G. MARCONI ORBITER:
THE FIRST INTERPLANETARY COMMUNICATIONS SATELLITE

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Abstract

The ASI/NASA G. Marconi Orbiter (GMO) will provide relay communications, timing and radiometric services to spacecraft approaching Mars and to relay users in the vicinity of Mars from 2008 to 2018. GMO will increase the quantity of data that relay users can send to Earth by orders of magnitude and dramatically increase the time during which operators on Earth can be in contact with robotic explorers on Mars. The GMO design team is developing standard processes and interfaces in cooperation with the designers of other Mars orbiters to enable relay users to easily access multiple relay orbiters.

Introduction

Nearly every orbiter sent to Mars beginning with the Viking orbiters in 1976 has carried a relay radio to facilitate communications between ground stations on Earth and robotic explorers (hereinafter "assets") at or near Mars.[1] Relay radios have numerous benefits to in-situ Mars elements:

- Range^2, which is proportional to the radiated power needed to transmit data from a sender to a receiver, is 75 dB to 122 dB lower for communications with a Mars relay orbiter than for communications directly with Earth.
- Depending on its orbit, a Mars relay orbiter may be in view for considerably longer periods than Earth is in view.
- A Mars relay orbiter can be used to track assets during critical maneuvers, such as Entry, Descent and Landing (EDL), over a much greater range of locations near Mars and with much higher data rates and resilience than direct Earth communications.
- A relay orbiter can provide timing and navigation services.

Heretofore, all orbiting relay radios at Mars have been on science orbiters whose primary missions have been to gather remote sensing data. Orbit and spacecraft characteristics for such missions are optimized for science experiments, not for relay support. As a result, orbiting relays have nearly always been on spacecraft in low orbits with low performance UHF relay antennas. Multipath interference generated by scientific instrumentation and other extraneous spacecraft elements mounted near relay antennas has also degraded performance.

The G. Marconi Orbiter (GMO) will be the first Mars orbiter optimized for its relay mission – the first true Mars communications satellite. A joint NASA and ASI project, GMO will be placed into a high orbit designed primarily for relay support. GMO will have both a high performance UHF relay antenna and an X-band relay antenna.

This paper briefly describes expected users of the GMO relay, GMO End-to-End Information System (EEIS) design, GMO operations, and test setups. A companion IAF paper[2] describes the GMO spacecraft.

Mars Relay Network

NASA's Mars Reconnaissance Orbiter will arrive at Mars two years before GMO, and the CNES Premier orbiter a couple of months after GMO. All three of these orbiters will have Electra relay radios, currently under development by JPL and Cincinnati Electronics.

There will be no relay users at Mars after the NASA Mars Exploration Rovers and the British Beagle II missions to be launched in 2003 until 2007. The relay users arriving in 2007 and later plan to rely on MRO, Premier and GMO for their relay needs. There thus can be a clean break between relay systems before 2007 and the MRO, Premier and GMO relay systems. The designers of MRO, Premier and GMO are working together and with future relay users to design a Mars Relay Network that is optimal from a network perspective.

Relay Users

Expected users of GMO – as well as other orbiters in the Mars Relay Network – include the CNES Net-Landers and a NASA Mars Scout mission in 2007, the NASA Mars Smart Lander (MSL) in 2009, a Mars Sample Return mission, and various other less well-defined robotic Mars probes.[1]

The NetLanders and MSL are each typical of a broad class of landers. NetLanders are limited to brief communications near local noon (to maximize solar power), while MSL can transmit for hours at a time any time during the day. Due to the short and infrequent communications of the NetLanders, they are generally well served by relays on science orbiters. MSL, on the other hand, will garner huge benefits from the use of GMO. Table 1 below shows daily data return possible from MSL and from NetLanders through MRO, GMO and Premier, as well as an MSL Direct-To-Earth link.

*Table 1. Data Return, Mb/Sol**

Link	MSL	NetLander
MSL Direct-To-Earth	155	N/A
MRO UHF Relay	58	4-6
Premier UHF Relay	155	5-18
GMO† UHF Relay	436	7-19
GMO X-Band Relay	14,000	N/A

Interoperability

GMO will be just a part of the Mars Relay Network – albeit a key part. Relay users generally need to utilize more than one relay orbiter. This raises significant interoperability issues that need to be addressed by the designers of both the relay orbiters and relay users:

- Interfaces between multiple assets and multiple orbiters
- Interfaces between multiple orbiter ground systems and multiple asset ground systems
- Test and verification of multiple pathways

To facilitate common interfaces for diverse relay elements, the Consultative Committee for Space Data Systems (CCSDS)[3] developed the Proximity-1 protocol. This protocol, however, covers just the data link and physical layer between the relay user and the relay orbiter. Furthermore, the Proximity-1 protocol can be implemented in several ways – a common application profile is needed for missions to Mars to ensure a well-defined implementation of the protocol that all relay users can rely on.

There is the potential for many differences in how data is processed between relay orbiter and asset Ground Data Systems. Common interfaces are desirable on the ground end of the link as well as the space end so that asset ground system designers need not design multiple interfaces to multiple relay orbiter ground systems.

It is also desirable for relay users to be able to thoroughly test their relay communications links before flight and while their missions are en route to Mars.

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* A sol is a Martian day, about 24 hours and 37 minutes.

† Reference 4450 km orbit.

These issues are addressed by GMO's End-to-End Information System design, which is being developed in collaboration with the designers of relay user missions and other Mars relay orbiters.

