Video Technologies for Mars

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Introduction

- *One desirable goal for missions to Mars is to provide real-time or near real-time television quality full motion video.*
- *Studied for a Mars Airplane mission to fly small plane down the Valles Marineris canyon on Mars for thirty (30) minutes.*
- *Micromission for Year 2003 included in the NASA Year 2000 Budget Proposal.*

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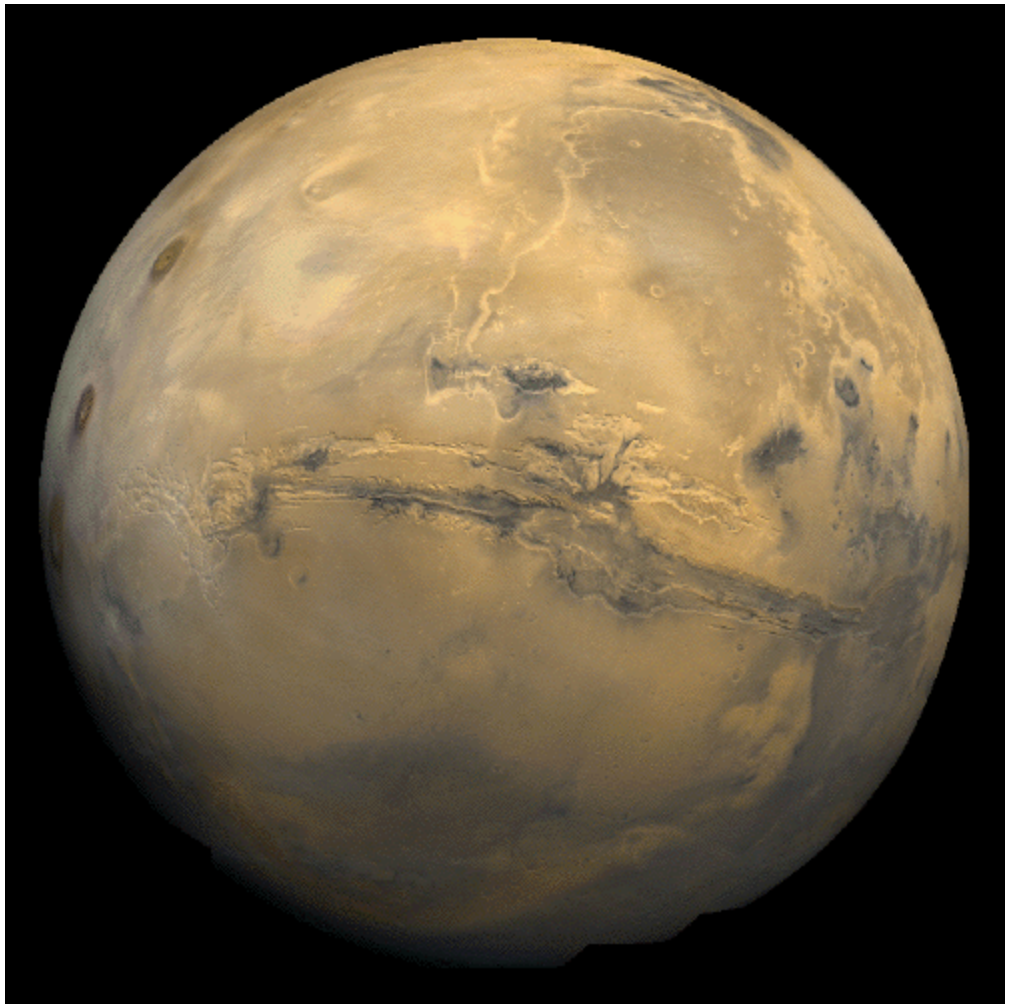
Introduction

- *The issues are largely the same for other Mars Airplanes (aerobots).*
- *The issues are largely the same for Mars Rovers (telerobots).*
- *The issues are largely the same for television coverage of manned missions.*

