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An Application of the "Virtual Spacecraft" Concept in Evaluation of the Mars Pathfinder Lander Low Gain Antenna

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In this presentation we describe the use of the Mars Pathfinder lander low gain antenna in a case study demonstrating f the utility of the "virtual spacecraft" concept in design and evaluation. The work to be described involved the interconnection of two JPL facilities by means of a computer network. These facilities were the Flight System Testbed and the Mesa Antenna Measurement Facility.

Outline

- The "Virtual Spacecraft" Concept
- Mars Pathfinder Lander Configuration
- The low gain antenna
  - Calculated pattern
  - Measured pattern
- Landing sequence / Spacecraft dynamics
- Antenna gain versus time during descent
- Concluding remarks

We begin with a description of the "virtual spacecraft" concept indicating both the overall vision and the current state. Then, the lander configuration will be shown together with the pattern of the low gain antenna located thereon. The goal was the simulation of the communications link performance during the landing sequence. This involved the use of the results of a Monte Carlo simulation of the spacecraft landing dynamics. Using this data the Antenna Measurement Facility was able to provide the Flight System Testbed with antenna gain versus time during the descent sequence for use in the link simulation.

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Virtual Spacecraft

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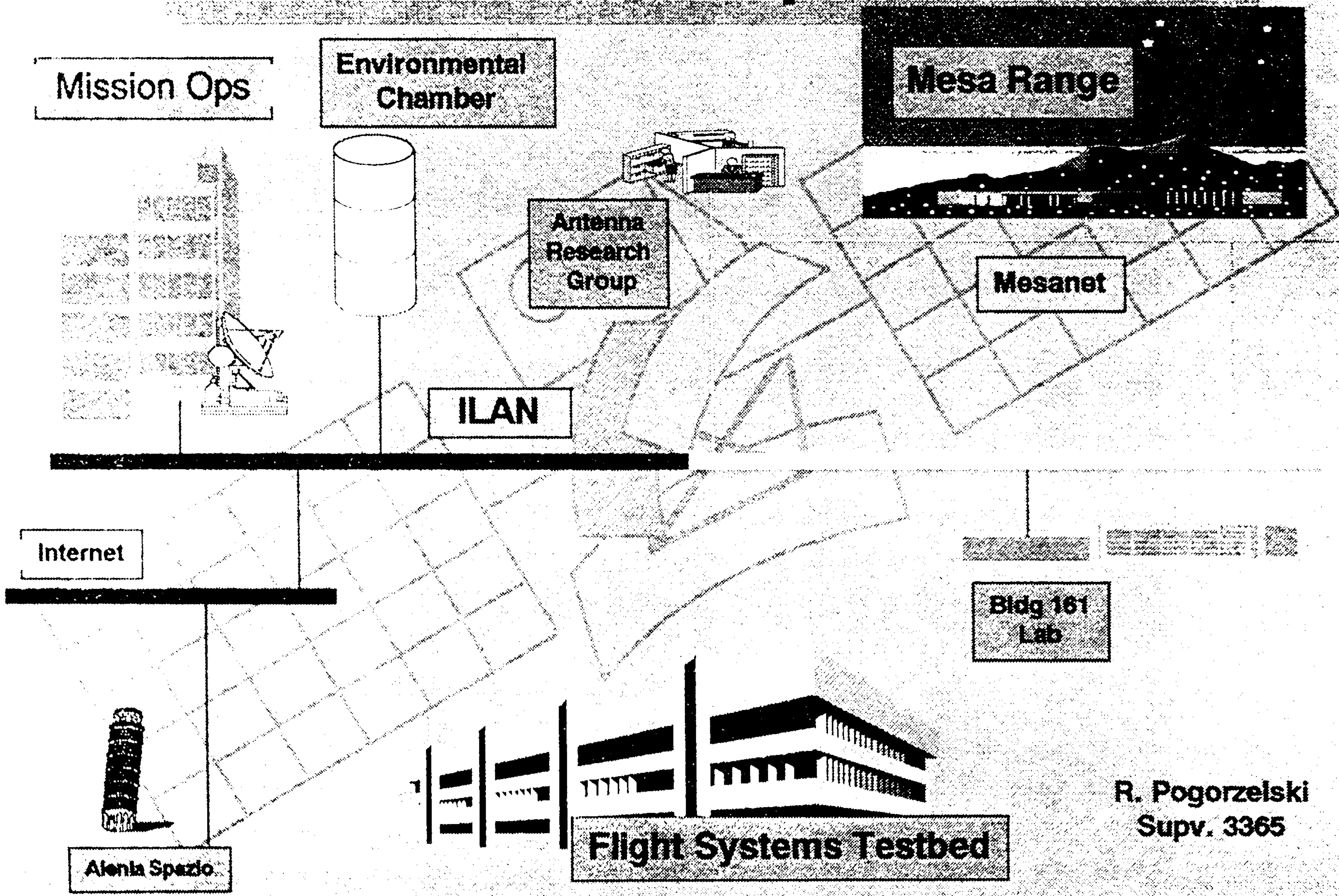
The “virtual spacecraft” consists of a set of spacecraft subsystems, some of which are implemented in hardware and some of which are computer simulations. These “subsystems” need not be co-located. Early in the design process, all or nearly all of the subsystems are computer models. As the design evolves, more and more of the system is implemented in hardware. Near the end of the design process, nearly all of the subsystems will be hardware albeit breadboard quality in most cases. This enables mission scenario simulation during the design process which in turn facilitates interactive collaboration between the designers and the mission operations personnel as well as the principal investigators involved in the mission.

