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MIP: the First ISRU Flight Experiment

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The beginning: 1996

- Many studies had shown that exploration of Mars could be far more effective if the local resources of the planet could be used to manufacture the fuel for the return voyage
- Since oxygen is the largest (by mass) fraction of rocket fuel, the generation of oxygen is the most critical need.
- But… although many people talked about it, nobody was doing anything…

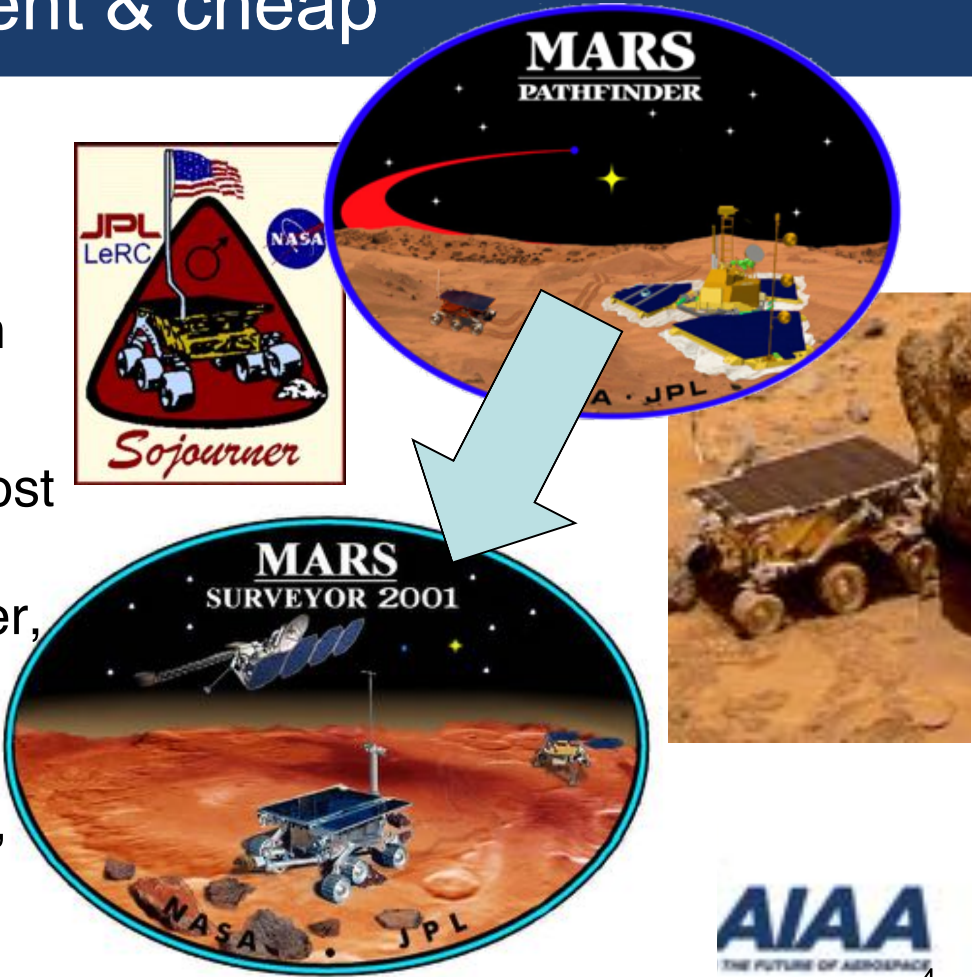
The beginning: MIP

- David Kaplan at NASA Johnson Spa
collaboration with NASA Lewis, now
proposed to the Human Exploration
that an upcoming robotic mission to
include a technology demonstration
demonstrate oxygen production on M
to develop the technology toward a h

- He believed that only an actual demonstration on Mars could break through the roadblock of engineering reluctance to rely on unproven technology.

Mars Surveyor: fast, frequent & cheap

- The landing of Mars Pathfinder in 1997 generated a high degree of excitement about Mars exploration
- The NASA Administrator made a commitment to sending two low-cost missions to Mars at each launch window, one lander and one orbiter, to be called the Mars "Surveyor" program.
- The missions would be small, fast, and cheap



We had a mission…

- MIP was agreed to be a payload for the second of the Surveyors landers, the Mars-2001 Surveyor Lander
- We had a project, and now we had a mission to fly it on!
- All we needed was an experiment, and a team to build it… on a short deadline and a tight budget

Selection of the Oxygen Generation Process

- Most readily accessible resource on Mars is the CO_2 atmosphere: available everywhere on the planet.
- Carbon dioxide is 72.5% oxygen by weight
- Several different methods of making oxygen from Martian carbon dioxide have been proposed.