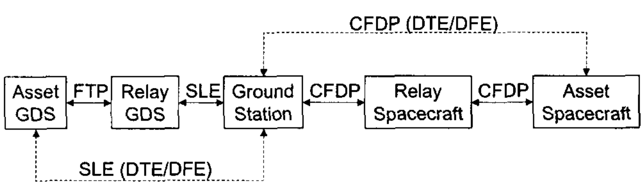
<u>End-to-End Information System</u>

The GMO End-to-End Information System (EEIS) design is based upon the following guidelines:

1. Communications between each asset and its associated Ground Data System (GDS) shall be in the form of data products.
2. The custody of data products shall be transferred at each major node of the network.
3. There shall be an accounting of data product transfers at each major node of the network.
4. Asset spacecraft can use the same interface regardless of which relay spacecraft they are using.
5. Asset spacecraft can use the same high-level protocol to communicate directly with Earth that they use to communicate through relay orbiters.
6. The interface between the relay orbiter GDS and the asset GDS must be the same for each relay orbiter.
7. The GMO EEIS must conform to CCSDS recommendations.

Upper layer protocols used between major network nodes are illustrated in Figure 1.

Figure 1. Upper Layer Protocols



Custody transfer operates by reliably transferring data products between each major node. Once the sender has received an acknowledgement from the recipient that the recipient has the complete data product, the sender is no longer be responsible for the data product and may erase it from memory.

The CCSDS File Delivery Protocol (CFDP) is normally used for data product transfers between the asset spacecraft and the relay spacecraft, as well as for product transfers between the relay spacecraft and the ground station.

CCSDS Space Link Extension (SLE) services are used for data product transfers between the ground station and the relay GDS. Finally, FTP is used for data product transfers between the relay GDS and the asset GDS.

Direct-To-Earth (DTE) and Direct-From-Earth (DFE) data product transfers utilize CFDP between the ground station and the asset spacecraft and SLE services between the ground station and the asset GDS.

Figure 2 shows a more detailed view of alternate information pathways for an asset with the ability to communicate directly with ground stations on Earth. The interfaces between relay and asset Ground Data Systems are being standardized to minimize the interface designs needed for each asset.

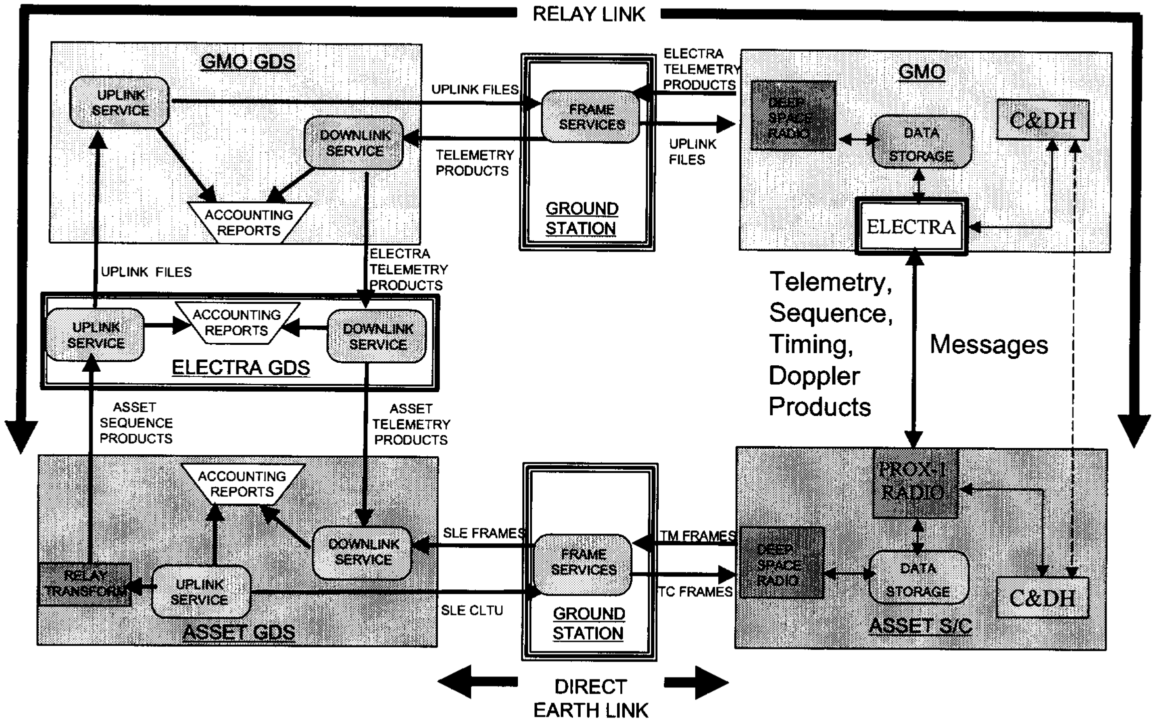


Figure 2. Alternate Asset EEIS Paths

Mission Operations

Alenia will operate the GMO spacecraft in Rome and JPL will operate the Electra relay in Pasadena, as shown in Figure 3. JPL will also navigate the spacecraft, which will be tracked by NASA's Deep Space Network (DSN) and by a new ASI tracking antenna in Sardinia, Italy.

