

**INNOVATIVE TECHNOLOGY OF DESIGN:
AN IDEA SEEDING TECHNIQUE USED IN
RESEARCH AND DEVELOPMENT OF
SPACECRAFT APPLICATIONS**

JPL

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ABSTRACT

NASA'S future missions aimed at robotically exploring the planets and the moons of our solar system require continuous development of new and innovative concepts.

Innovative Technology of Design (Tech Optimizer and Invention Machine-Lab) has been demonstrated as an effective idea-seeding technique for generating inventive new concepts for spacecraft applications.

Three specific applications were considered:

- **Automatic Directional Control System (for space and automotive vehicle)**
- **Very low temperature battery for space**
- **Technology roadmap for space soil penetrators probes**

ACKNOWLEDGMENT

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TECHNOLOGY TRANSFER FACTS

- **INVENTIVENESS AND QUALITY MAKE JPL A WORLD CLASS SPACE INSTITUTION**
- **JPL'S STRATEGIC PLAN, IN RESPONSE TO THE NASA CONTRACT, IS TO CONTINUOUSLY DESIGN AND DEVELOP ONE-OF-A-KIND SPACE TECHNOLOGY**
- **JPL'S NEWLY DEVELOPED TECHNOLOGIES, ONCE PROVEN, ARE TO BE CONTINUOUSLY TRANSFERRED TO INDUSTRY**
- **AFTER A WHILE, NEW TECHNOLOGY "DRY-OUT" OR "THIN-OUT" COULD TAKE PLACE**
- **THERE IS AN OBVIOUS NEED TO ESTABLISH A MECHANISM TO CONTINUOUSLY REPLENISH NEW TECHNOLOGIES THROUGH INNOVATION**
- **INNOVATIVE TECHNOLOGY OF DESIGN (TECH-OPTIMIZER AND INVENTION MACHINE LAB) HAS FOUND A NICHE AT JPL AS A TOOL FOR GENERATING NEW INNOVATIVE SPACE TECHNOLOGY CONCEPTS**

APPLICATIONS

- **THREE APPLICATIONS OF THE “INNOVATIVE TECHNOLOGY OF DESIGN” WERE IMPLEMENTED AND PUBLISHED:**

- 1 - **USING TRIZ TO CONCEIVE AUTOMATIC DIRECTIONAL CONTROL SYSTEM FOR SPACE AND AUTOMOTIVE VEHICLE
PUBLISHED: 2ND ANNUAL TOTAL PRODUCT DEVELOPMENT SYMPOSIUM, NOVEMBER 6-8, 1996, POMONA, CALIFORNIA, USA**
- 2 - **INVENTIVE RESEARCH AND DEVELOPMENT OF VERY LOW TEMPERATURE RECHARGEABLE SPACE BATTERY USING TRIZ AND IM-LAB
PUBLISHED: FIRST USER’S SYMPOSIUM OF INNOVATIVE TECHNOLOGY OF DESIGN, FEBRUARY 3, 4, 1997, NEW ORLEANS, LOUISIANA, USA**
- 3 - **TRIZ AND INNOVATIVE TECHNOLOGY OF DESIGN USED IN THE DEVELOPMENT OF A TECHNOLOGY ROAD FOR SPACE SOIL PENETRATOR PROBES
PUBLISHED: INNOVATION IN TECHNOLOGY MANAGEMENT SYMPOSIUM, JULY 27-31, 1997, PORTLAND, OREGON, USA**

**USING TRIZ
TO CONCEIVE AUTOMATIC
DIRECTIONAL CONTROL SYSTEM
FOR SPACE AND AUTOMOTIVE VEHICLE**

- SUMMARY -

GYROSCOPE (BACKGROUND)

- **GYROS ARE USED IN SPACECRAFT GUIDANCE AND NAVIGATION FOR AUTOMATIC DIRECTIONAL CONTROL.**
- **MICRO GYROS ARE IN GREAT DEMAND.**
- **AUTOMOTIVE INDUSTRY IS A NEW CUSTOMER FOR SMALL, LOW COST GYROS FOR AUTOMOBILE NAVIGATION MANAGEMENT CONTROL.**
- **INTEGRATED OPTICAL RATE SENSOR (IORS), POTENTIALLY, SATISFIES ALL THE ABOVE REQUIREMENTS .**