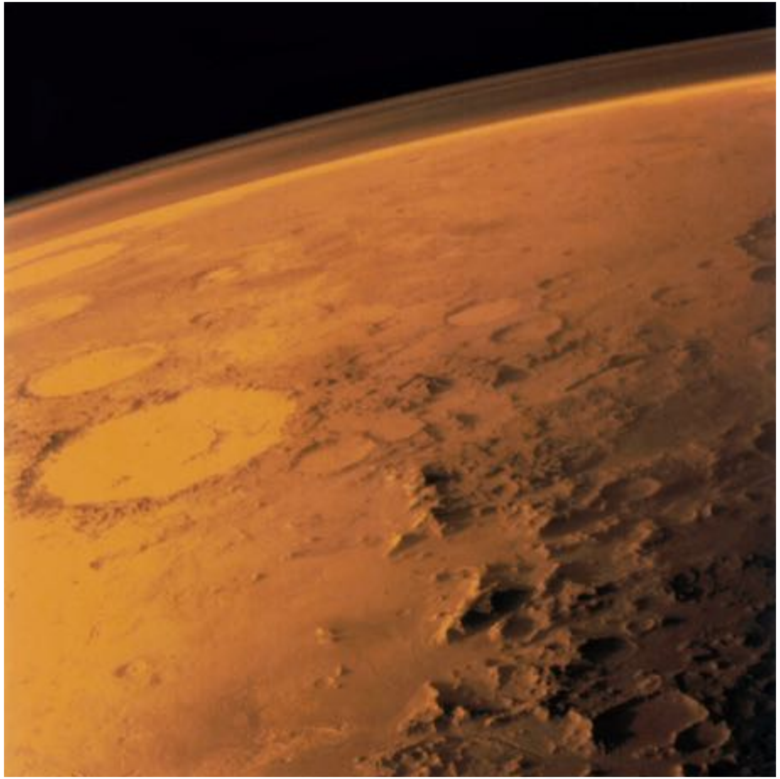


Image from Viking Orbiter

Oxygen Generation: Solid Oxide Electrolysis

Process selected was to generate oxygen by direct electrolysis:

- (cathode): $CO_2 + 2e^- \rightarrow O^{2-} + CO$
  Applied field moves oxygen ions move through the solid electrolyte
- (anode): $2\ O^{2-} \rightarrow O_2 + 4e^-$
- (net) $2CO_2 \rightarrow O_2 + 2\ CO$

Done via a high-temperature (~750°C) electrolysis using a zirconia-based solid electrolyte