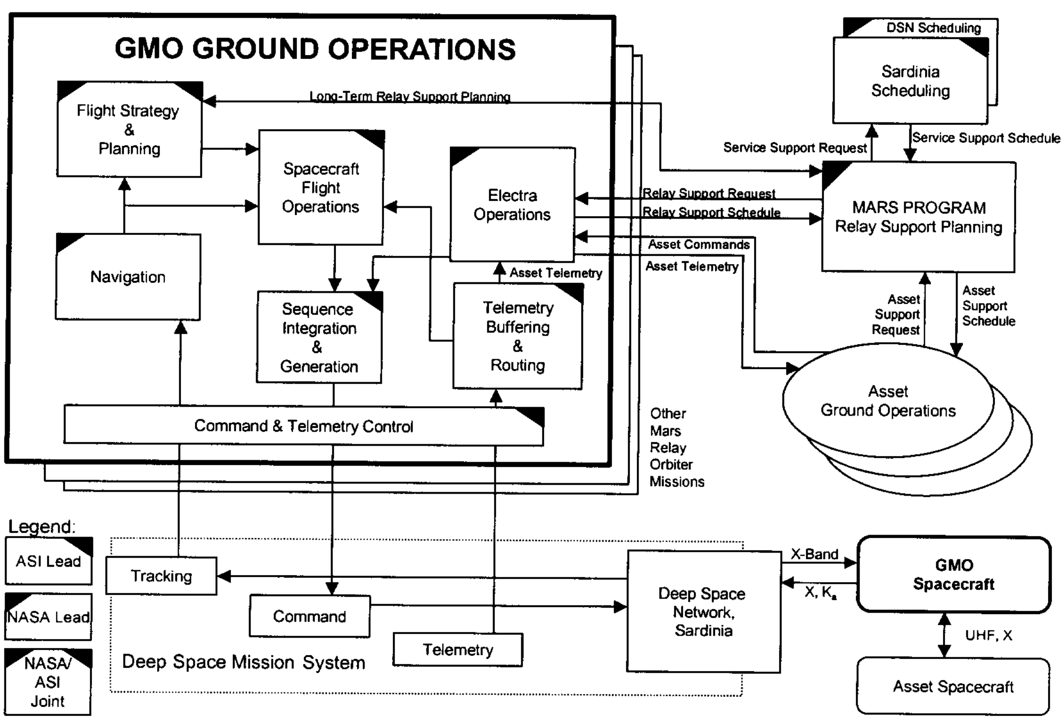


Figure 3. Mission Operations Diagram

Each asset mission will interface with GMO through Electra operations. Support requests and scheduling will be coordinated by a Mars Program relay support planning team.
Figure 4 illustrates GMO operations information flow.

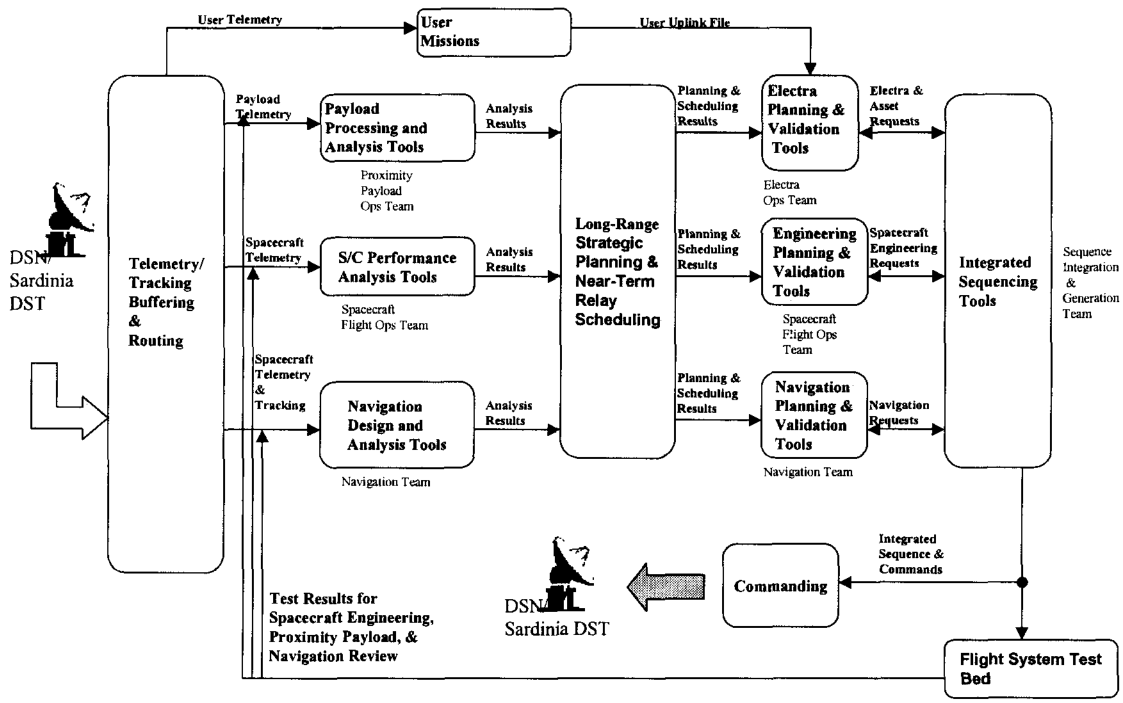


Figure 4. GMO Operations Information Flow

Relay Testing

The NASA Mars Program requires all missions sent to Mars to maintain communications during critical events – in particular, during entry, descent and landing of probes sent to the surface of the planet. It is very difficult to maintain communications with Earth during such critical events because even if a high gain antenna is available, it normally cannot be pointed during the critical event. Relay links must therefore be used when assets first arrive at Mars. It is thus imperative that proper operation of relay communications be verified before the asset arrives at Mars.