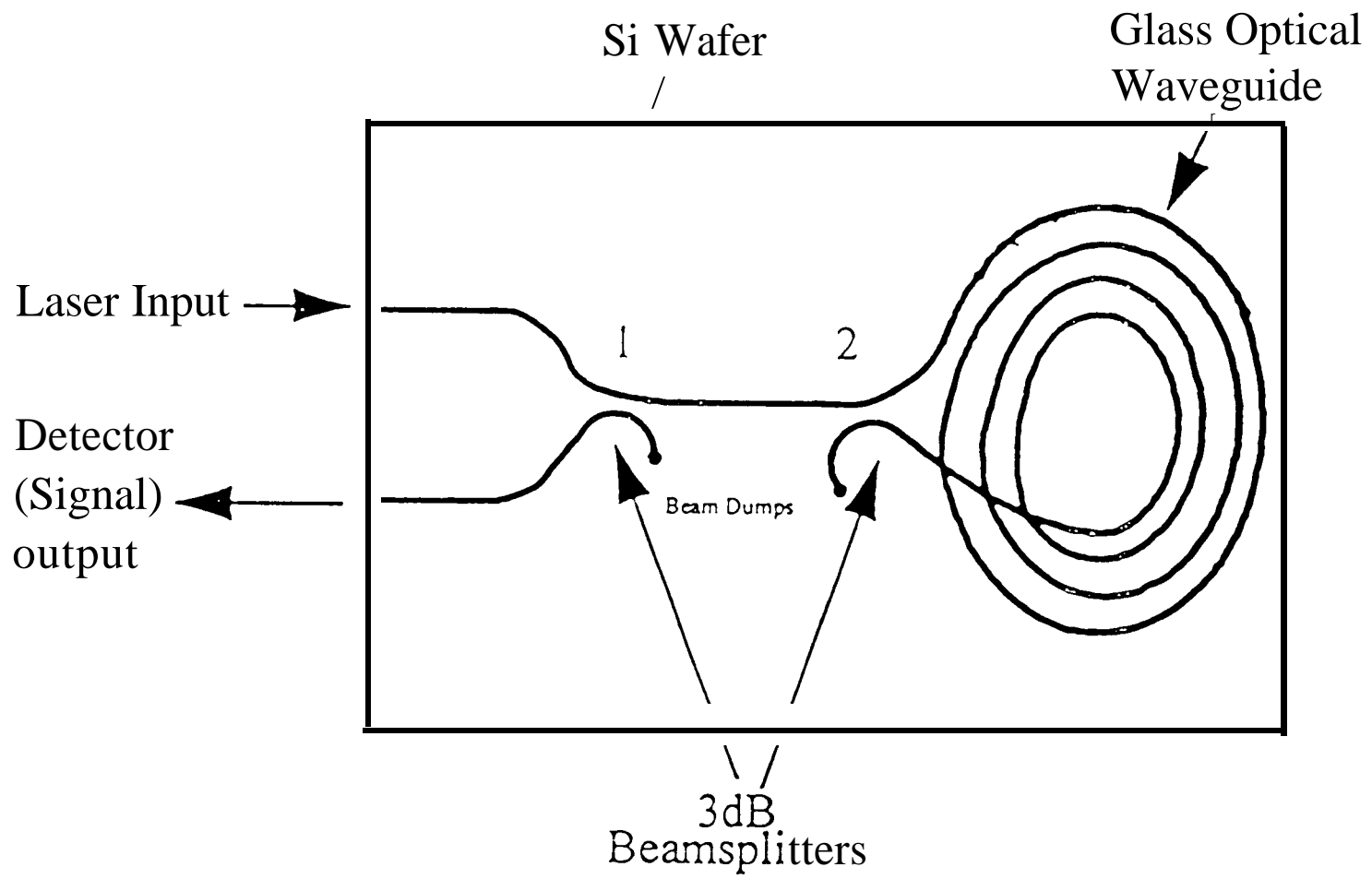


Figure 1. IORS Top View

TECHNICAL DESCRIPTION

- **IORS IS A MICRO-OPTICAL WAVEGUIDE ON A RECTANGULAR SILICON WAFER.**
- **THE OPTICAL WAVEGUIDE IS SPUTTERED GLASS ON SILICON WAFER UTILIZING AN E-BEAM FORMED MASK FOR WAVEGUIDE FABRICATION.**
- **POLARIZED LASER LIGHT IS COUPLED INTO OPTICAL WAVEGUIDE. LIGHT PROPAGATES TO BEAMSPLITTER 2, THAT SPLITS LIGHT EQUALLY, THUS FORMING TWO BEAMS THAT PROPAGATE IN OPPOSITE DIRECTION IN THE SPIRAL WAVEGUIDE.**
- **COUNTER-PROPAGATING LIGHT RECOMBINES AT BEAMSPLITTER 2 WHERE 3 dB OF LIGHT IS LOST (HALF).**
- **THE REMAINING HALF OF RECOMBINED LIGHT PROPAGATES TO BEAMSPLITTER 1, THAT SPLITS THE LIGHT EQUALLY; ONE-HALF OF THE LIGHT RETURNS TO THE OPTICAL SOURCE (AND IS LOST), AND ONE-HALF IS COUPLED TO THE PHOTODETECTOR.**

PRINCIPLE OF OPERATION

- **THE DEVICE MEASURES RATE OF ROTATION UTILIZING “SAGNAC EFFECT.”**
- **WHEN NO ROTATION IS PRESENT, COUNTER PROPAGATING LIGHT BEAMS IN THE SPIRAL WAVEGUIDE RECOMBINE AT BEAMSPLITTER 2, IN PHASE.**
- **AT A ROTATION RATE INPUT Ω , THE COUNTER-PROPAGATING LIGHT BEAMS IN THE SPIRAL WAVEGUIDE RECOMBINE AT BEAMSPLITTER 2, OUT OF PHASE.**

WHERE DELTA PHASE; $\Delta\Phi = (4\pi LR\Omega)/(\lambda c)$

L = LENGTH OF SPIRAL WAVEGUIDE

R = MEAN RADIUS OF SPIRAL WAVEGUIDE

λ = WAVELENGTH OF LIGHT

c = SPEED OF LIGHT

Ω = INPUT ROTATION RATE

TECHNICAL PROBLEMS TO BE SOLVED

- **ROTATION RATE SENSITIVITY IS PROPORTIONAL TO THE LENGTH OF THE WAVEGUIDE. THUS, WE WANT TO MAKE THE OPTICAL PATH LENGTH OF THE SPIRAL WAVEGUIDE AS LONG AS POSSIBLE.**
- **UNFORTUNATELY, THE LOSSES IN THE OPTICAL WAVEGUIDE ARE LARGE, 0.2 dB/cm.**
- **IF THE LOSSES ARE TOO LARGE, NO LIGHT CARRYING OUTPUT SIGNAL IS DETECTED, AND THUS NO ANGULAR RATE CAN BE MEASURED.**
- **LOSSES ARE BELIEVED TO BE DUE TO WAVEGUIDE ROUGHNESS.**
- **ALSO DUE TO BEAMSPLITTER 1 AND 2, THREE-QUARTERS OF THE LIGHT IS ALSO LOST (GENERIC TO “SAGNAC EFFECT”)**

CONFLICTING ENVIRONMENT

- **MANAGEMENT CONFLICT: IN ORDER FOR IORS TO BE COMPETITIVE, IT HAS TO BE MASS PRODUCED, LOW COST, LOW WEIGHT AND SMALL VOLUME. BUT, BEFORE IT IS MASS PRODUCED, THE IORS HAS TO BE HIGH ROTATION RATE SENSITIVE.**
- **TECHNICAL CONFLICT:**
 - **LOW COST, LOW WEIGHT, SMALL VOLUME, AND HIGH RATE SENSITIVE ISA NEW UN-PROVEN TECHNOLOGY.**
 - **SHORT OPTICAL WAVEGUIDE HAS LITTLE LIGHT LOSS, BUT PERFORMS AT A REDUCED ANGULAR RATE SENSITIVITY.**
 - **LONG OPTICAL WAVEGUIDE HAS AN IMPROVED ANGULAR RATE SENSITIVITY, BUT HAS LARGE LIGHT LOSSES AND OUTPUT CANNOT BE MEASURED.**

CONFLICTING ENVIRONMENT (CONTINUED)

- **PHYSICAL CONFLICT/ CONTRADICTION: PHYSICAL CONTRADICTION IS WHEN A REQUIREMENT HAS OPPOSITE PARAMETER CHARACTERISTICS.**

IN IORS CASE, THE WAVEGUIDE HAS TO BE SHORT, AND THE WAVEGUIDE HAS TO BE LONG.