Valles Marineris



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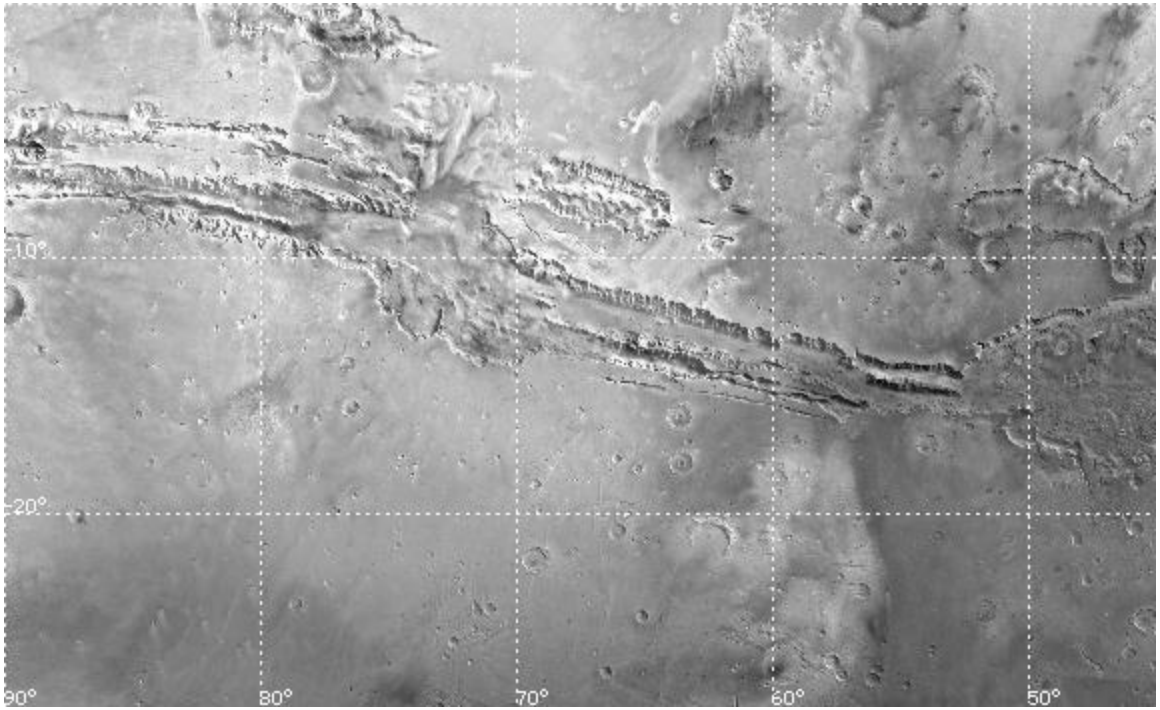
Valles Marineris



