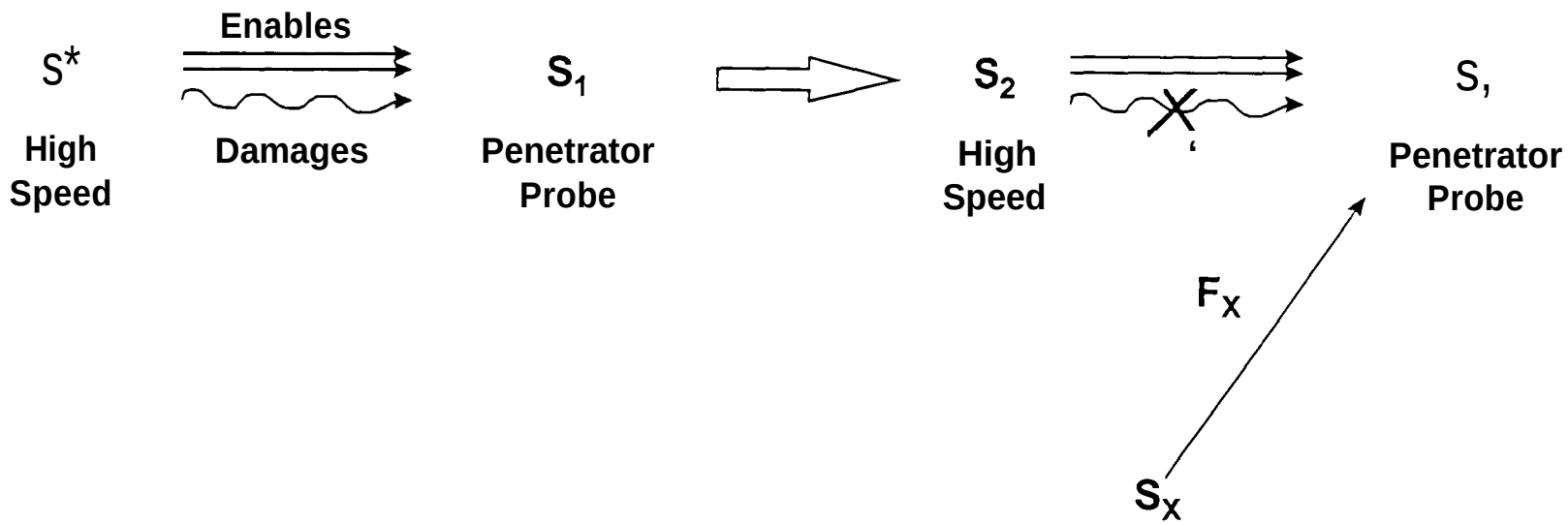
PROBLEM ANALYSIS USING "S"-FIELD (CONTINUED)



Note: 1) Low speed will not damage aftbody components

2) But, low speed will not enable forebody soil penetration

PROBLEM ANALYSIS USING "S"-FIELD
(CONTINUED)