BY ELIMINATING THIS PHYSICAL CONTRADICTION, THE IORS ANGULAR RATE SENSITIVITY WILL BE IMPROVED AND THE PROBLEM WILL BE SOLVED.

IM - "PRINCIPLES"

STANDARD FEATURES CONFLICT

LENGTH OF STATIONARY OBJECT
vs.
ILLUMINATION INTENSITY

LENGTH OF STATIONARY OBJECT
vs.
LOSS OF INFORMATION

LENGTH OF STATIONARY OBJECT
vs.
MEASUREMENT ACCURACY

RECOMMENDED INVENTIVE PRINCIPLE

3 LOCAL QUALITY
#25 SELF-SERVICE

3 INTERMEDIARY
#26 COPYING

#32 CHANGE OF COLOR
#28 CHANGE MECHANICAL DESIGN
3 LOCAL QUALITY

IM - "PRINCIPLES" (CONTINUED)

"PRINCIPLES" INTERPRETATION:

LOCAL QUALITY:

GO FROM A UNIFORM STRUCTURE OF EXTERNAL ENVIRONMENT (LIGHT?) TO A NON-UNIFORM ENVIRONMENT

COPYING:

IF VISIBLE OPTICAL "COPIES" ARE USED, GO TO INFRARED OR ULTRAVIOLET "COPIES"

CHANGE OF COLOR:

CHANGE COLOR OF CLAD OR WAVEGUIDE

SELF SERVICE:

USE LIGHT LOST (REFLECTED) AS A REFRACTANT AGENT TO PREVENT FUTURE REFLECTION

CHANGE MECHANICAL DESIGN:

INTRODUCE FERROMAGNETIC PARTICLES INTO WAVEGUIDE MATERIALS AND CHANGE THE PHENOMENA WITH AN ELECTROMAGNETIC FIELD.

INCLUDE PHOTOLUMINESCENT PARTICLES INTO CLAD TO REFLECT LIGHT BACK INTO WAVEGUIDE.

IM - "PRINCIPLES" (CONTINUED)

41 INVENTIVE IDEAS/POSSIBLE SOLUTIONS WERE GENERATED

IM-PREDICTION

- **PREDICTION TREE ANALYSES WERE EXPLORED.**
- **“OBJECT 1- ACTION - OBJECT 2“ INTERACTIONS WERE EVALUATED.**
- **22 SUGGESTED INVENTIVE IDEAS/POSSIBLE SOLUTIONS WERE GENERATED.**
- **SOME WERE SIMILAR WITH ONE GENERATED BY IM-PRINCIPLES, BUT MOST OF THEM WERE NEW OR HAD A DIFFERENT ANGLE, OR APPROACH.**

IM-PREDICTION (CONTINUE⇒)

EXAMPLES OF NEW SUGGESTED SOLUTIONS:

- IMPROVE WAVEGUIDE REFLECTION AND DIMINISH REFRACTION BY CHANGING THE CLAD MATERIAL FROM UNIFORM TO COMPOSITE, MULTIPLE MATERIALS.
- USE OF AN INTERMEDIARY CARRIER ARTICLE FOR THE INPUT POLARIZED LIGHT = USE MODULATION.
- INSTEAD OF CONTINUOUS ACTION, USE PERIODIC ACTION.
- IMPROVE WAVEGUIDE REFLECTION BY USING PHASE TRANSITION PHENOMENA (E.G. VOLUME ANISOTROPY CHANGE, LIGHT ABSORPTION CHANGE, ETC.).
- USE ULTRASONIC VIBRATION DURING GLASS SPUTTERING FOR WAVEGUIDE FORMATION, ETC., ETC., ETC.

IM = EFFECTS

- **IM-E IS A REFRESHER OF KNOWLEDGE RELATED TO PHYSICAL, CHEMICAL AND MECHANICAL EFFECTS.**
- **SINCE POLARIZATION OF INPUT LIGHT IS ONE EFFECT THAT WAS NEEDED TO BE CONSIDERED, TWO LIGHT EFFECTS WERE SEARCHED FOR AND PROVIDED AS REFERENCE INFORMATION BY IM-E.**
 - **ABSORPTION OF LIGHT**
 - **DOUBLE REFRACTION**
- **IM-E PROVIDED FOLLOWING SUGGESTION:**
“INCREASE POLARIZATION OF INPUT LIGHT”

CONCLUSIONS

- **TRIZ OFFERED THE OPPORTUNITY TO USE THIS REVOLUTIONARY KNOWLEDGE-BASED WAY OF THINKING TO IDENTIFY NEW AND INNOVATIVE IORS-RELATED PROBLEM SOLVING SOLUTIONS.**
- **64 IM™ -LAB™ INVENTIVE IDEAS/SUGGESTED POSSIBLE SOLUTIONS WERE WELL BEYOND THE NUMBER OF SOLUTIONS ONE ALONE COULD HAVE GENERATED IN THE SAME AMOUNT OF TIME.**
- **TECHNOLOGY EVOLUTION AND PREDICTION PROVED TO BE A POWERFUL TOOL FOR NEW CONCEPT GENERATION.**
- **THIS PROVED TO BE A STRATEGIC THINKING APPROACH TO IDENTIFY CONTRADICTIONS AND IDENTIFY SOLUTIONS.**
- **TWO NEW SPECIFIC SOLUTIONS HAVE PATENT-LEVEL QUALITY.**

**INVENTIVE RESEARCH
AND DEVELOPMENT OF
VERY LOW TEMPERATURE
RECHARGEABLE SPACE BATTERY
USING TRIZ AND IM-LAB**

- SUMMARY =

BACKGROUND

- **NASA'S OUTER PLANETS MISSIONS REQUIRE HIGH SPECIFIC ENERGY RECHARGEABLE BATTERIES THAT CAN BE OPERATED AT VERY LOW TEMPERATURES.**
- **CURRENT SOA BATTERIES ARE UNABLE TO DELIVER ELECTRICAL POWER UNDER SUCH SEVERE CONDITIONS (i.e. BELOW -400).**
- **AT SUCH LOW TEMPERATURES, THE ELECTROLYTE FREEZES AND/OR BECOMES HIGHLY VISCOUS WHICH RESULTS IN VERY POOR IONIC TRANSPORT (LOW IONIC CONDUCTIVITY).**

PROBLEM

- **THE BATTERIES CONSIDERED ARE UNABLE TO PERFORM AT LOW TEMPERATURE.**
- **PRIMARY REASON APPEARS TO BE THE HIGH CURRENT RESISTANCE OF THE SYSTEM:**
 - **ELECTRODE FUNCTION**
 - **ELECTROLYTE FUNCTION**
 - **CELL COMPONENTS FUNCTION**
- **BECAUSE THE ELECTROLYTE CONTRIBUTES THE MOST TO THE HIGH CURRENT RESISTANCE AT LOW TEMPERATURES, THE PROBLEM CAN BE RESTATED AS:**



AT LOW TEMPERATURE, THE BATTERY ELECTROLYTE IS UNABLE TO PERFORM ITS CONDUCTIVITY FUNCTION (THAT OF ENABLING THE FLOW OF ELECTRICITY) DUE TO HIGH CURRENT RESISTANCE.