At present, the FST and the Antenna Measurement Facility are linked by network and measured data can be transferred to the FST. We have not yet established the means for the FST to control the measurement but this is planned.

The Virtual Spacecraft Concept



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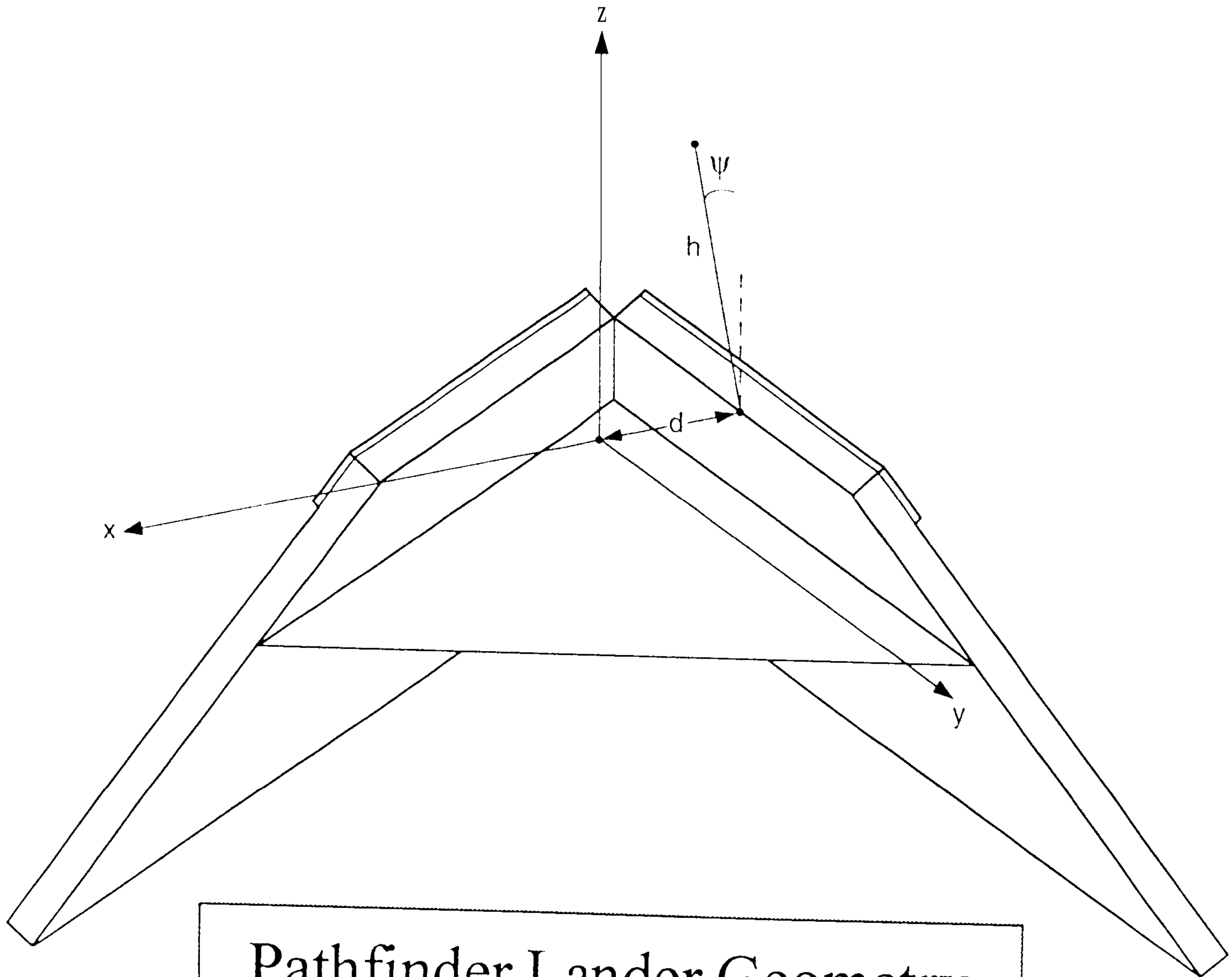
Lander Configuration