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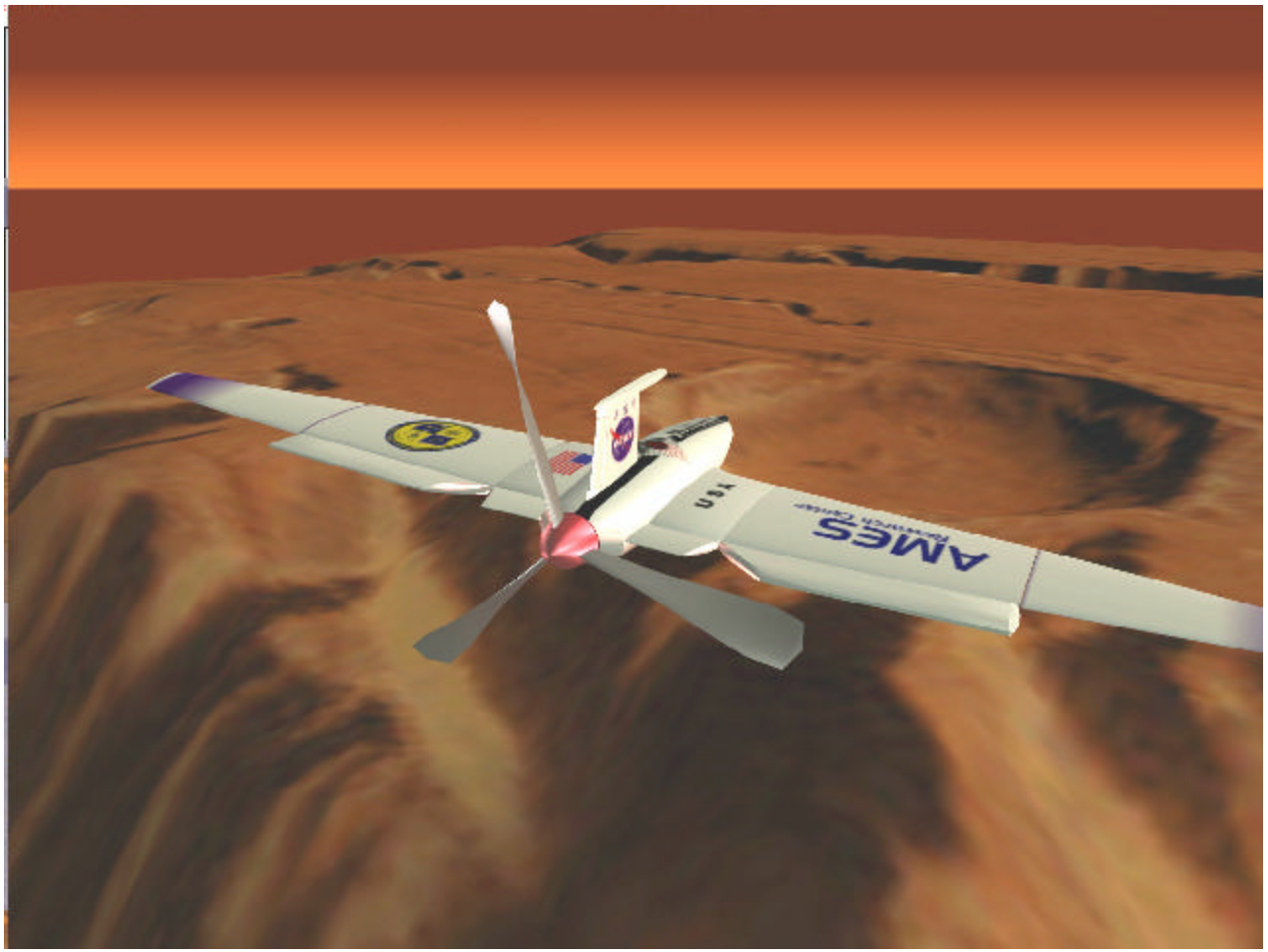
Valles Marineris

- *May have been formed by flowing water in the distant past.*
- *Other possibilities? Tectonic or volcanic activity? Fissure from asteroid impact?*
- *High resolution zoom pictures of canyon walls to look for sedimentation or other features.*

Wings on Mars

- *There have been many proposals for airplanes to fly on Mars.*
- *Larry Lemke et al recently*
- *Many more. Apologies to the unnamed.*

A Mars Airplane



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Kittyhawk (MAGE Proposal)