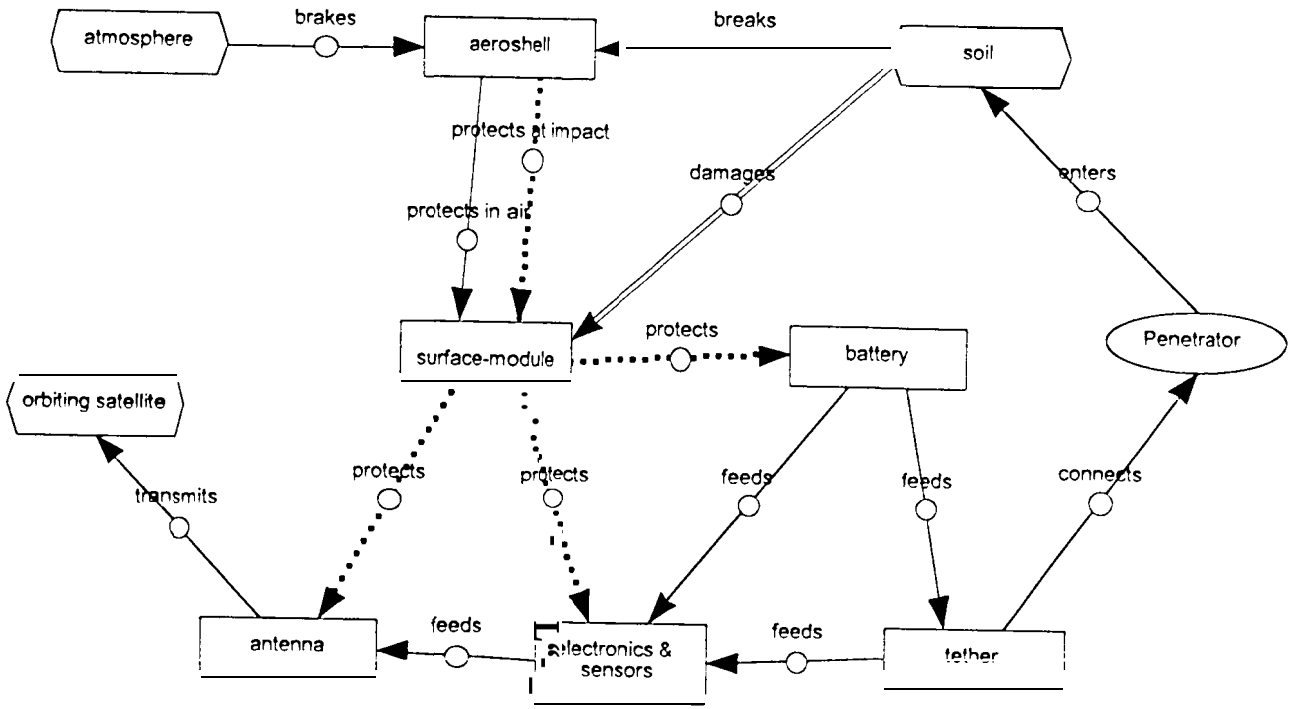
Where: Sx - Existent other system resources or new included object

Fx - New field to be used

IM TECH OPTIMIZER - ANALYZER

- Functional Analysis
- Trimming
- Problem Identification

FUNCTION ANALYSIS



FUNCTION TABLE

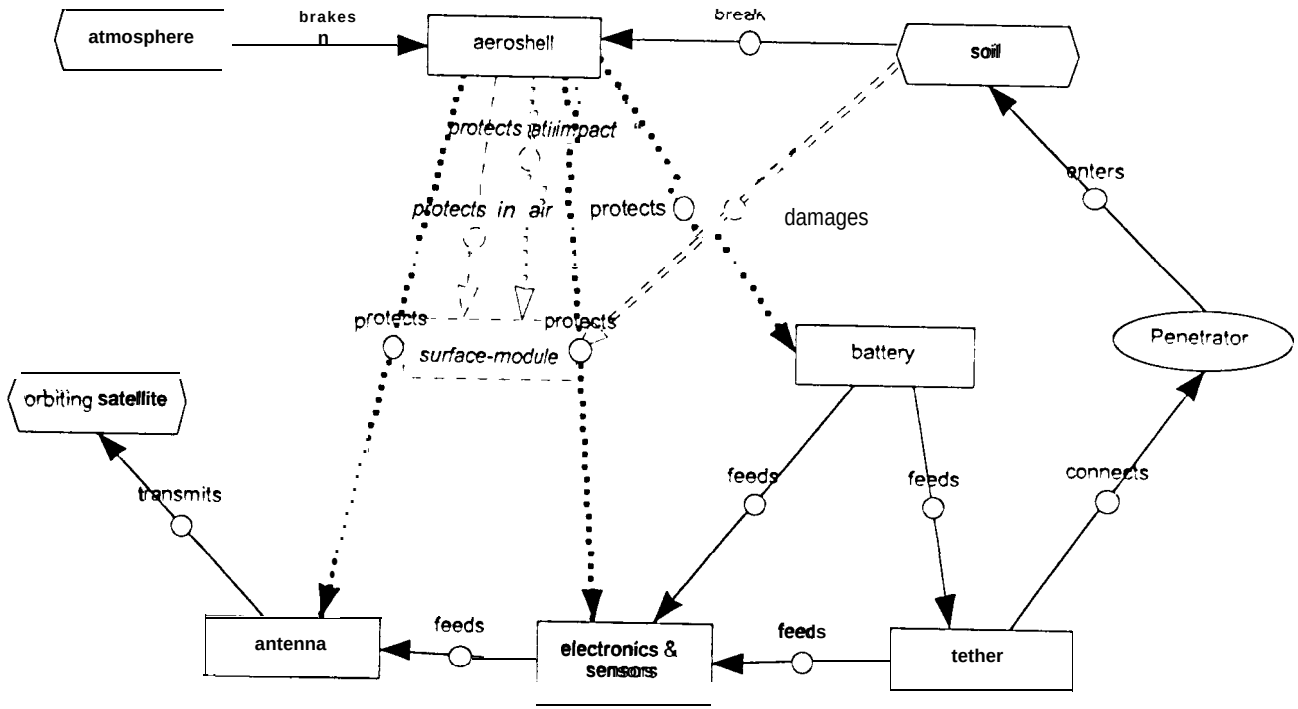
This table shows the results of function analysis.