For purposes of assessment of the low gain antenna performance at X-band, this configuration was used to represent the lander during descent to the Martian surface. It is assumed to be a collection of perfectly conducting panels as shown. The antenna is tipped approximately 12 degrees from vertical to accommodate the tilt of the lander hanging beneath the parachute. A crude mock-up of the configuration was constructed from aluminum and foil covered foam for measurement purposes. This configuration was also used in a computational model based on APATCH, a computer code based on high frequency asymptotic theory.



Pathfinder Lander Geometry

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Mockup Photograph

This is a photograph of the physical mock-up showing the low gain antenna, a short monopole with a small metallic skirt.

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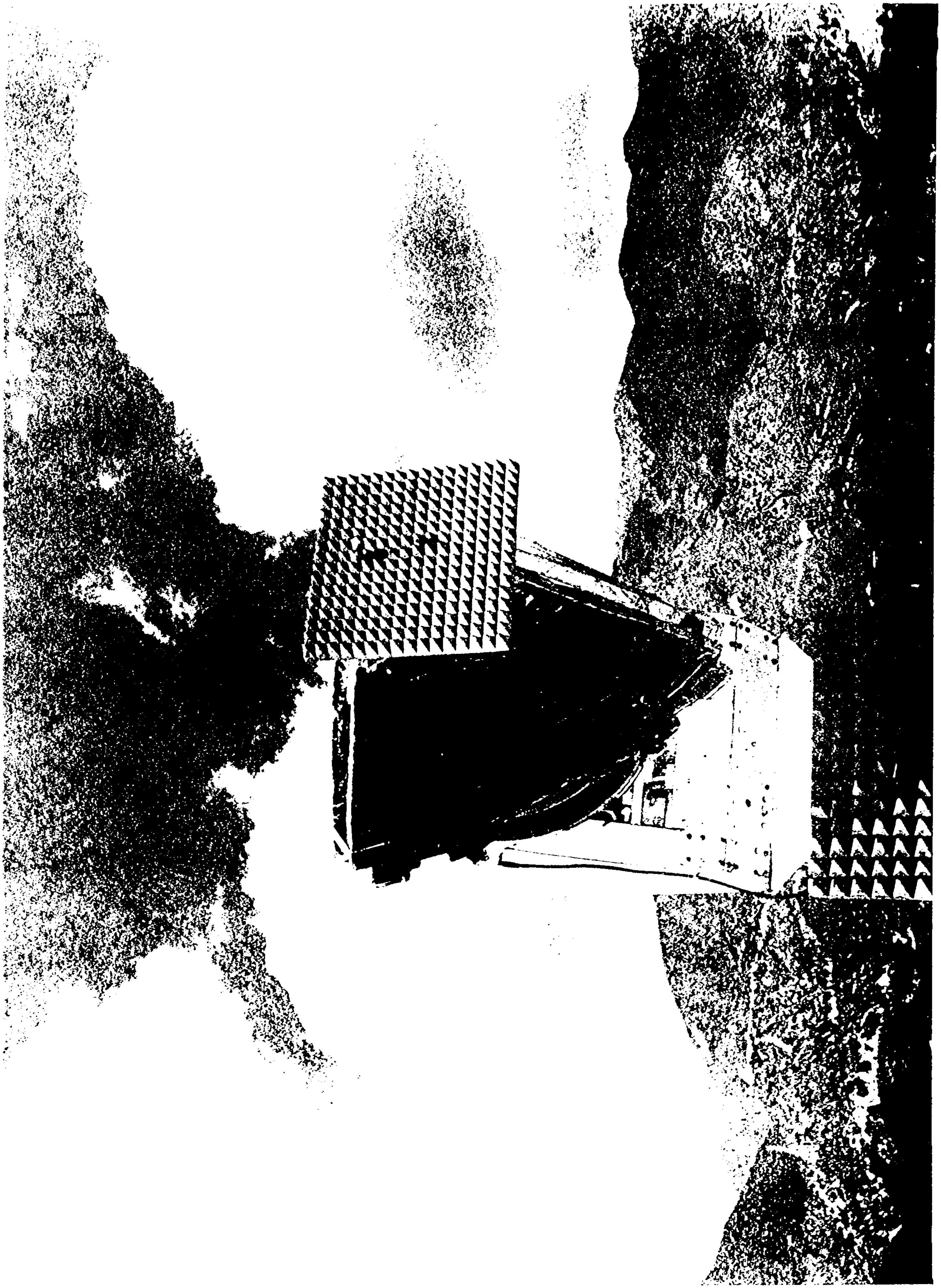
Mockup Photograph