It is difficult to predict the performance of a UHF antenna that is placed on a platform shared with other spacecraft elements. Thus it is difficult to conduct complete tests on the ground.

Furthermore, since assets will generally need to be able to communicate through multiple relay orbiters, there needs to be a way to verify performance through two or more relay orbiters. This can be a difficult and unwieldy process. GMO relay test facilities are being designed in conjunction with those of other relay orbiters to facilitate multimission relay tests. Figure 5 shows the major nodes of a typical relay link.

Figure 5. Relay Nodes

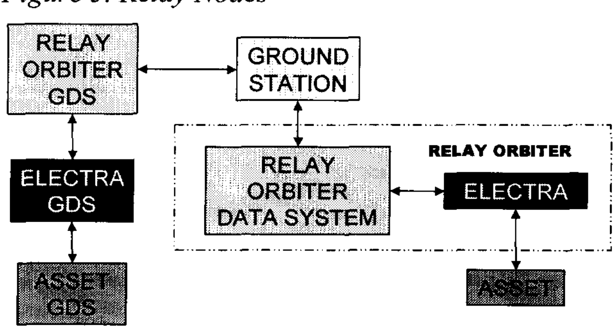
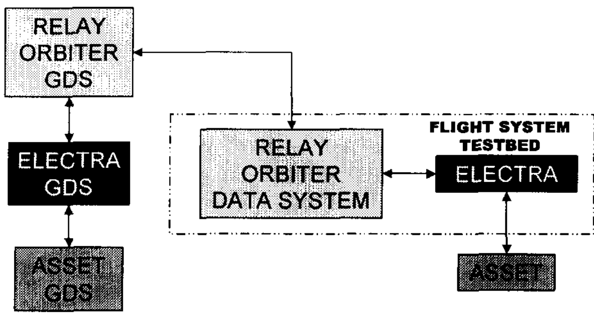


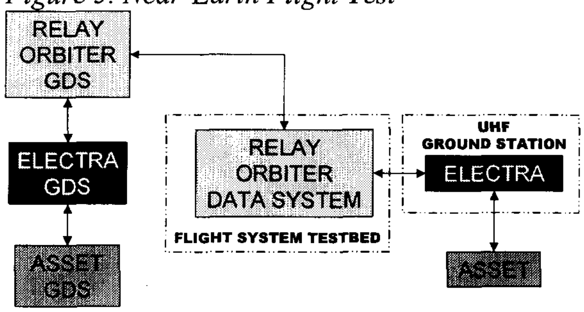
Figure 4 shows the nodes could be rearranged for end-to-end relay tests. A simulated or duplicate relay orbiter data system would be connected to an Electra relay. These relay tests would verify the entire end-to-end relay process, except for the ground station. A simulated or duplicate relay orbiter data system would be available for each relay orbiter, and the relay tests could then be conducted at a single location for all of the relay orbiters which the asset mission plans to use.

Figure 4. Multimission End-to-End Relay Tests



This approach can be extended to flight tests after launch of the asset, as illustrated in Figure 5. In this case, tests can be conducted through multiple simulated or duplicate relay orbiter data systems while the asset is close enough to earth to test its relay communications through a ground station on Earth.

Figure 5. Near-Earth Flight Test



Conclusion

GMO will add revolutionary capabilities to the Mars relay network, increasing data return by orders of magnitude and fundamentally enhancing the connectivity of the blue planet to the red planet. The GMO design team is coordinating its data and ground system developments with those of other future Mars orbiters to ensure standardized interfaces, which will ease the integration of future relay users into the network and facilitate operations of both the Mars relay network and the users of this network.

Acknowledgements

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The authors wish to acknowledge the contributions of Shel Rosell of JPL, who generated the initial GMO MOS/GDS design, and Greg Kazz and Edward Greenberg, also of JPL, for many useful discussions on Mars relay network EEIS design.

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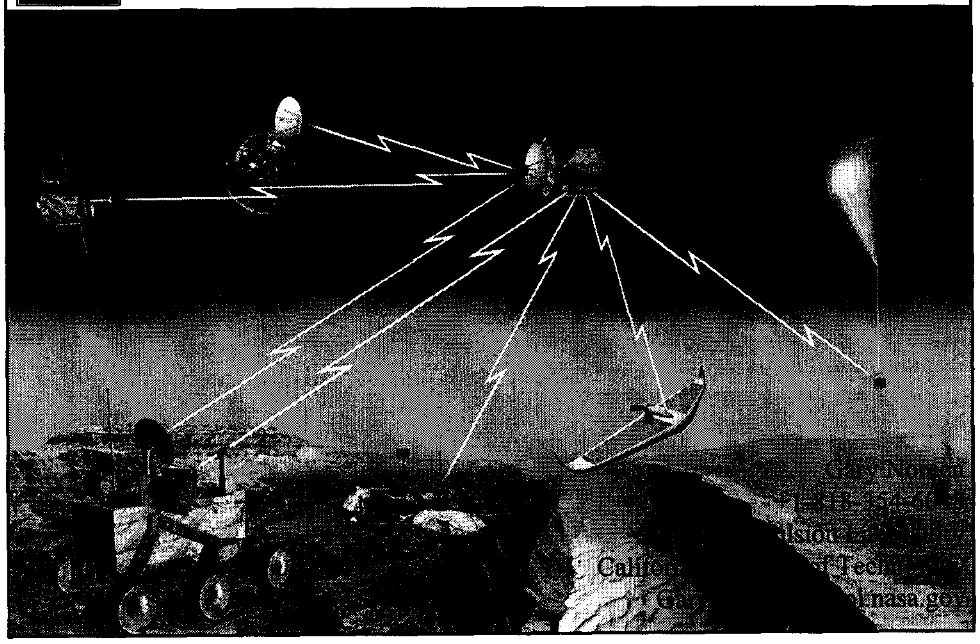
1 Noreen, G., et. al., G. Marconi Orbiter and the Mars Relay Network, AIAA Communications Satellite Conference, Montreal, May 13-15, 2002.