CONFLICTING BATTERY ENVIRONMENT

- **MANAGEMENT CONFLICT: NASA IS PLANNING TO EXPLORE DISTANT PLANETS AND MOONS WITHIN OUR SOLAR SYSTEM. THE FARTHER FROM THE SUN, THE LOWER THE TEMPERATURE. BUT, NO RECHARGEABLE BATTERY CAN OPERATE AT VERY LOW TEMPERATURES (BELOW -40° C).**
- **TECHNICAL CONFLICT: AT VERY LOW TEMPERATURES, THE BATTERY ELECTROLYTE BECOMES FROZEN OR VERY VISCOUS, THUS THE IONS WITHIN THE ELECTROLYTE CANNOT MOVE AND THUS NO CURRENT FLOW BETWEEN ANODE AND CATHODE TAKES PLACE.**

CONFLICTING BATTERY ENVIRONMENT

(CONTINUED)

- PHYSICAL CONTRADICTIONS TO BE SOLVED:
THERE ARE SOUND TECHNICAL REASONS TO HAVE THE BATTERY CONDUCTING IONIC SPECIES "TO BE" IN CONTACT WITH THE SUPPORTING ELECTROLYTE/ SOLVENT SYSTEM AT AMBIENT TEMPERATURE; AND TO HAVE THESE IONIC SPECIES "NOT TO BE" IN CONTACT WITH THE ELECTROLYTE SOLVENT SYSTEM (WHICH CAN FREEZE OR BECOME HIGHLY VISCOUS) AT VERY LOW TEMPERATURE.

CONTRADICTION



TO BE "AND" NOT TO BE



THAT IS THE QUESTION

?

ANALYSIS OF VERY LOW TEMPERATURE R&D USING IM-LAB

• BY USING IM-LAB:

- PRINCIPLES (38)
- PREDICTIONS (85)
- EFFECTS (43)

• OVER 166 POTENTIAL NEW SOLUTIONS WERE GENERATED IN A VERY SHORT TIME.

• FOUR COMPOSITE CONCEPTS ARE CURRENTLY DOCUMENTED AS POTENTIAL NEW NASA TECHNOLOGY INVENTION AND REPORT.

TECHNOLOGY DATABASE CONCEPT CANDIDATES TO CONCEIVE AND DEVELOP NEW PRODUCTS

1. CHANGE EXTERNAL TEMPERATURE (USE RESOURCES OF THE SYSTEM)

ADD HEAT (ELIMINATE THE HARMFUL EFFECT)

**SUBTRACT HEAT (MAKE THE CONFLICT WORSE -
BLESSING IN DISGUISE)**

2. CHANGE BATTERY DESIGN (FUNCTIONS, SYSTEMS, PROPERTY)

- ELECTROLYTE

CELL DESIGN & COMPONENTS

- CELL TYPE

3. USE OTHER FIELDS (SYSTEM BECOMES MORE DYNAMIC)

MAGNETIC FIELD ACTION

•SUPERCONDUCTING MAGNETIC ENERGY STORAGE

ULTRASONIC FIELD ACTION

TECHNOLOGY DATABASE CONCEPT CANDIDATES TO CONCEIVE AND DEVELOP NEW PRODUCTS (CONTINUED)

4. USE ALTERNATIVE ENERGY STORAGE DEVICE (FUNCTIONS STAY THE SAME; CHANGE OBJECT, TOOL & FIELD)

PRIMARY BATTERY

- **CAPACITORS**

THERMOELECTRICS

- **FUEL CELL**
- **NUCLEAR**

FLYING WHEEL

5. USE HYBRID SYSTEMS (COMBINATION OF ALL THE ABOVE)

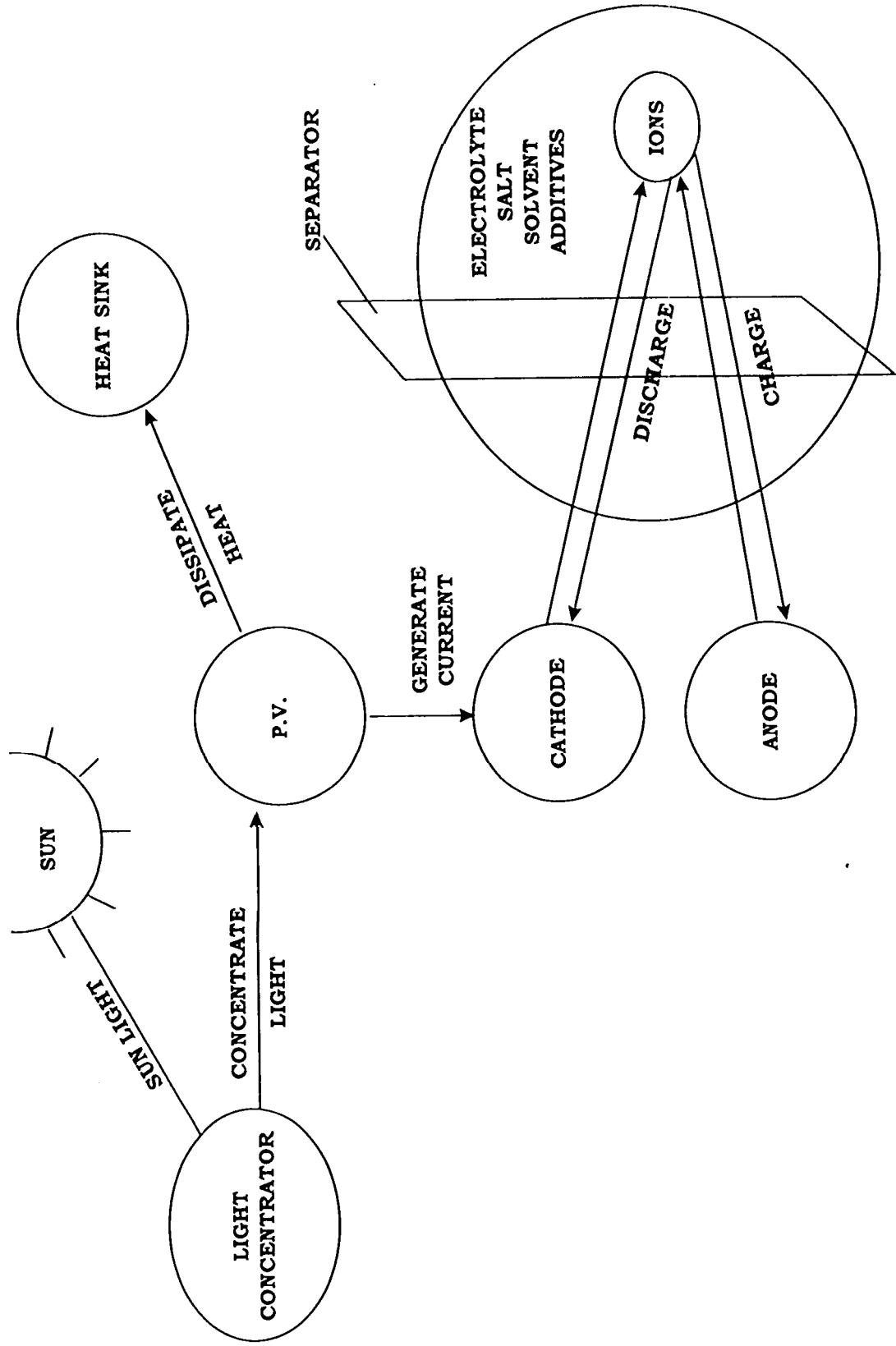
THE MOST VALUABLE IDEAS GENERATED BY IM-LAB