This shows the mock-up with a square of rf absorbing material in place. This configuration was used to limit the interaction between the antenna and the lander. This results in an antenna pattern more closely resembling that of the antenna in free space (without the lander present).



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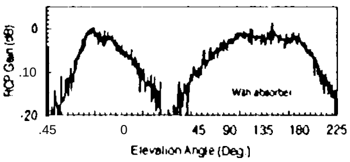
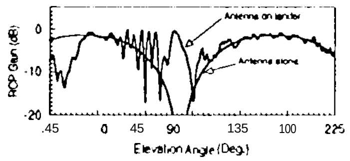
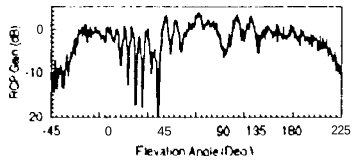
Low Gain Antenna Patterns

- Antenna simulated with three element colinear array.
- Patterns computed using program APATCH with and without lander body.





Calculated antenna patterns.



Measured patterns of antenna on lander.

Frequency: 8.425 GHz

The plot in the upper right shows the pattern of the antenna with the absorber in place. The antenna used in the simulation consisted of three colinear dipoles weighted so as to match the free space pattern of the actual antenna. This is shown in the lower left plot along with the computed pattern when this antenna is mounted on the lander. Note the evidence of significant integration. The plot at the lower right shows the measured pattern of the antenna on the lander. Qualitative agreement with the corresponding calculated result is evident,