Element	Function action	Element	Rank	Parameter	Performance
battery	feeds	electronics & sensors	A3		adequate
	feeds	tether	A I		adequate
atmosphere	brakes	aeroshell			adequate
soil	damages	surface-module	H		
	breakes	aeroshell			adequate
Penetrator	enters	soil			adequate
electronics & sensors	feeds	antenna	A2		adequate
antenna	transmits	orbiting satellite	A1		adequate
tether	connects	Penetrator	B		adequate
	feeds	electronics & sensors	A3		adequate
aeroshell	protects at impact	surface-module	A3		n/adequate
	protects in air	surface-module	A3		adequate
surface-module	protects	battery	A2		n/adequate
	protects	antenna	A2		n/adequate
	protects	electronics & sensors	A3		n/adequate

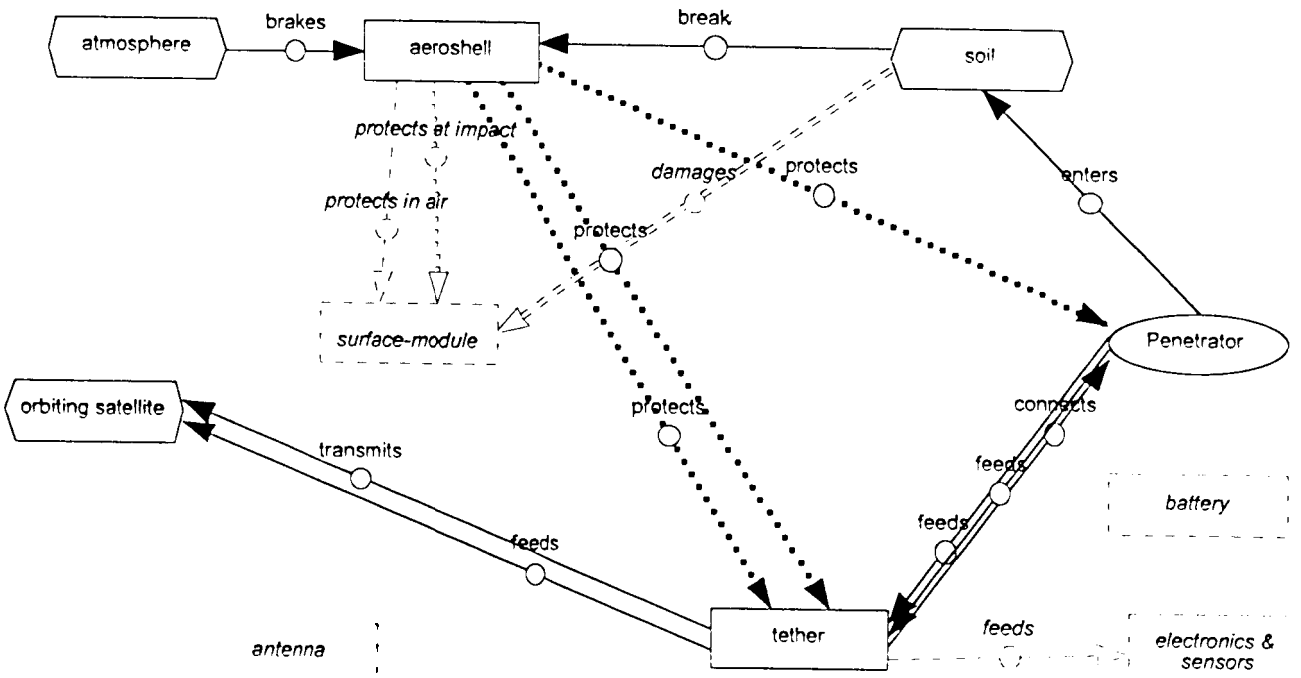
Legend

B - basic function
An - auxiliary function of rank **"n"**
H - harmful function

TRIMMING -1


atmosphere
brakes
n
aeroshell
break
soil
protects at impact
protects in air
protects
damages
enters
protects
protects
surface-module
battery
Penetrator
orbiting satellite
transmits
feeds
feeds
connects
antenna
feeds
electronics &
sensors
feeds
tether