1. PROVIDE HEAT

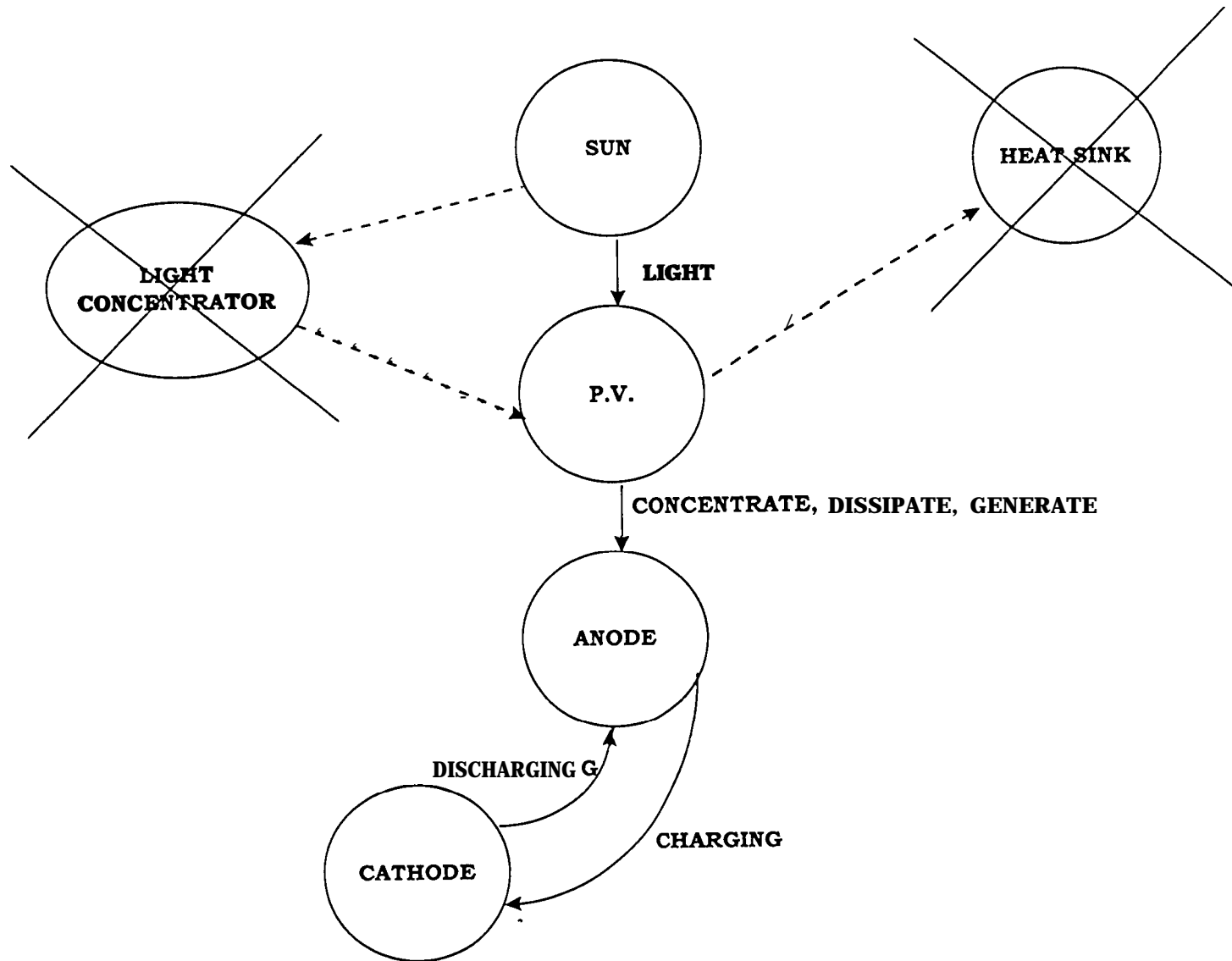
- **CHANGE TEMPERATURE.**
- **MAKE A PART OR OBJECT PERFORM MULTIPLE FUNCTIONS; ELIMINATE THE NEED FOR OTHER PART OR OBJECT.**
- **BRING CLOSER TOGETHER (OR MERGE) IDENTICAL OR SIMILAR OBJECTS; ASSEMBLE IDENTICAL OR SIMILAR OBJECTS TO PERFORM PARALLEL OPERATIONS. (MAKE OPERATIONS CONTIGUOUS OR PARALLEL; BRING THEM TOGETHER IN TIME AND SPACE.)**
- **USE PHENOMENA OCCURRING DURING PHASE TRANSITION (e.g. VOLUME CHANGE, LOSS OR ABSORPTION OF HEAT, ETC.).**
- **USE HARMFUL FACTORS (PARTICULARLY, HARMFUL EFFECTS OF THE ENVIRONMENT OR SURROUNDINGS) TO ACHIEVE A POSITIVE EFFECT.**