2 Marcozzi, M, The G. Marconi Orbiter, International Astronautical Congress, Houston, October 10-12, 2002.

3 http://ccsds.org/

Guglielmo Marconi Orbiter



Overview

G. MARCO ARS 2007

- Mars Relay Network
- Relay Users
- G. Marconi Orbiter (GMO) performance
- Mission operations
- End-to-End Information System (EEIS) design
- Test & verification

October 10, 2002

GKN-2

Mars Relay Network

- Relay communications
  - Range^2 reduced by a factor of up to 6.4×10^{21} (218 dB)
  - Gigantic improvement in ability to communicate with in-situ elements
- UHF relay radios added to most Mars science orbiters
  - Now orbiting Mars: NASA Mars Global Surveyor & Mars Odyssey
  - 2003 ESA Mars Express, 2005 NASA Mars Reconnaissance Orbiter, 2007 CNES Premier Orbiter
  - Relay performance limited by primary science mission
    - Low orbit optimized for science, not relay
    - Omnidirectional relay antenna on shared platform
- Guglielmo Marconi Orbiter (2007)
  - High orbit optimized for relay service
  - High performance steered relay antennas

G. MARCONI MARS 2007

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Relay Users

- 2003 (before GMO)
  - 2 NASA Mars Exploration Rovers
  - British Beagle II
- 2007
  - European (CNES) NetLanders
  - NASA Mars Scout
- 2009
  - NASA Mobile Science Laboratory (MSL)
- 2011 & Beyond
  - NASA Mars Scout
  - NASA Mars Sample Return

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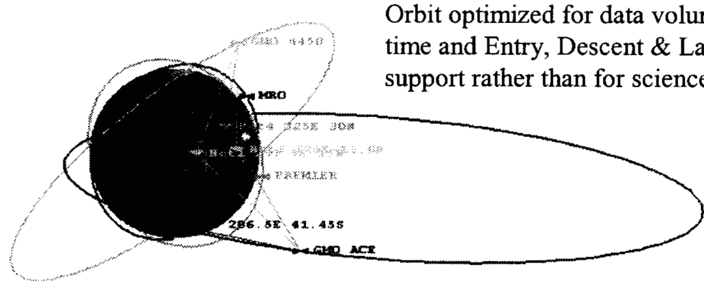
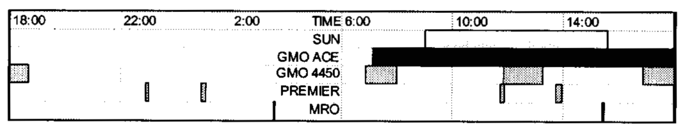
High GMO Orbit Increases Contact Time



Orbit optimized for data volume, contact time and Entry, Descent & Landing (EDL) support rather than for science observations

High orbit → EDL tracking for wide range of landing sites, long contact times
Long contact times → operational flexibility, traverse monitoring



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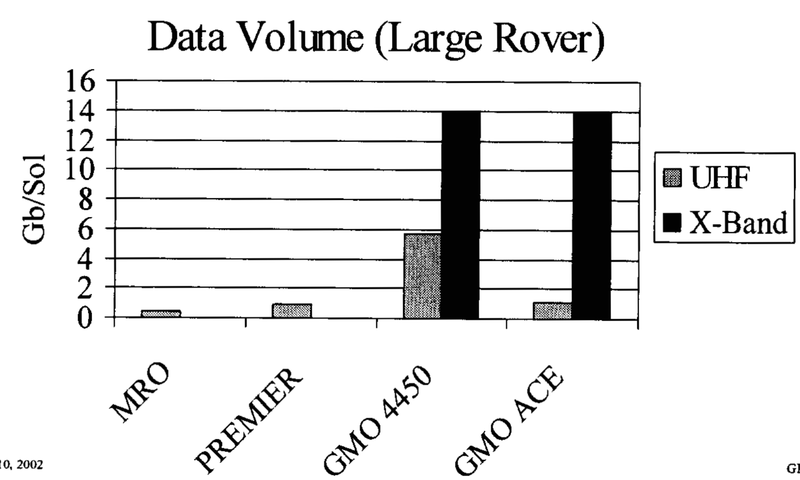
Increased Data Return

High orbit + X-band = huge increase in data return



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Mars Relay Network End-to-End Information System

JPL Alenia

G. MARCO RS 2007

- Electra relay radio will be carried by all Mars orbiters beginning with NASA Mars Reconnaissance Orbiter in 2005
- Break between 2003 and 2007 landers being used to develop new end-to-end information system with greater commonality
- Objective: make orbiter & ground system transparent to relay user