TRIMMING - 2


atmosphere
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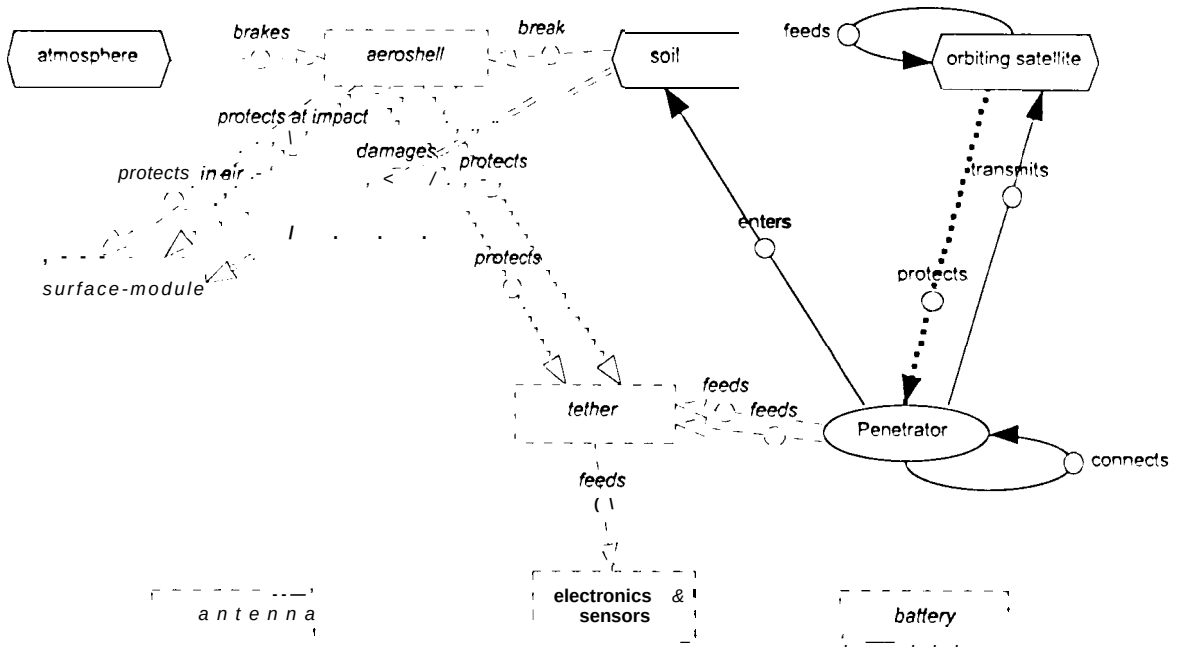
surface-module
Penetrator
orbiting satellite
protects
connects
transmits
feeds
feeds
battery
feeds
tether
feeds
electronics & sensors
antenna

TRIMMING -3


atmosphere
brakes
aeroshell
break
soil
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orbiting satellite
protects at impact
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protects
protects in air
surface-module
enters
transmits
protects
protects
tether
feeds
feeds
Penetrator
connects
feeds
antenna
electronics & sensors
battery

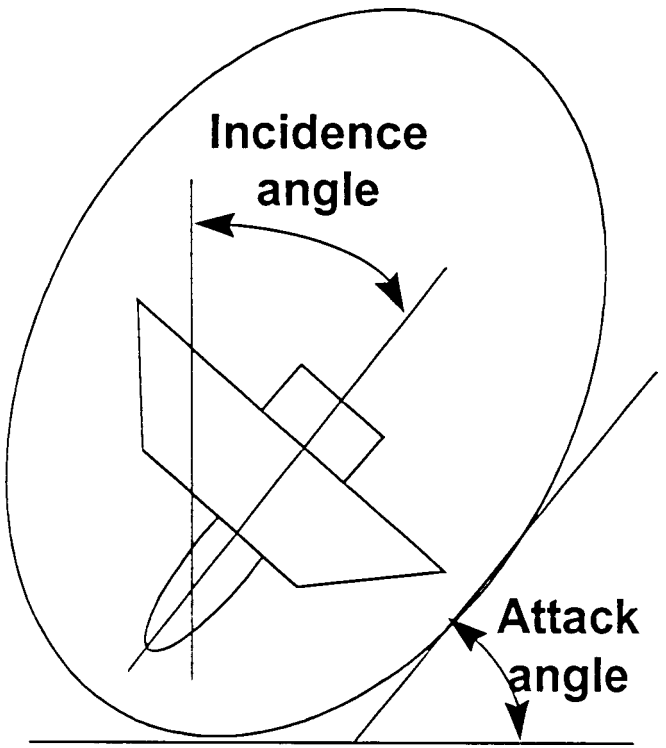
SIMPLIFYING THE OBJECT - PROBLEM DESCRIPTION