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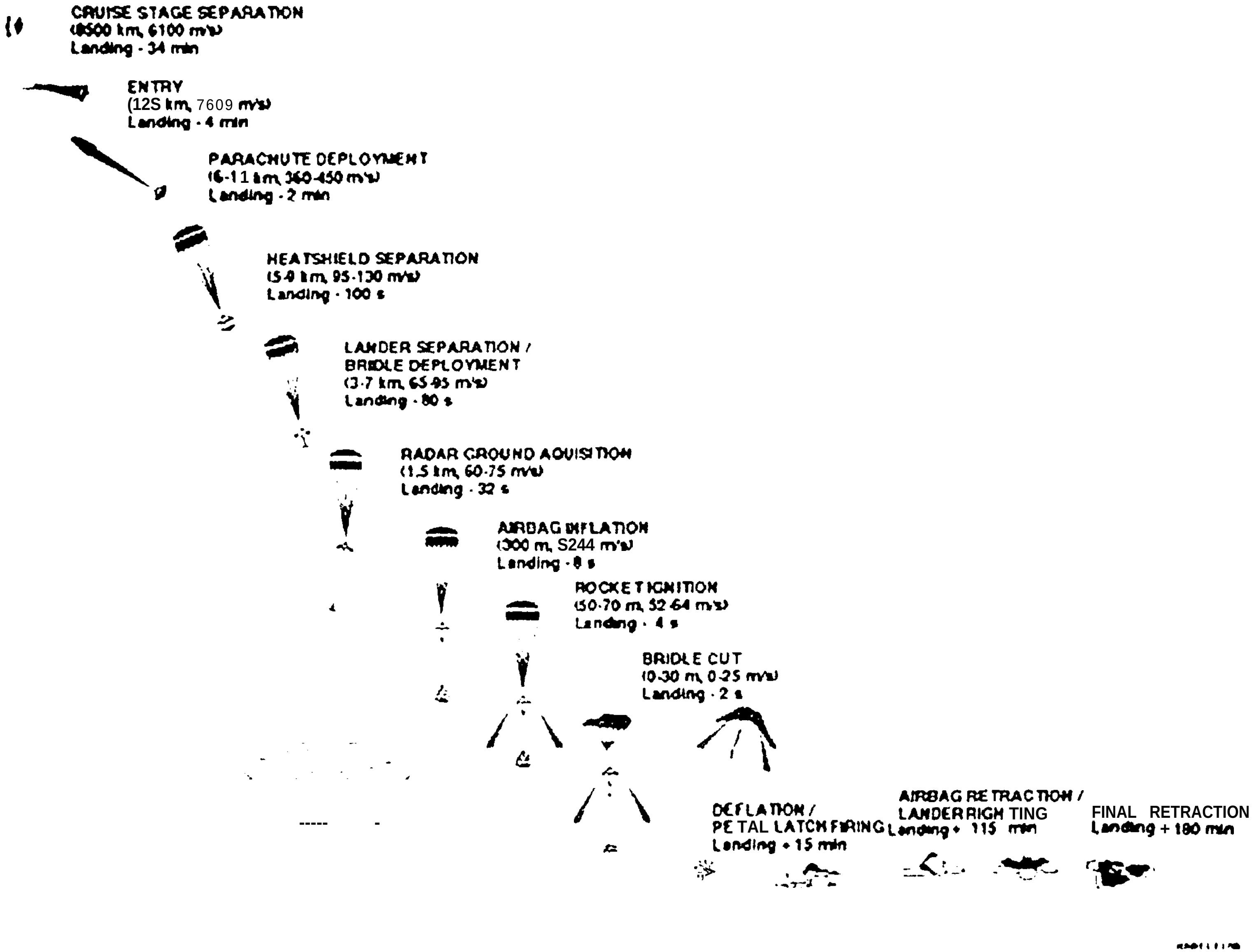
Landing Sequence

This diagram indicates the sequence of events during the descent to the Martian surface. Early in the sequence the direction to theearth is nearly directly normal to the-triangular top of the lander; that is, nearly in the null of the antenna were it not for interactions with the lander. Later in the descent, line to the earth is nearly normal to the antenna. During this sequence, the motion of the lander is expected to result in rapid variation of the antenna gain.


CRUISE STAGE SEPARATION
(8500 km, 6100 m/s)
Landing - 34 min
ENTRY
(125 km, 7609 m/s)
Landing - 4 min
PARACHUTE DEPLOYMENT
(6-11 km, 360-450 m/s)
Landing - 2 min
HEATSHIELD SEPARATION
(5-9 km, 95-130 m/s)
Landing - 100 s
LANDER SEPARATION /
BRIDLE DEPLOYMENT
(3-7 km, 65-95 m/s)
Landing - 80 s
RADAR GROUND AQUISITION
(1.5 km, 60-75 m/s)
Landing - 32 s
AIRBAG INFLATION
(300 m, 52-64 m/s)
Landing - 8 s
ROCKET IGNITION
(50-70 m, 52-64 m/s)
Landing - 4 s
BRIDLE CUT
(0-30 m, 0-25 m/s)
Landing - 2 s
DEFLATION /
PETAL LATCH FIRING
Landing + 15 min
AIRBAG RETRACTION /
LANDER RIGHTING
Landing + 115 min
FINAL RETRACTION
Landing + 180 min