FUNCTIONAL ANALYSIS

= ORIGINAL SYSTEM =



PRUNING SYSTEM FUNCTIONS TO CREATE NEW DESIGN OF OBJECTS



THE MOST VALUABLE IDEAS GENERATED BY **IM-LAB** (CONTINUED)

2. USE MAGNETIC PARTICLES AND FIELD (FERROMAGNETISM)

- **USE ELECTRIC, MAGNETIC AND ELECTROMAGNETIC FIELD TO INTERACT WITH THE OBJECT.**
- **USE FIELDS IN CONJUNCTION WITH FIELD-ACTIVATED (e.g. FERROMAGNETIC) PARTICLES.**
- **MAKE ONE PART PASS THROUGH A CAVITY IN THE OTHER.**
- **MAKE AN OBJECT POROUS OR ADD POROUS ELEMENTS (INSERTS, COATINGS, ETC.).**
- **IF AN OBJECT IS ALREADY POROUS, USE THE PORES TO INTRODUCE USEFUL SUBSTANCE OR FUNCTION.**
- **INVERT THE ACTION USED TO SOLVE THE PROBLEM.**

THE MOST VALUABLE IDEAS GENERATED BY M-LAB (CONTINUED)

3. PROVIDE OSCILLATION OR VIBRATION

- IMPROVE WETABILITY
- CHANGE TEMPERATURE
- DIVIDE AN OBJECT INTO INDEPENDENT PARTS
- INCREASE THE DEGREE OF FRAGMENTATION (OR SEGMENTATION) OF AN OBJECT
- MAKE AN OBJECT POROUS OR ADD POROUS ELEMENTS (INSERTS, COATINGS, ETC.)
- INSTEAD OF CONTINUOUS ACTION, USE PERIODIC OR PULSATING ACTION
- APPLY SUPERFLUIDITY
- APPLY SURFACE TENSION
- USE RESONANCE FREQUENCY
- USE COMBINED ULTRASONIC AND ELECTROMAGNETIC FIELD OSCILLATIONS

THE MOST VALUABLE IDEAS GENERATED BY IM-LAB (CONTINUED)

4. USE HARMFUL FACTORS

- AMPLIFY A HARMFUL FACTOR TO SUCH A DEGREE THAT IT IS NO LONGER HARMFUL.
- CHANGE THE CONCENTRATION OR CONSISTENCY.
- INVERT THE ACTION(S) USED TO SOLVE THE PROBLEM (e.g. INSTEAD OF HEATING AN OBJECT, COOL IT).
- APPLY PLASTICITY OF A SUPERCONDUCTOR.
- APPLY SURFACE TENSION SUPERCONDUCTOR.
- APPLY IONIC EXCHANGE SUPERCONDUCTOR.
- APPLY SUPERCONDUCTING MAGNETIC ENERGY STORAGE.

CONCLUSION

- **TRIZ AND IM-LAB OFFERED THE OPPORTUNITY TO USE THIS REVOLUTIONARY KNOWLEDGE-BASED WAY OF THINKING TO IDENTIFY NEW AND INNOVATIVE PROBLEM SOLVING SOLUTIONS TO NASA VERY LOW TEMPERATURE BATTERY RESEARCH AND DEVELOPMENT.**
- **OVER 166 INVENTIVE IDEAS/SUGGESTED POSSIBLE SOLUTIONS WERE GENERATED USING TRIZ TECHNIQUES AND IM-LAB SOFTWARE. THIS NUMBER OF SOLUTIONS WAS WELL BEYOND THE NUMBER OF SOLUTIONS ONE ALONE COULD HAVE GENERATED IN THE SAME AMOUNT OF TIME.**
- **TECHNOLOGY EVOLUTION AND PREDICTION AND PRUNING TECHNIQUES PROVED TO BE A POWERFUL TOOL FOR NEW CONCEPT GENERATION.**
- **THIS PROVED TO BE A STRATEGIC THINKING APPROACH TO IDENTIFY CONTRADICTIONS AND IDENTIFY SOLUTIONS.**
- **FOUR NEW SPECIFIC CONCEPTS HAVE PATENT LEVEL QUALITY. ONE CONCEPT IS ALL DOCUMENTED AND MODEL DEMONSTRATION IS BEING FINALIZED IN SUPPORT OF A PATENT APPLICATION THAT WAS SUBMITTED. THE OTHER THREE ARE Now IN THE MODEL DEMONSTRATION PHASE.**

**TRIZ AND
INNOVATIVE TECHNOLOGY OF DESIGN
USED IN THE DEVELOPMENT
OF A TECHNOLOGY ROADMAP
FOR SPACE SOIL PENETRATOR PROBES**

- SUMMARY -

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.**

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.

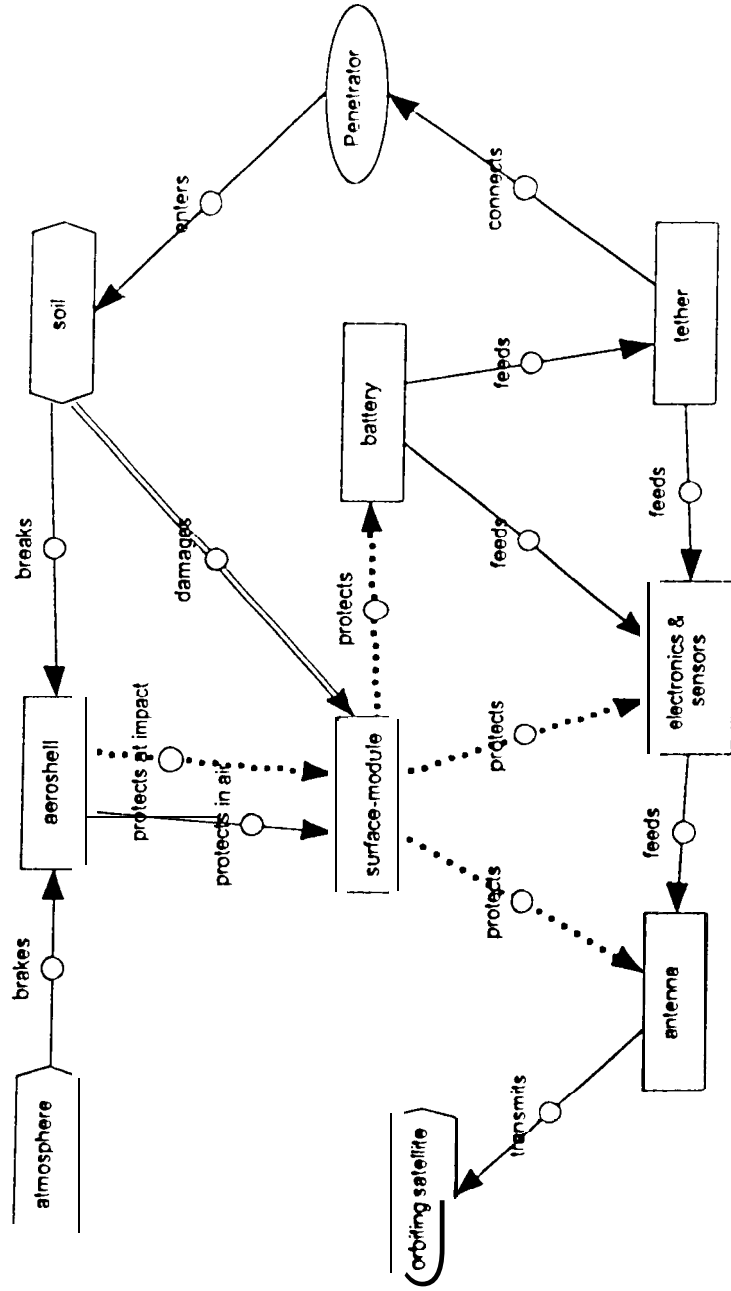
In order for the aftbody components to stay intact, the soil striking speed has to be low.