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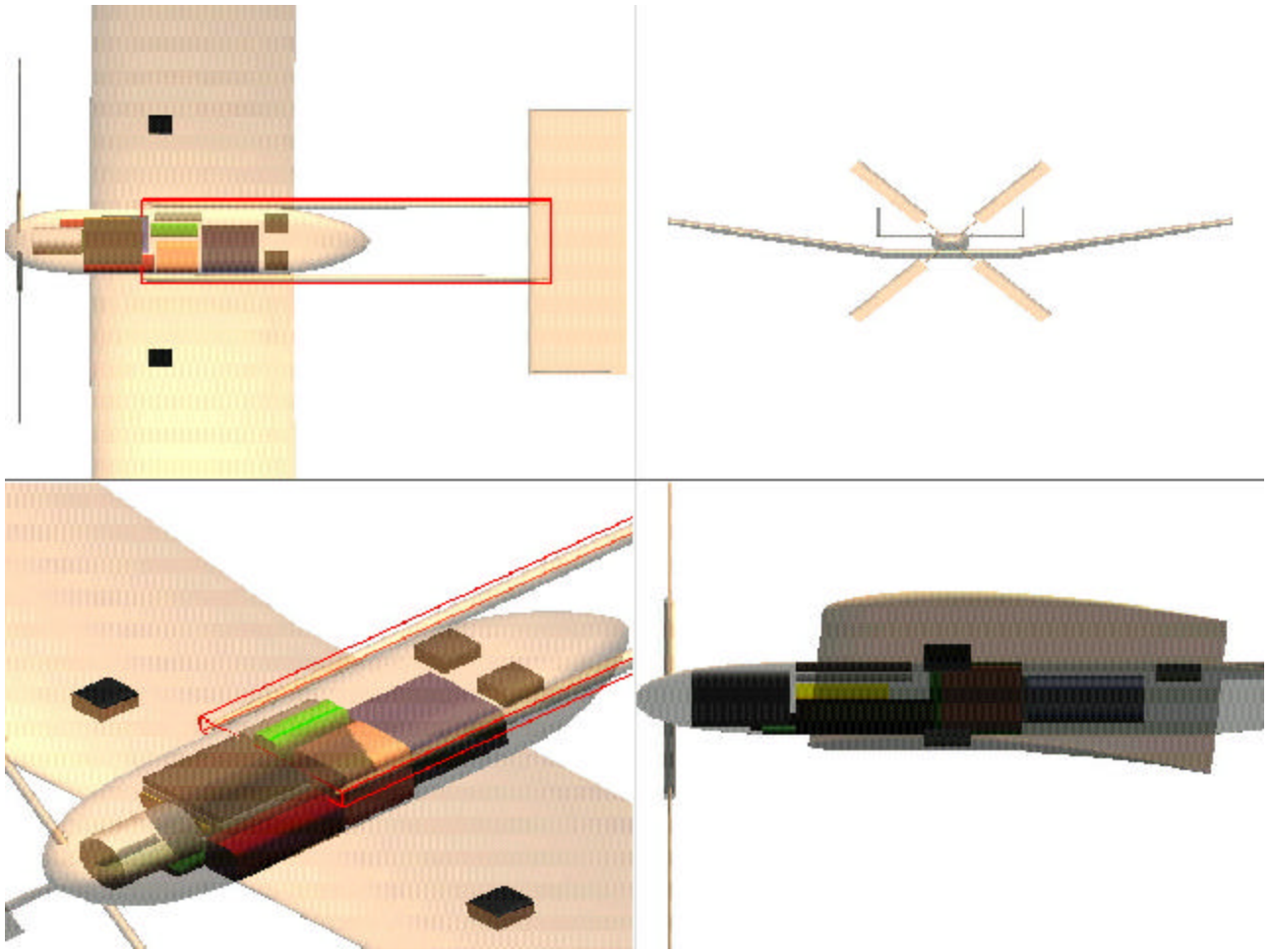
Ames Plane for Year 2000



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Baseline Proposal

- *NTSC Color Television Camera (CCD)*
- *MPEG-1 or MPEG-2 Encoder Board*
- *352 by 240 pixels at 30 frames per second*
- *4:2:0 Digital Video Format (subsample the color components by two horizontally and vertically)*

Video System Parameters

- *TOTAL WEIGHT: 2 Kilograms*
- *TOTAL SIZE: 120 mm by 220 mm by 30 mm (792 cm^3)*
- *TOTAL POWER DISSIPATION: 20 W*
- *BITRATE: 1 Mbit/second (not including error correcting codes)*
- *MINIMUM ACCEPTABLE BIT ERROR RATE: 10^{-6} (assuming random errors)*

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Video System Parameters

- *1 Mbit/second exceeds any bit rate achieved from Mars to Earth.*
- *Constant Bitrate (CBR) MPEG Encoder if possible. Given very tight bitrate contraints of communication links, want to limit the bitrate to fixed maximum if possible.*

Back of the Envelope

- *TOTAL WEIGHT: 1 Kilogram*
- *TOTAL SIZE: 100 mm by 200 mm by 10 mm (200 cm^3)*
- *TOTAL POWER DISSIPATION: 15-20 Watts*
- *Based on COTS CMOS components!*
- *NOT SPACE QUALIFIED*