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Mission Operations

JPL Alenia

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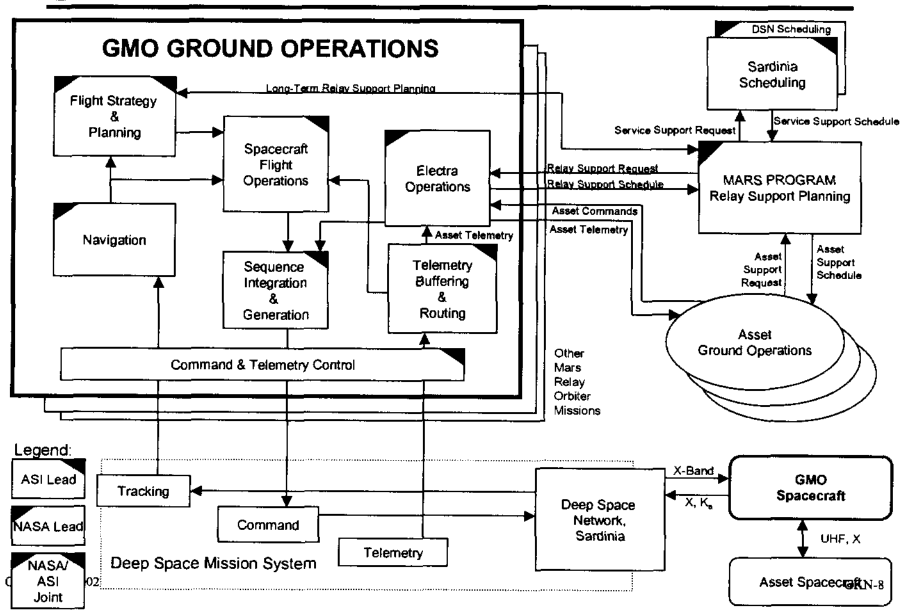