- **Problem 1.1**
  - **– Trimming 'surface-module'**
  - **- How to make 'aeroshell' perform 'protects' 'battery', 'electronics and sensors,' and 'antenna'?**
- **Problem 1.2**
  - **- Trimming 'surface-module'**
  - **- How to make 'forebody' perform action 'feed' forebody from 'battery', 'electronics' and 'antenna'?**
- **Problem 1.3**
  - **– Trimming 'surface-module'**
  - **– How to make 'tether' perform action 'feed' 'electronics' and 'antenna'?**
- **Problem 1.4**
  - **- Trimming 'surface-module'**
  - **– How to trim action 'protects at impact'?**
- **Problem 1.5**
  - **- Trimming 'surface-module'**
  - **– How to trim action 'protects in air'?**

INVENTION MACHINE - LAB
USED TO IDENTIFY SOLUTIONS
TO DEFINED PROBLEMS

- By using:
  - "Principles"
  - Predictions
  - Effects
- Ten new concepts were generated
- The concepts could be considered as candidates of a technology roadmap for future space missions

MARS PENETRATOR



CONFLICT RESOLUTION

Improved
- Increased speed to penetrate deep

Deteriorated
- Shape
- Reliability
- Harmful action on object

PRINCIPALS

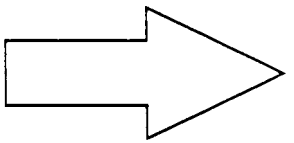
Nested dolls
- Early cushioning
- Cheap short life
- Change design, use field
- Use pneumatic - hydraulic
- Division of parts
- Blessing in disguise
- Segmentation, etc.

CONTRADICTION

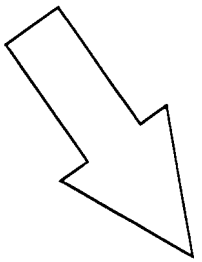
The speed of penetrator has to be high (80,000 Gs) or 200 meters/see to penetrate the Martian soil up to two meters in depth, and the speed has be low so that the penetrator's battery and electronics are not damaged at impact.