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Hitachi MPEG Camera

- *TOTAL WEIGHT: 540 grams*
- *TOTAL SIZE: 83.8 mm by 142.2 mm by 55.9 mm (666 cm^3)*
- *TOTAL POWER DISSIPATION: 6.5 Watts*
- *Includes battery pack, hard disk, etc.*
- *NOT SPACE QUALIFIED*

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Video System Parameters

- *This conservative estimate includes substantial extra weight and volume for radiation shielding, rugged packaging, and extra power for heaters or radiation hardened CMOS.*
- *The overhead for error correcting codes is not included since this varies from code to code.*

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Reasons for MPEG

- *Many verified (tested and debugged) real-time MPEG encoder and decoder chips and chip designs from multiple manufacturers exist. Selecting MPEG does not lock NASA into a single manufacturer or design.*

Reasons for MPEG

- *Successful products use MPEG at 352 by 240 pixels at 30 frames per second in 4:2:0 format using the default quantization matrices, meaning 1 Mbit/second video, to provide television quality video.*
- *VideoCD players, CD-I players, etc.*

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Reasons for MPEG

- *MPEG compression outperforms most other image and video compression technologies.*
- *Wavelet video and image compression is not standardized. All working implementations are proprietary. Very few hardware implementations exist. Expertise is hard to find.*

Reasons for MPEG

- *MPEG is preferable to the ITU-T H.261, H.263, and H.263+ videoconferencing standards because MPEG supports bi-directionial predictive pictures, B pictures, for better compression.*
- *Videoconferencing standards are designed for "talking heads" video with static backgrounds.*

Reasons for MPEG

- *MPEG is preferable to ISO JPEG still image compression, e.g. Motion JPEG, for full motion video because MPEG exploits the small differences between successive frames.*
- *Much greater compression ratio than Motion JPEG.*

Reasons for MPEG

- *C programming language implementations of MPEG encoders and decoders, both MPEG-1 and MPEG-2, are publicly available.*
- *ISO Standard Documents*
- *Over a dozen in-depth books.*
- *Many MPEG Experts*

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MPEG Problems

- *MPEG is sensitive to single bit errors. In a worst case, a single bit error can corrupt a half-second of video.*
- *No publicly available Verilog, VHDL, or other Hardware Description Language (HDL) MPEG encoders or decoders exist with timing problems solved. All hardware implementations are proprietary.*

Hardware Video Encoder

- The Mars Airplane will need to compress the "low resolution" video in real-time.
- 30 minutes of uncompressed NTSC video is 131 Gigabits (color) or 44 Gigabits (black and white).
- MPEG at 352 by 240 by 30 frames per second requires 5,000 MIPS to encode.

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Alternative Compression

- *Wavelet Video Compression*
- *MPEG-like video using Block Discrete Cosine Transform (DCT) and motion estimation, but designed to reduce senstivity to errors. For example, Error Resilient Entropy Coding (EREC) proposed by Swann and Kingsbury.*

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Color and Bitrates

- Can reduce bitrate slightly by sending black and white, the luminance color component, only.
- Color is already subsampled in 4:2:0
- Naively one third of 4:2:0 video is color
- MPEG compressed color more.
- Only gain about 20 percent.

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Below Television Quality

- *15 frames per second (jerky)*
- *176 by 120 pixels (grainy, blocky)*
- *Increase quantization step size (artifacts such as blocking, ringing, and blurring)*
- *Push down to 384 Kbits/second? Quality will be poor.*
- *Slide show may be preferable!*

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Noisy Channel Issues

- *BER 10^{-5} for current missions*
- *BER 10^{-6} by 2003?*
- *Error correcting codes add to required bitrate but are needed to achieve "low" bit error rates in deep space.*
- *MPEG sensitive to bit errors.*

Noisy Channel Issues

- *MPEG at BER of 10^{-4} is visual noise!*
- *MPEG at BER of 10^{-5} is poor*
- *MPEG at BER of 10^{-6} is fair (can use)*
- *MPEG at BER of 10^{-7} is good (can use)*
- *Actual errors with error correcting codes are not random bit errors :-(*

Space Hardening

- 10-20,000 rads (Silicon) for Earth to Mars missions.
- COTS parts have thresholds as low as 500 rads and as high as 100,000 rads(Si).
- Off the shelf MPEG Encoders are commercial "bulk" CMOS. May not withstand radiation. Must test.