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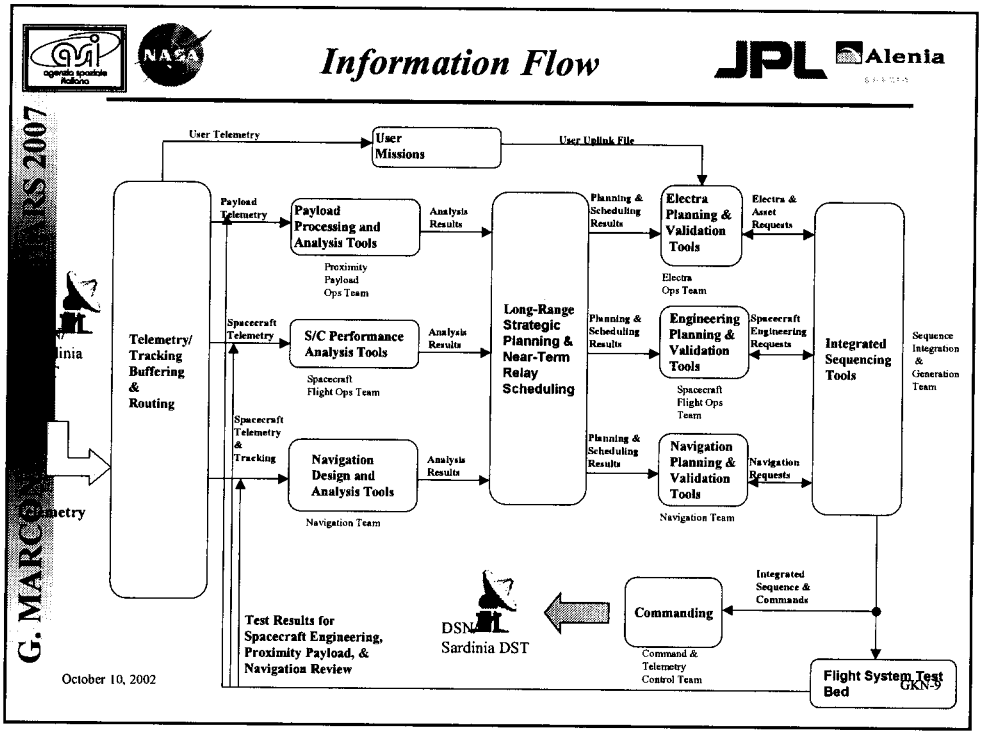
Information Flow
JPL
Alenia
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User Telemetry
User Missions
User Uplink File
Payload Telemetry
Payload Processing and Analysis Tools
Analysis Results
Proximity Payload Ops Team
Telemetry/ Tracking Buffering & Routing
Spacecraft Telemetry
S/C Performance Analysis Tools
Spacecraft Flight Ops Team
Spacecraft Telemetry & Tracking
Navigation Design and Analysis Tools
Navigation Team
Long-Range Strategic Planning & Near-Term Relay Scheduling
Planning & Scheduling Results
Electra Planning & Validation Tools
Electra Ops Team
Electra & Asset Requests
Engineering Planning & Validation Tools
Spacecraft Engineering Requests
Navigation Planning & Validation Tools
Navigation Requests
Integrated Sequencing Tools
Sequence Integration & Generation Team
Integrated Sequence & Commands
Commanding
Command & Telemetry Control Team
DSN
Sardinia DST
Test Results for Spacecraft Engineering, Proximity Payload, & Navigation Review
Flight System Test Bed