POWER OF ANALOGY

MONKEY SEES

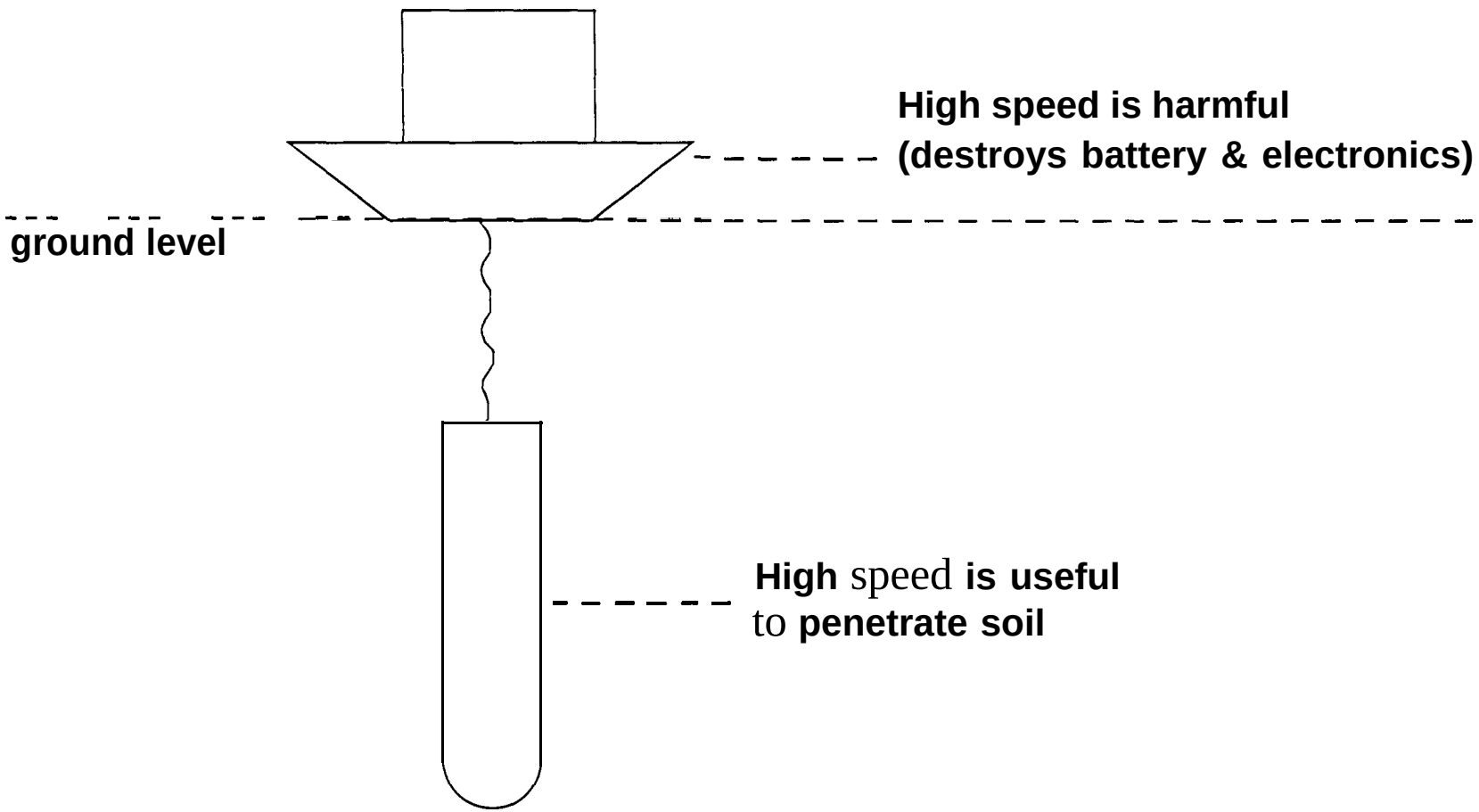


POWER
OF
ANALOGY



MONKEY DOES

SEPARATION IN TIME AND SPACE

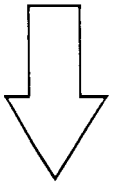


CONCEPT #1

TIME AND SPACE SEPARATION OF AFTBODY & FOREBODY

1. Further separate the soil probe components (in time and space)

- **The forebody will plummet at high speed to enter soil**
- **The aftbody will "soft land" separately to protect components**
- **Maintain connection via radio waves or a very long tether**

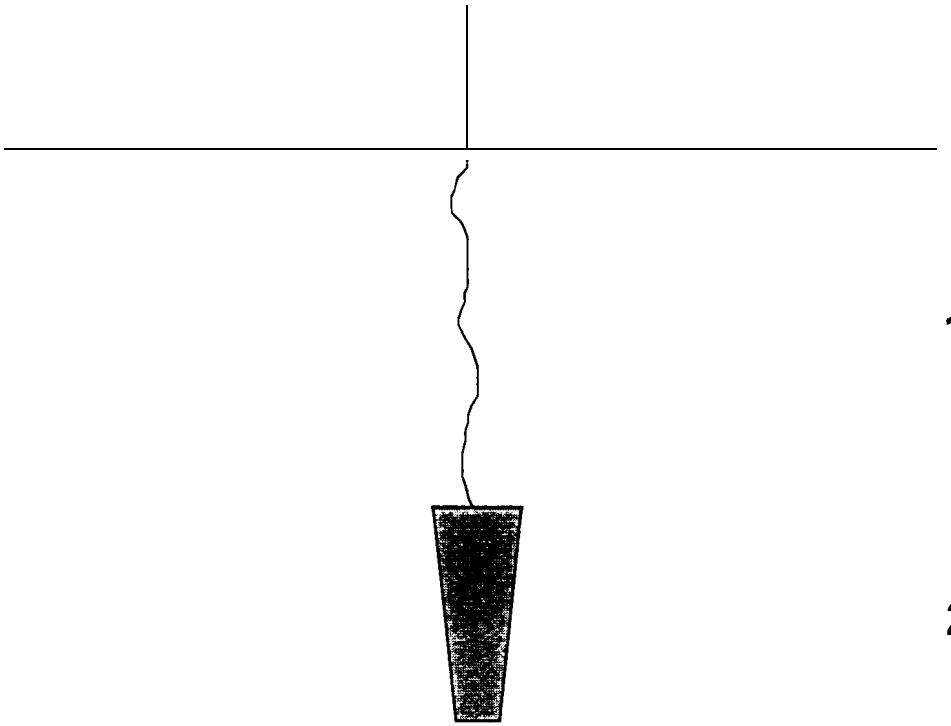


NEW PROBE IS GENERATED:

FOREBODY NEEDS OWN POWER AND ANTENNA

CONCEPT #2

TRIM (AFTBODY)
USE ONLY PENETRATOR [FOREBODY)
WITH TETHER AS ANTENNA



New Problem Generated:

1) Penetrator needs to include power system of its own, transceiver and antenna

2) Tether could act as antenna

CONCEPT #3

PNEUMATIC (AIR BAG)

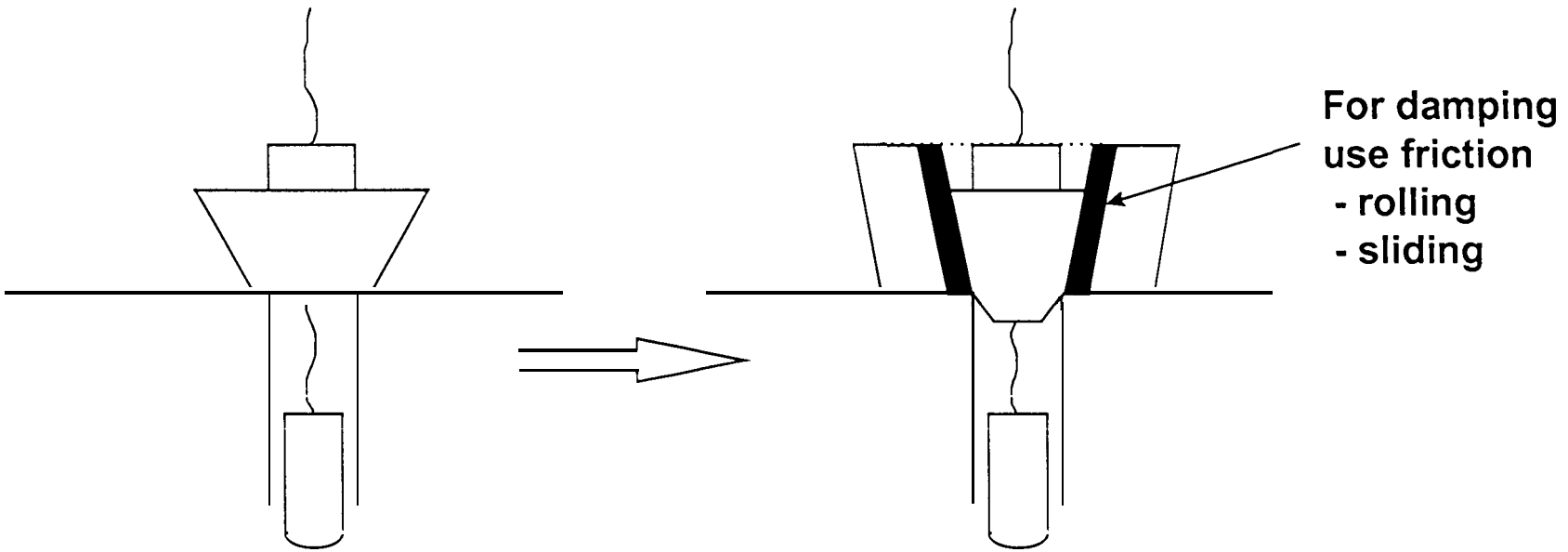
- Volume change at impact
- Hydraulic flexible shells and thin film
- Even pressure distribution

Air bag

CONCEPT #4

DIVIDE AFTBODY INTO COMPONENTS: FIXED & SEMI-FIXED

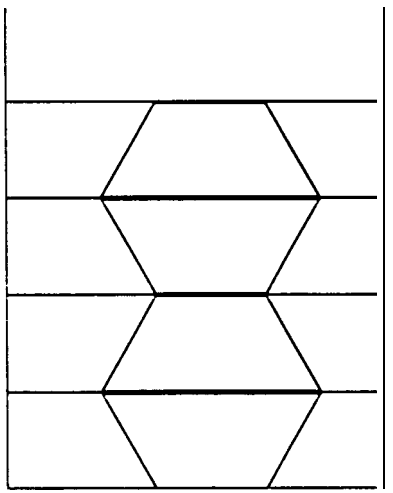
- Change surface module from fixed into sem -fixed by segmentation and changed design