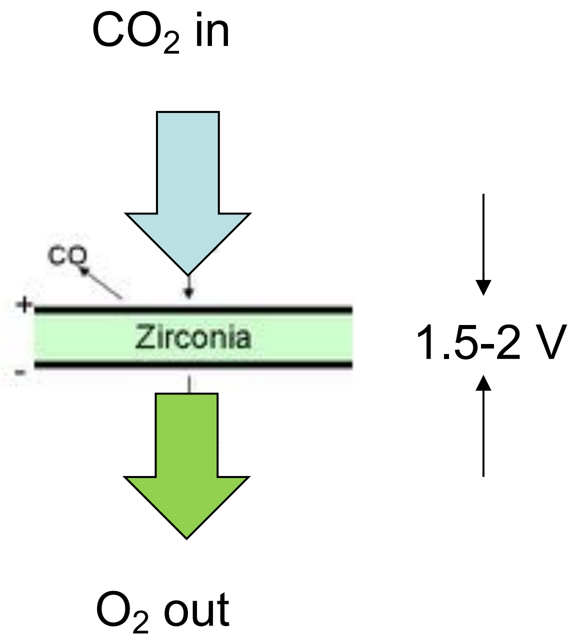
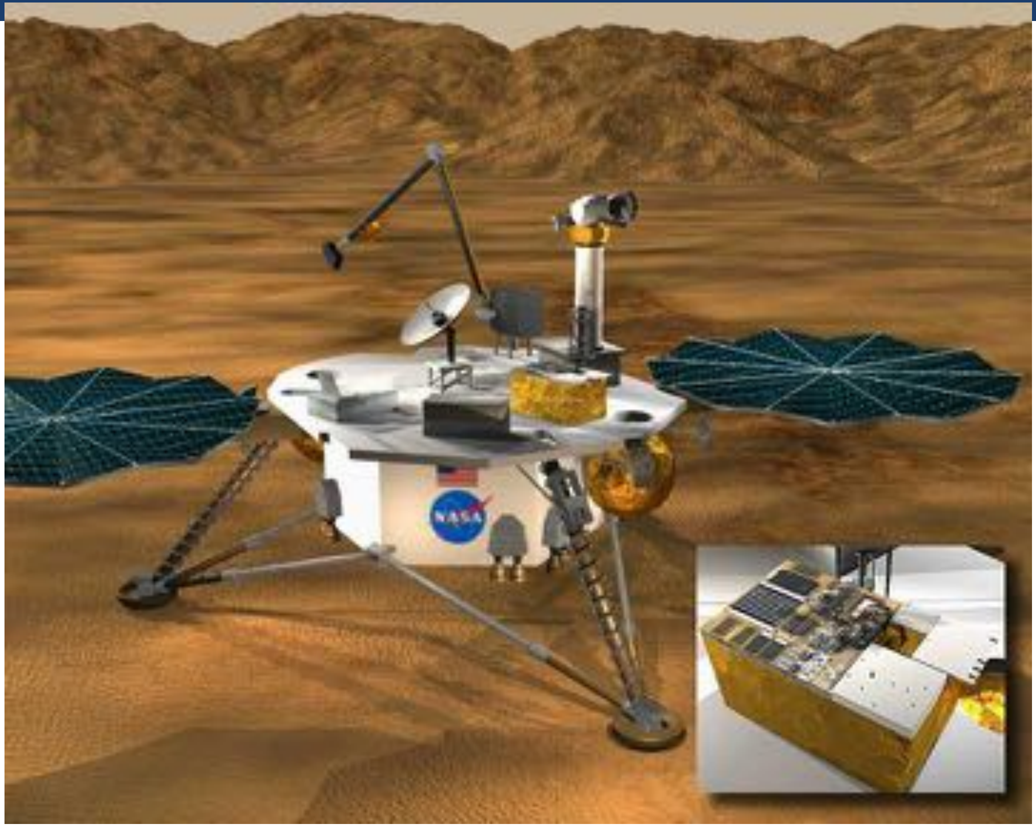


Image from Viking Orbiter

MIP



The MIP experiment set

MIP comprised five experiments, to demonstrate the key components of the in-situ propellent production:

- Mars Atmospheric Acquisition and Compression (MAAC)
  Lead: Co-Investigator **Paul Karlmann,** JPL
- Oxygen Generator Subsystem (OGS)
  Lead: Co-Investigator **K. R. Sridhar,** University of Arizona
- Mars Thermal Environment & Radiator Characterization (MTERC)
  Lead: Co-Investigator **David Brinza**, JPL
- Mars Array Technology Experiment (MATE)
  Lead: Co-Investigator **David Scheiman**, OAI/NASA Glenn
- Dust Accumulation and Repulsion Test (DART)
  Lead: Co-Investigator **Geoffrey Landis** OAI/NASA Glenn

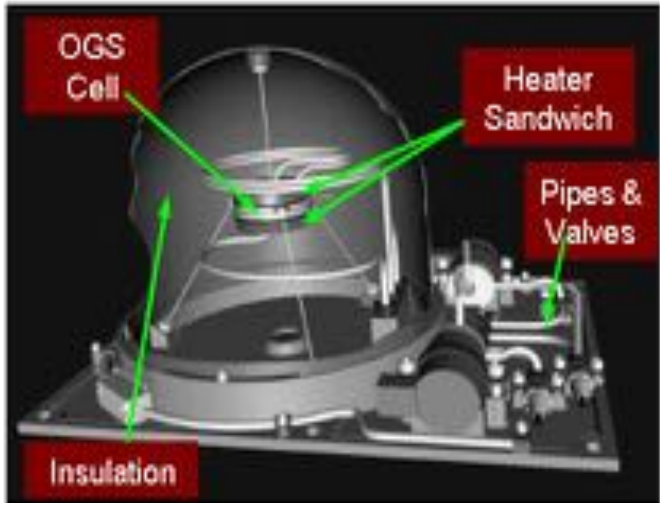
Mars Atmospheric Acquisition and Compression