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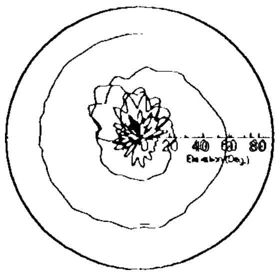
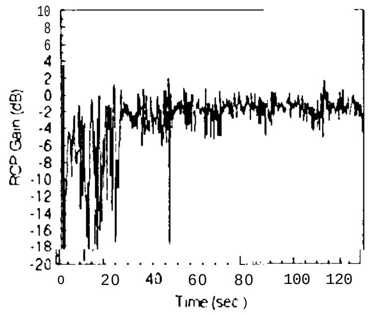
Link Simulation



Trajectory of the earth in the field of view of the antenna.



Calculated antenna gain during descent.

The plot on the left is one sample of the Monte Carlo dynamics simulation and indicates the angular location of the earth as viewed from the lander. The plot on the right is the resulting computed antenna gain versus time during the descent. The expected gain variation is obviously present and, in fact, precludes the use of amplitude modulation for this link.

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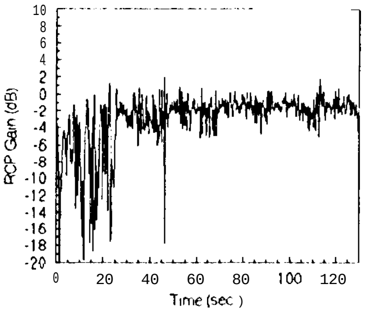
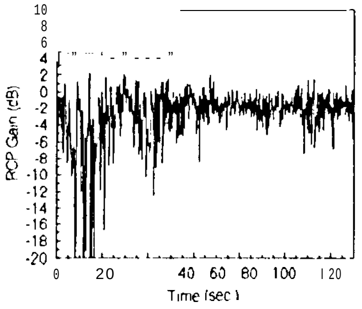
Link Simulation (Continued)



Calculated antenna gain during descent.



Measured antenna gain during **descent.**

This is a comparison of the computed (modeled) and measured antenna gain during descent. The measured result was obtained by programming the antenna range positioner to trace out the trajectory necessary to cause the transmit antenna to follow the path of the earth the in field of view of the antenna as indicated by the Monte Carlo dynamics simulation. Although, in principle, this could be done under command of the Flight System Testbed, the positioners used were not capable of executing this motion in real time so the gain data had to be prerecorded at a slower rate and then "played back" during the communications link simulation. Nevertheless, only the gain on the trajectory had to be measured as opposed to a full hemispherical pattern for later interpolation.

Concluding Remarks

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- Phase Measurements
  - The Pathfinder simulation used gain only.
  - Simulations using phase require more sophisticated data treatment.
    - Phase affected by distance to transmit site.
    - Distance varies during positioner motion,
    - Robotic model can be used to compensate for this variation.
- Latency
  - Positioners are inherently slow.
  - Pathfinder required pre-recording of data.
  - Deep space maneuvers are typically very slow so real-time positioner control may be feasible in those cases.

It is intended that this system provide to the testbed both amplitude *and phase* data concerning the measured antenna. Phase data is considerably more involved to obtain. It requires that phase variations due to positioner motion induced variations in transmitter/receiver distance be removed from the data. The means for doing this is under development using robotics theory to model the positioner. The results will be reported at a later date.

For the present case study, latency required that data be prerecorded. However, the physical motion involved here is much more rapid than that typically encountered in a deep space spacecraft maneuver. Thus, it is anticipated that in such situations the range positioners will be able to operated in real time under control of the FST simulation. This is a goal for our next case study.

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'I'he virtual spacecraft concept is embodied in a set of subsystems, either in the form of hardware or computational models, which together represent all, or a portion of, a spacecraft. For example, the telecommunications transponder may be a hardware prototype while the propulsion system may exist only as a simulation. As the various subsystems are realized in hardware, the spacecraft becomes progressively less virtual. This concept is enabled by JPL's Mission System Testbed which is a set of networked workstations running a message passing operating system called "TRAMEL" which stands for Task Remote Asynchronous Message Exchange Layer. Each simulation on the workstations, which may in fact be hardware controlled by the workstation, "publishes" its operating parameters on TRAMEL and other simulations requiring those parameters as input may "subscribe" to them. In this manner, the whole simulation operates as a single virtual system.