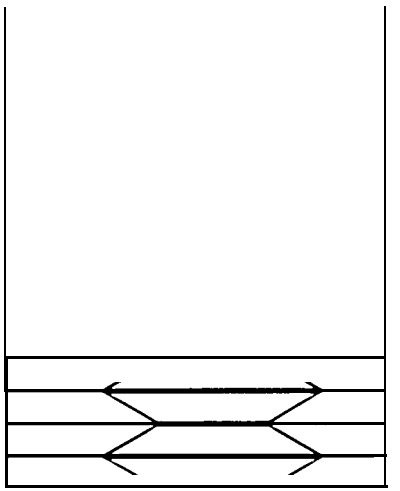
CONCEPT #5

USE SHAPE MEMORY EFFECTS

- Use plates with Shape Memory, "Belville Springs" made up of Shape Memory Metal (NiTi alloy)
- At high impact the plates will expand, creating a damping effect



Before

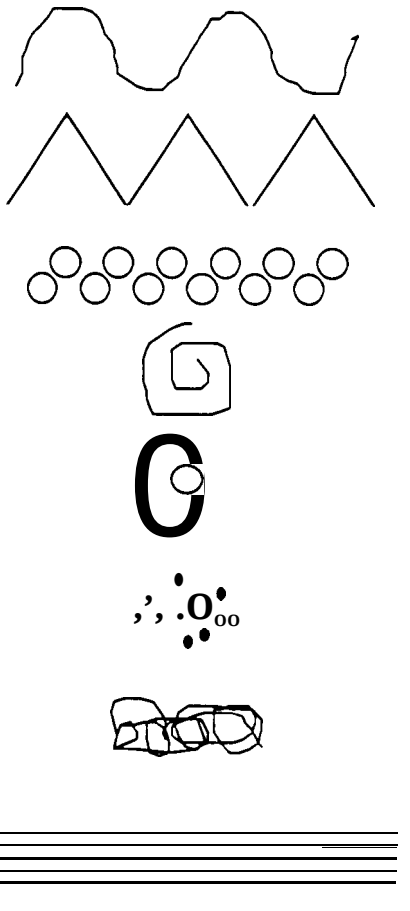


After

CONCEPT #6

USE MECHANICAL DAMPING

- **Use deformable substances and shapes**
  - **– Flexible shells and thin films**
  - **– Corrugated surfaces**
  - **– Small balls**
  - **Spiral shape**
  - **Torus shape**
  - **Loose materials**
  - **Gels with high densities**
  - **Capillary contraction**



CONCEPT #7

USE MECHANICAL FIELD DAMPING

- Use magnetic field damping
  - Paramagnetism
  - Magnetic fluid

CONCEPT #8

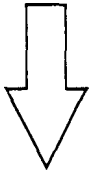
AIR SHELL PROVIDES CUSHIONING

- Fill air shell with:
  - Foam
  - Viscous material
  - Gels
- Use more than one shell
  (Nested Doll Principles)

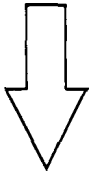
CONCEPT #9

USE HARMFUL EFFECT FOR USEFUL PURPOSE

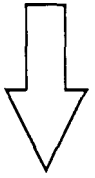
Convert impact stress energy to electricity



Piezo electricity



ELECTRETS



As energy source needed by forebody

CONCEPT #10

TRIM ENTIRE SOIL PROBE

- Use powerful laser beams to strike soil samples; then
- Use spectral analysis to determine soil composition and water content

CONCLUSION

- TRIZ and Innovative Technology of Design™ presented advanced methodology which generated inventive concept solutions for NASA Planetary Missions that robotically perform in-situ soil analyses and detection of vital life supporting components such as water
- Both IM-Techoptimizer and the three IM-Lab software were used
- A technology road map of 10 concepts was identified
- The mini air bag concept was filed as a NASA new technology report
- The other nine concepts are being evaluated

CONCEPT #7

USE MAGNETIC FIELD DAMPING

- **Use magnetic field damping**
  - **Paramagnetism**
  - **Magnetic fluid**