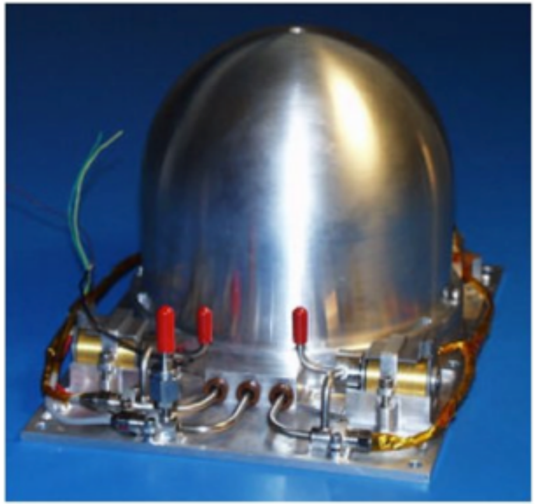
- The MAAC collects and compresses atmosphere using a carbon dioxide sorption pump.
- The pump is a pressure vessel filled with a zeolite that adsorbs CO_2 at low temperatures during the night.
- When temperature rises in the daytime, zeolite releases the adsorbed CO2, pressurizes it, and stores it for use by OGS.
- The net result is to compress the atmosphere from 800 Pa to 55 kPa using the Mars day/night thermal cycle.

Oxygen Generation Subsystem (OGS)

- The OGS designed and fabricated at the University of Arizona under OGS co-Investigator K. R. Sridhar, on a contract to NASA JSC.
- OGS was designed to produce propellant-grade, pure oxygen by zirconia electrolysis of carbon dioxide.

Oxygen Generation Subsystem (OGS)





Left: labelled schematic. Right: flight unit.

- The flight unit built for the Surveyor mission had a mass of 1 kg and produces 0.04 g/hr. of O_2 at 131.5mA cell current, at approximately 1.6V applied voltage
- Oxygen production rate was limited by the power provided by the lander: 15 watts maximum (daytime only; no night operations)

Mars Thermal Environment & Radiator Characterization

- Thermal management is critical for efficient operation of an ISPP plant, but when MIP was proposed, little was known about thermal management on Mars
- Waste heat is rejected to space via thermal radiators.
- MTERC was to characterize and demonstrate the performance of thermal radiators and measure the night sky temperature.
- The MTERC experiment included four radiator plates: two with high emissivity and two with low emissivity.
- One high and one low emissivity plate were protected by a movable cover to serve as the experiment control radiators, allowing the effect of dust deposition on the radiator performance to be observed.

Mars Thermal Environment & Radiator Characterization

- The MTERC experiment included four radiator plates: two with high emissivity and two with low emissivity.
- One high and one low emissivity plate were protected by a movable cover to serve as the experiment control radiators, allowing the effect of dust deposition on the radiator performance to be observed.