This paper describes a simulation designed to evaluate a communications link between the earth and the Mars Pathfinder Lander module as it descends under a parachute through the Martian atmosphere toward the planet's surface. This link includes a transmitter and a low gain antenna on the spacecraft and a receiving antenna and receiver on the earth as well as a simulation of the dynamics of the spacecraft. The transmitter, the ground station antenna, the receiver and the dynamics are all simulated computationally while the spacecraft antenna is implemented in hardware on a very simple spacecraft mock-up. The dynamics simulation is a record of one output of the ensemble of outputs of a Monte Carlo simulation of the descent. Additionally, the antenna/spacecraft mock-up system was simulated using APATCH, a shooting and bouncing ray code developed by Demaco, Inc. The antenna simulation, the antenna hardware, and the link simulation are all physically located in different facilities at JPL separated by several hundred meters and are linked via the local area network (LAN).

The Mars Pathfinder Lander low gain antenna is an azimuthally isotropic short monopole with a small skirt to limit radiation into the lower hemisphere. Thus, it has a pattern null in the vertical direction. The lander mock-up is a truncated three sided pyramid, as represented in

Figure 1, simulating the descent configuration of the spacecraft. 'l'he low gain antenna is mounted on a support mast about 6" long on the lander at the middle of the top edge of one of the petals. The mast is tilted by about 12 degrees inboard placing the phase center of the antenna slightly above the lander as shown. The antenna model was established by matching the far zone pattern of a three element colinear array to the measured free space antenna pattern. This required a complex weighting of 4.0 for the center element and 0.5 at -135 degrees for the end elements. Interaction of the radiation from the antenna with the spacecraft significantly modifies the pattern. So much so, in fact, that the modulation scheme for the actual flight link had to be modified as a result. An example computed pattern of the antenna when mounted on the mock-up is shown in Figure 2a along with that of the antenna alone for comparison. Figure 2b shows the measured pattern of the antenna on the mock-up.

As the spacecraft descends toward the surface beneath the parachute it swings and rotates causing the earth to execute a complicated trajectory through the pattern of the antenna. As mentioned earlier, the dynamics of the spacecraft during this phase of the mission was simulated via Monte Carlo techniques. One sample of the resulting ensemble of trajectories of the earth was selected for this study and this selected sample is shown in Figure 3.

The link simulation was carried out on the Mission System Testbed. The dynamics record as a function of time published angular coordinates of the earth relative to the lander at a sequence of times. These were used by the antenna simulation (or measurement) to provide corresponding antenna gain and phase to the link simulation process which computed bit error rate and corresponding errors in the message. Figure 4 shows the calculated antenna gain as a function of time during the descent of the lander. The message was "peter piper picked a pepper" repeated continuously. Example output of the link for our simulation looks like this. "peter piper pickow w?cnrqperpeter piper picked a pepper peter ..." Note that the errors are localized where the antenna gain drops as one might expect.

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EXTERNAL SUBMISSIONS

Section 336

Peer Review

Paper/Proposal Title:

AN APPLICATION OF THE "VIRTUAL SPACECRAFT" CONCEPT IN EVALUATION OF THE MARS PATHFINDER LANDER LOW-GAIN ANTENNA

- ❑ Refereed Paper
  - ❑ Full Paper
  - ❑ Letter/Communication
- ☑ Conference Paper
- ❑ Trade Magazine Article/Newsletter
- ❑ Proposal

Author(s):
R. J. POGORZELSKI AND R. J. BECKON

Recommended Action:

- ❑ Submit as is.
- ☑ Modify as suggested. Minor suggested grammar change
- ❑ Not to be submitted at this time.

Suggested Modification(s):

See text

General Comments:

This is an interesting paper - I assume you will address the mismatch between the computed & measured data in the talk (if necessary)

Q: Does the test bed US the measured data or computed data?

Reviewer: J. Vacchione Section: 336 Date: 12/11/96