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Space Hardening

- Aluminum box around MPEG Encoder Board.
- Rugged circuit board and packaging may be required.
- Radiation hardened CMOS or SOS. Radiation hardened MPEG encoder chip or chip set is big project.

Space Hardening

- MPEG chip design is demanding!
- High risk of failure.
- No public timing information.
- Timing changes for each semiconductor process.
- MPEG sensitive to small errors. Must get the design right.

Slide Show Option

- *8.25 Kbits/second Mars Pathfinder*
- *Max 85 Kbits/second Mars Global Surveyor*
- *256 Kbit/second in 2003?*
- *Slide Show (reduce frame rate)*

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Slide Show Option

- *MPEG exploits small differences between successive frames.*
- *At low frame rates (1 frame per second) differences between successive frames may be too large for effective use of MPEG.*
- *Errors propagate across frames in MPEG.*

Slide Show Option

- *At some low frame rate, better to use still image compression such as ISO JPEG still image compression for slide show.*
- *Still image restricts errors to a single frame.*
- *Naive MPEG at 1 fps: 33.3 Kbits/second*
- *Naive JPEG at 1 fps: 66 Kbits/second*
- *Still a demanding bitrate for Earth to Mars*

Slide Show Option

- *POWER, WEIGHT, and VOLUME essentially the same as MPEG video system. Just substitute still image encoder, either ASIC or CPU, for MPEG Encoder.*
- *Space Hardening Issues are the same.*
- *Noisy Channel Issues may differ.*
- *Can use software image encoding. More flexibility. Wavelets!*

Mars Local Relay

- *Several Gigabits of RAM has been sent to Mars already.*
- *30 minutes of MPEG-1 video requires 1.8 Gigabits of storage.*
- *Can forward stored video at slower than real-time rates, e.g. 256 Kbits/second*
- *Several hour delay with store and forward.*

Mars Local Relay

- *Several Gigabits of RAM*
- *High Gain Antenna to Earth*
- *For Valles Marineris, a communication satellite in Geosynchronous Mars Orbit over the canyon seems ideal.*
- *Fly Mars Airplane toward a land station on canyon floor?*

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Mars Local Relay

- *Geosynchronous Mars Orbit Satellite*
- *Delayed Flyby of Mars (as in MAGE)*
- *Balloon*
- *Land Station*
- *Other concepts?*

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Mars Local Relay

- *A store and forward relay on Mars or in Mars orbit can retransmit corrupted data.*
- *Retransmission eliminates noisy channel problems at cost of longer delay. Must wait for retransmission of the corrupted data.*
- *With four to eight minute Earth to Mars delay, video never used in real-time.*

Mars Local Relay

- *A Mars Local Relay, especially a Geosynchronous Mars Orbit satellite, can be justified to support multiple missions, not just Mars Airplanes.*
- *Local Relay can include science instruments.*
- *Local relay could include video camera as well. Dust storms.*

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Mars Local Relay

- *Can relay be a micromission itself?*
- *Accompany the Mars Airplane somehow arriving in orbit ahead of the plane?*
- *It is difficult to secure funding and support for pure support missions that enable other missions since there is no immediate payback and dollar cost is substantial.*

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Conclusion

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Conclusion

- *Principal obstacle to video appears to be the limited bit rates of current or near future Mars to Earth communication links.*
- *A local relay station such as a Geosynchronous Mars Orbit communications satellite may offer a solution.*

Further Information

- *White Paper on Video Technologies for Mars Airplane*
- *http://zeus.arc.nasa.gov/mars.pdf*
- *In Adobe Acrobat Portable Document Format (PDF)*