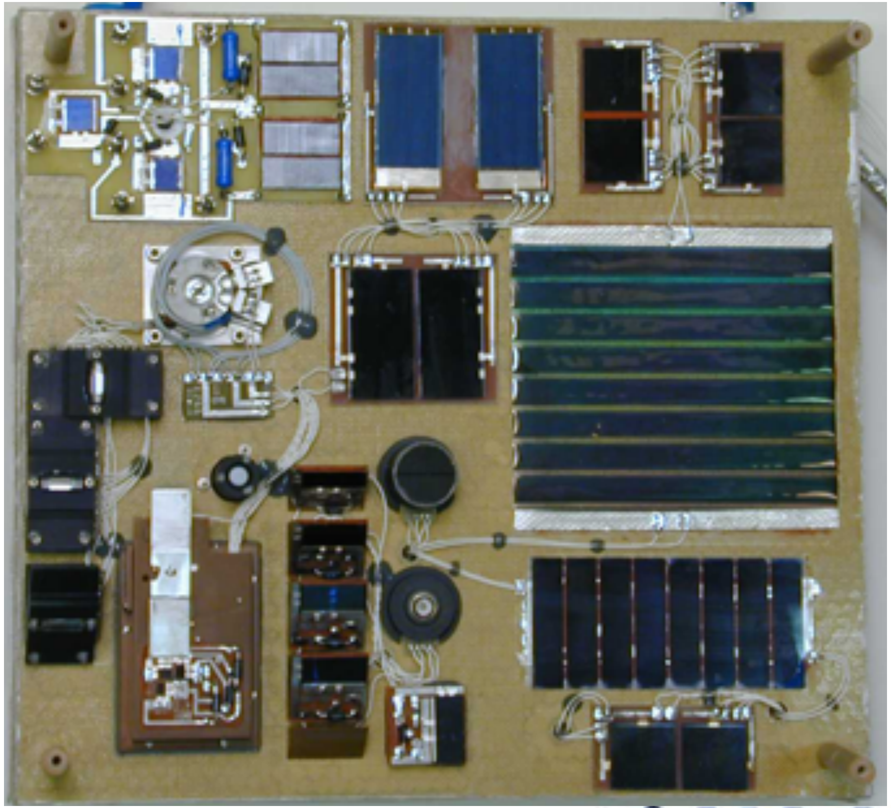
MTERC

Mars Array Technology Experiment

- Power production is critical to In-situ propellant production, but little was known about solar array performance on Mars
- MATE was to test the performance of several advanced photovoltaic solar cells in the Martian solar environment and measure the direct and scattered solar spectrum at the Mars surface.
- MATE incorporated five different individual solar cell types, two different solar cell strings, and temperature sensors to characterize promising solar cell materials and designs, plus radiometers and a dual spectrometer.
- Besides measuring the solar spectra on Mars, the dual spectrometer were intended quantify daily variations in spectra and intensity and improve atmospheric modeling.

Mars Array Technology Experiment (MATE)

- MATE included five different individual solar cell types, two different solar cell strings, and temperature sensors to characterize promising solar cell materials and designs.
- MATE incorporated two radiometers and a dual spectrometer from 300 to 1700 nm, incorporating two separate photodiode arrays each with its own fiber optic feed and grating.



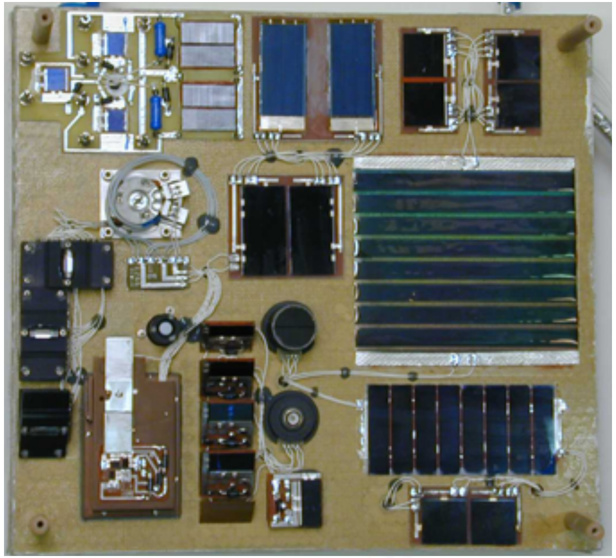
Experiment deck showing MATE solar cells (right side) and DART (left)

Dust Accumulation and Removal Test (DART)

Pathfinder data suggested that dust settling from the Martian atmosphere could be a significant factor in the degradation of solar arrays on Mars. DART was to measure the dust settling rate, investigate the properties of settled dust and to test techniques to mitigate the settling of airborne dust onto solar arrays

.To measure the properties of settled dust, DART incorporated:

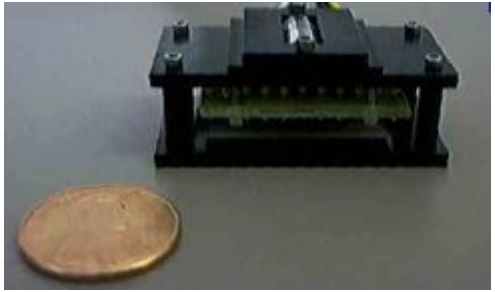
- Dust accumulation monitor
- Microscope.
- Tests of methods to mitigate dust deposition.
- Sun position sensor package.