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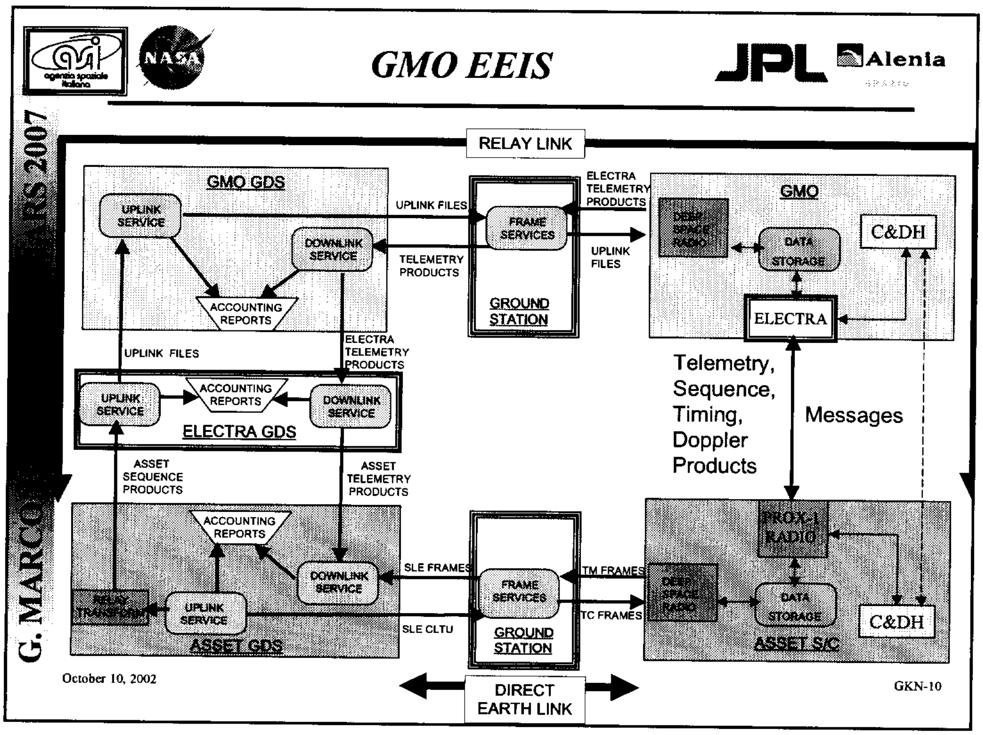
GMO EEIS
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G. MARCONI MARS 2007
RELAY LINK
GMO GDS
UPLINK SERVICE
DOWNLINK SERVICE
ACCOUNTING REPORTS
UPLINK FILES
TELEMETRY PRODUCTS
FRAME SERVICES
GROUND STATION
ELECTRA TELEMETRY PRODUCTS
UPLINK FILES
GMO
DEEP SPACE RADIO
DATA STORAGE
C&DH
ELECTRA
UPLINK FILES
ELECTRA TELEMETRY PRODUCTS
ACCOUNTING REPORTS
ELECTRA GDS
Telemetry, Sequence, Timing, Doppler Products
Messages
ASSET SEQUENCE PRODUCTS
ASSET TELEMETRY PRODUCTS
ACCOUNTING REPORTS
DOWNLINK SERVICE
SLE FRAMES
SLE CLTU
RELAY TRANSPONDER
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TM FRAMES
TC FRAMES
PROX-1 RADIO
ASSET S/C
DIRECT EARTH LINK
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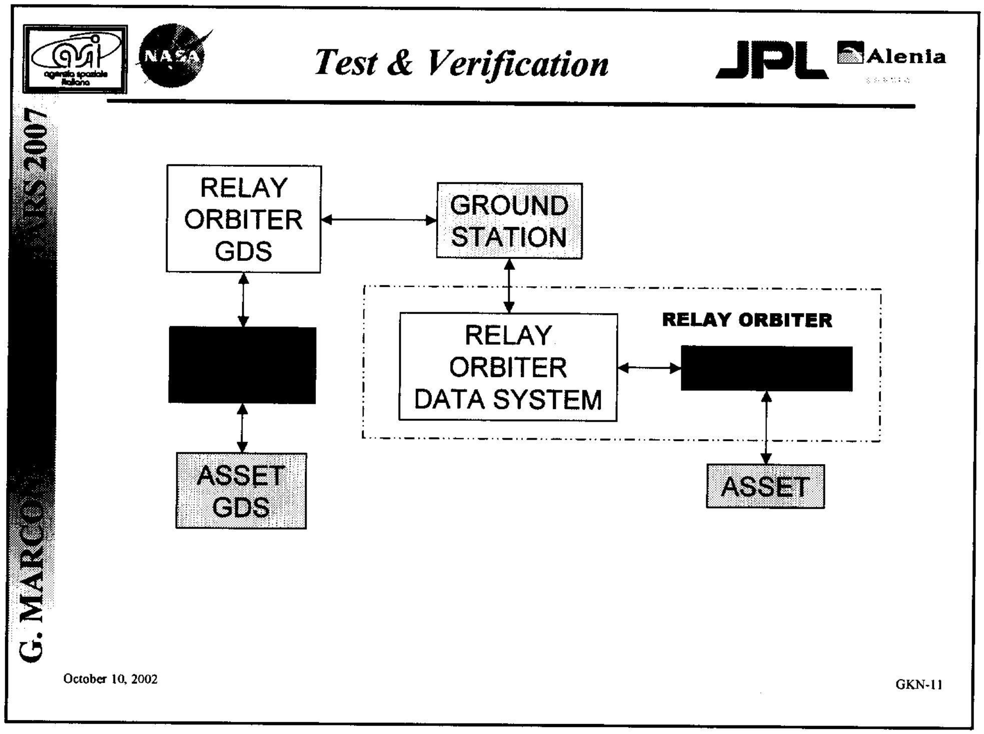
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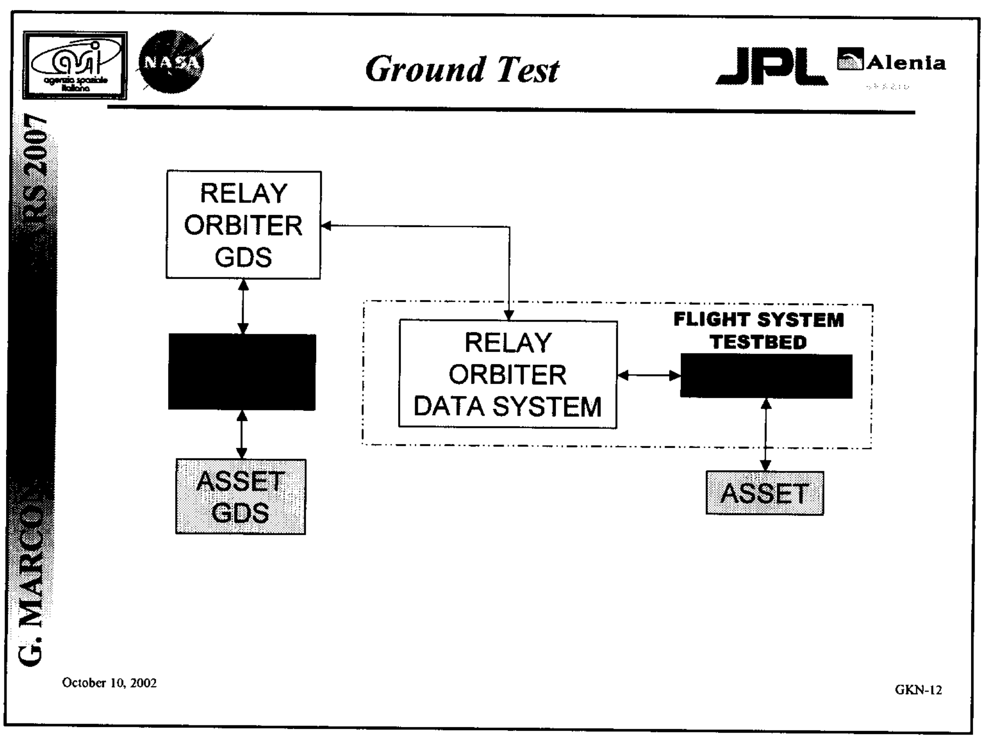
GKN-11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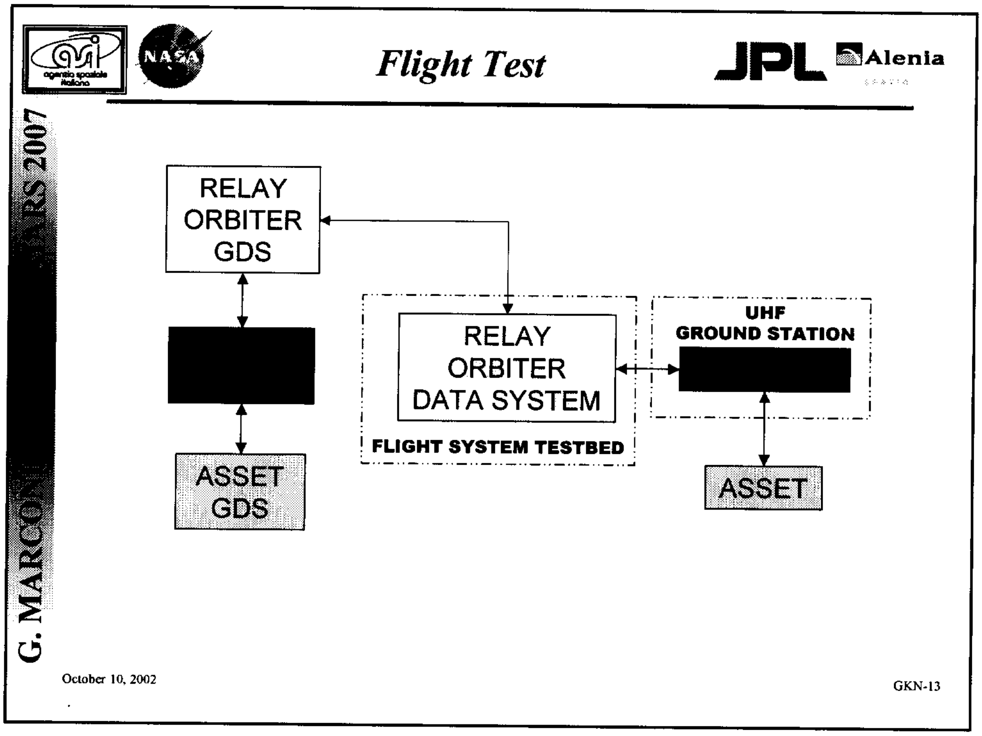
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