CONTRADICTION

HIGH SPEED AND LOW SPEED

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	A1		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 EXTENT, LEVELS OF CONTRADICTION AND INNOVATIVE CONCEPT SOLUTIONS

- **Less trimming creates least contradictions and least innovative concept solutions. Simple problem leads to simple solutions.**
- **Medium trimming creates medium contradictions that leads to**
 - **medium concept solutions.**
- **Aggressive trimming creates large contradictions that generates**
 - **advanced innovative concept solutions. This is the situation**
 - **when the effort to solve the problems is greater, but the reward**
 - **for the payoff is also greater.**



TECHNOLOGY ROAD MAP

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

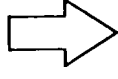
CONFLICT RESOLUTION

Improved

- Increased speed to penetrate deep

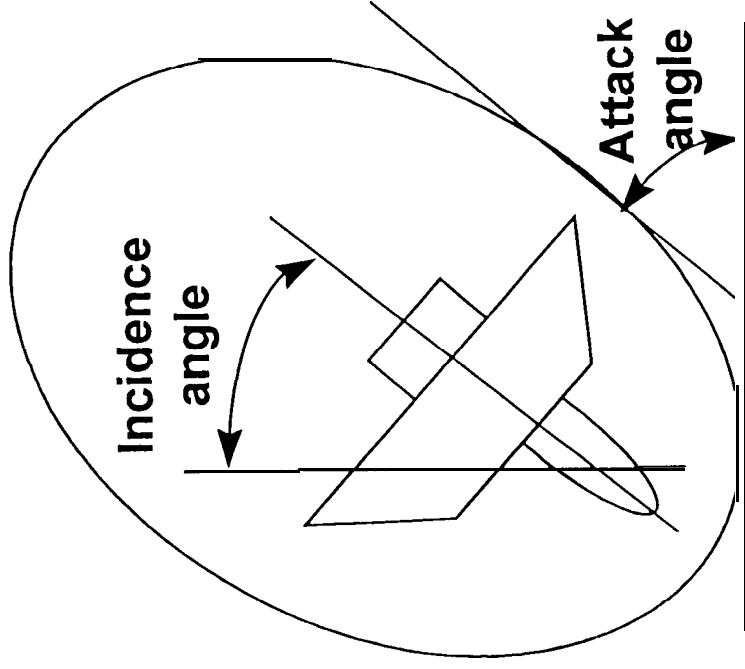
Deteriorated

- 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.



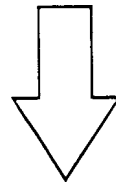
CONCEPT #1

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

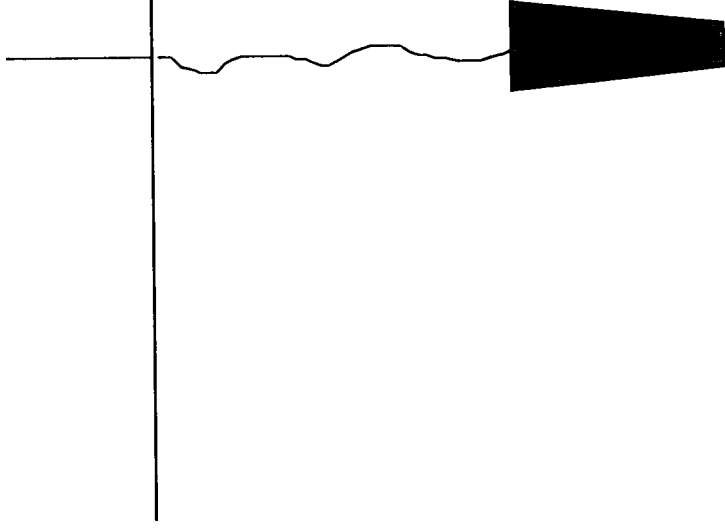


NEW PROBE IS GENERATED:

FOREBODY NEEDS OWN POWER AND ANTENNA

CONCEPT #2

TRIM (AFTBODY)
US ONLY PENETRATOR (FOREBODY)
WITH TETHER AS ANTENNA



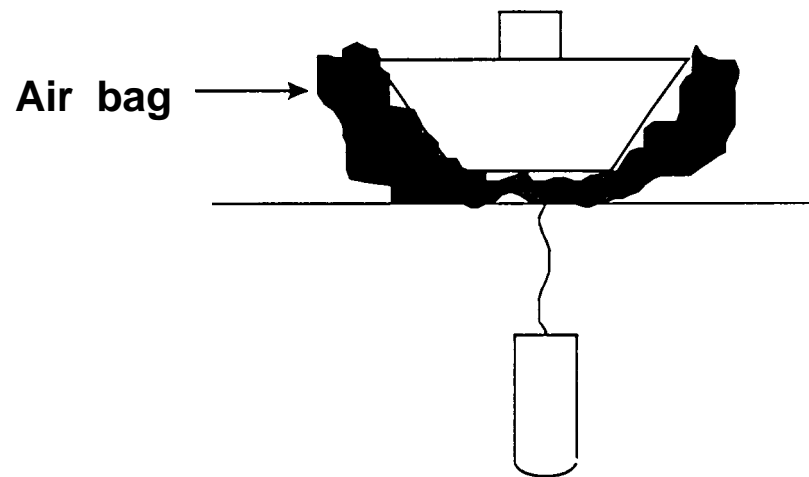
New Problem Generated:

- 1) Penetrator needs to include power system of its own, transceiver and antenna
- 2) Tether could act as antenna

CONCEPT #3

PNEUMATIC (AIR BAG)

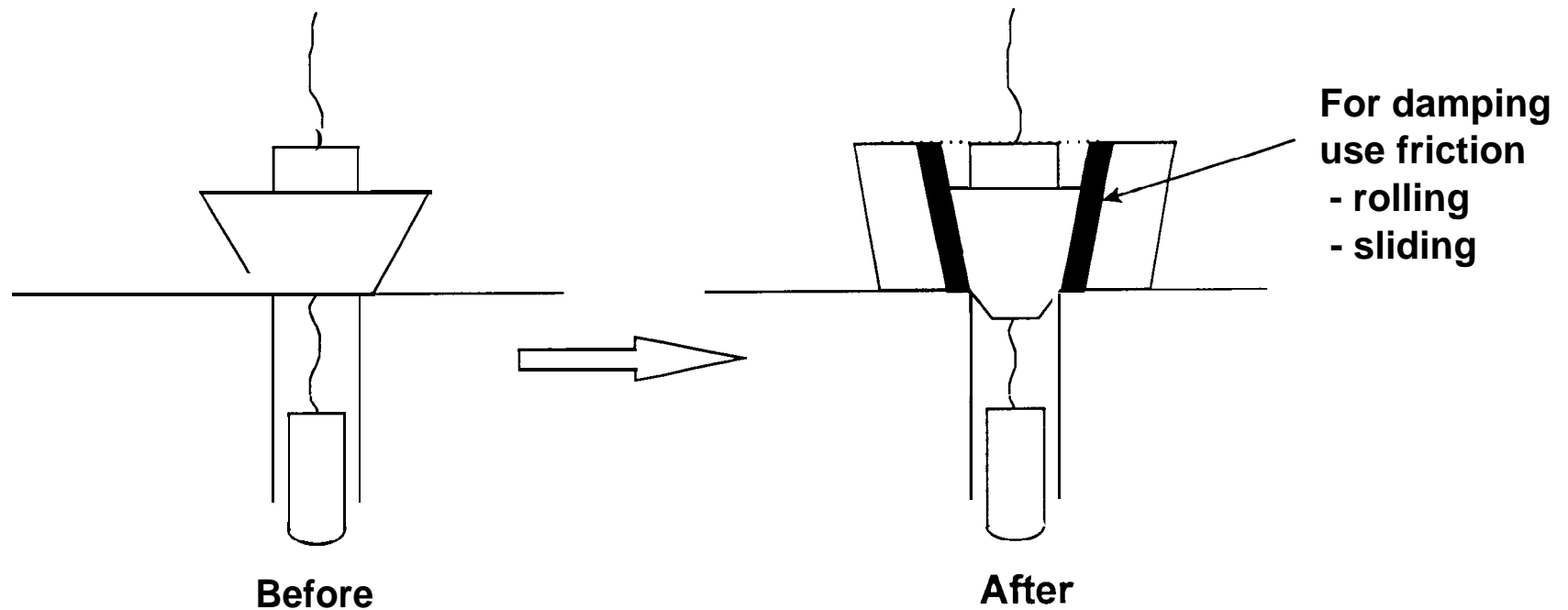
- Volume change at impact
- Hydraulic flexible shells and thin film
- Even pressure distribution



CONCEPT #4

DIVIDE AFTBODY INTO COMPONENTS: FIXED & SEMI-FIXED

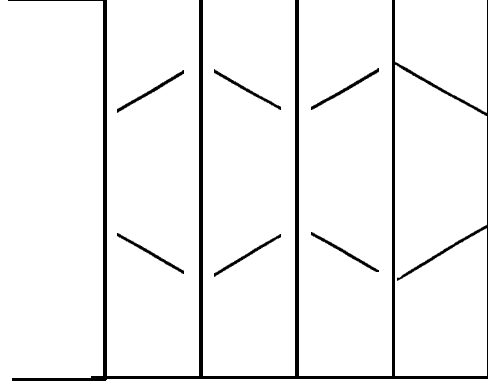
- Change surface module from fixed into semi-fixed by segmentation and changed design



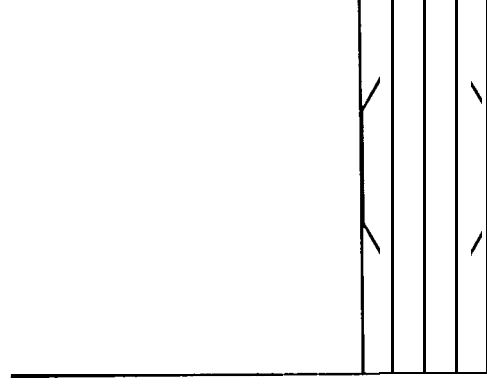
CONCEPT #5

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



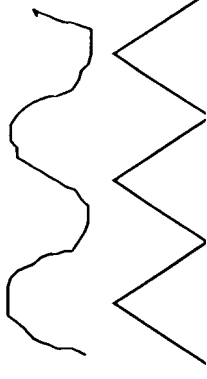
After

CONCEPT #6

USE MECHANIC^L BAMPING

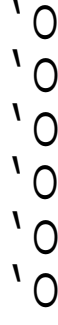
- Use deformable substances and shapes

- Flexible shells and thin films



- Corrugated surfaces

- Small balls



- Spiral shape



- Torus shape



- Loose materials



- Gels with high densities



- Capillary contraction



CONCEPT #7

USE MAGNETIC FIELD DAMPING

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

CONCEPT #8

AIR SHELL PROVIDES CUSHIONING

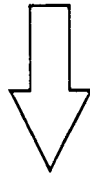
- **Fill air shell with:**
 - **Foam**
 - **Viscous material**
 - **Gels**

- **Use more than one shell
(Nested Doll Principles)**

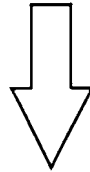
CONCEPT #9

USE HARMFUL EFFECT FOR USEFUL PURPOSE

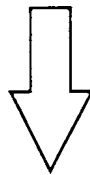
Convert impact stress energy to electricity



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**