Experiment deck showing
MATE solar cells (right side) and DART (left)

Dust Accumulation and Removal Test (DART)

- **Dust accumulation monitor**: rotating cover using shape memory alloy actuation, similar to the MAE experiment on the Sojourner
- **Microscope.** Resolution ~1μm; measures the amount and the properties of settled dust, and determine the rate of dust deposition, the particle size distribution, the particle opacity, shape, and information about the particle composition from measurements of the optical properties.
- **Dust mitigation.** Tests of dust mitigation and removal, including tilted solar cells, low-friction surface coatings, and high-voltage electrostatic dust repulsion.
- **Sun position sensor** to calibrate solar cell performance against sun angle for both MATE and DART.



Sun position sensor (shown with penny for scale)

Tilted solar cells, to test rate of dust accumulation as function of tilt angle.

MIP: Flight hardware

External envelope:
40 x 24 x 25 cm
(15.7 x 9.4 x 9.8 inches)

Total mass:
8.5 kg (18.7 lb.)

Maximum power:
15 W.

Fabrication of the MIP flight hardware was completed in 1999, and was delivered for qualification testing in preparation for integration onto the lander in the summer of 2000.

Mars 2001 Surveyor Lander

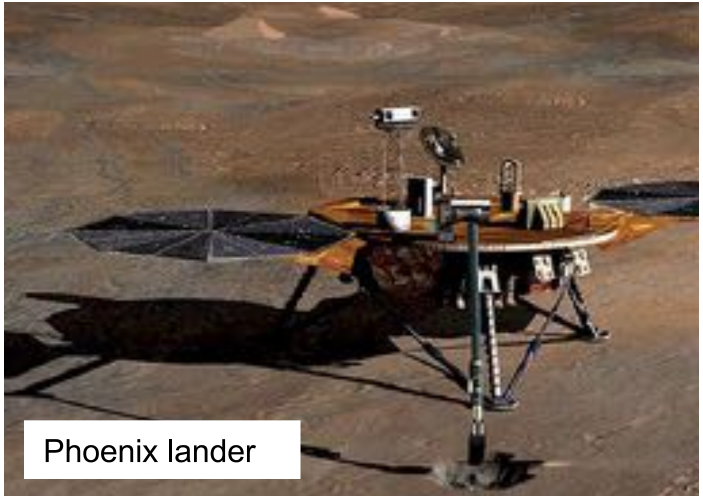
Mars-2001 Surveyor Lander spacecraft integrated into aeroshell for testing in 1999

The End

- On December 3, 1999, the first of the Mars Surveyor Lander spacecraft, the Mars Polar Lander, crashed during its landing sequence.
- Since the Mars 2001 Surveyor lander was an identical spacecraft, the Surveyor Lander program was put on hold.
- A review board concluded that the “faster better cheaper” approach to planetary spacecraft resulted in too many cuts of critical safety checks, and the program was cancelled.

After the End

- The spacecraft built for the 2001 Surveyor mission was eventually refurbished and flown as the Phoenix mission… but with a different set of experiments.



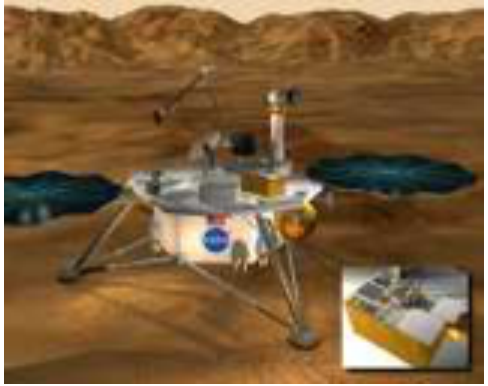
Phoenix lander

- Although MIP ultimately never flew, the core concept of making oxygen by solid-electrolyte electrolysis of the Martian carbon dioxide was resurrected twenty years later in the form of the MOXIE package, launched to Mars this year

…but that's another story.

Acknowledgement

➢ I would like to acknowledge the entire MIP team for their exceptional work in putting together an exemplary experiment package on a tight budget and a tighter schedule, and making it come in on time, on spec, and on budget.



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