FROM GTO TO THE PLANETS

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Abstract

Most Ariane 5 launches will provide slots for auxiliary payloads — up to eight payloads at 100 kg apiece. Recent analyses has established that these slots can be used to send small science payloads to Mars, Venus, or a range of near-Earth and main-belt asteroids. This paper discusses the Ariane 5 configuration, mission analyses, and launch scheduling issues associated with these opportunities and describes some applicable candidate mission concepts.

1. Introduction

The Ariane 5 launch vehicle is designed to carry large commercial satellites to orbit many of which are delivered to a geosynchronous transfer orbit (GTO). Like the Ariane 4 before it, the Ariane 5 will, in most launches, provide opportunities to orbit small auxiliary payloads. Ariane 4 has carried 22 such payloads each weighing up to 80 kg to Earth orbit. For Ariane 5, using the Ariane Structure for Auxiliary Payload (ASAP) the maximum mass is increased to 100 kg. Customers pay one million dollars (US) for each slot to cover Arianespace integration costs. Recent analysis has established that the Ariane 5 ASAP can be synergistic with state-of-the-art small spacecraft concepts to provide exciting opportunities for planetary missions. Potential targets include Mars, Venus, the Moon, near-Earth asteroids, and main-belt asteroids. These planetary opportunities are based on a launch to GTO followed by application of the mission design strategy discussed below.

2. Configuration

The ASAP platform, which can be used in most Ariane 5 launch configurations, has eight mounting rings placed uniformly around the circumference of the aft part of the payload area. Each can support a 100-kg payload in an area 80 cm (height) x 60 (width) cm x 60 cm (depth). An important proposed variation, currently under study by Arianespace, is the so called "banana" or "twin" configuration, would provide for mounting a single payload on two rings, doubling the upper limit on payload mass and substantially increasing the available volume.[1]

3. Launch Opportunities and Performance

3.1 Mars

The opportune launch periods from Earth to Mars appear about every 26 months and last 2-4 weeks. This is the time interval when escape energy is minimum and the delivery mass to Mars is maximized for a given launch vehicle. There may be two launch periods about a month apart, with one having a longer flight time to Mars than the other. The shorter flight time trajectories are called Type 1 and the longer Type 2.

To adapt these short launch periods into the Ariane 5 launch schedule, it is necessary to be aboard and launched into GTO many weeks before the Mars injection opportunities. After GTO launch, a wait time in space (in GTO or another orbit) is acceptable, but a major trajectory problem arises. This is how to transfer from the highly eccentric and specifically oriented GTO to the correct escape direction and energy on a date which falls within the two week Mars launch period. In a very limited way, this can be done with a single maneuver, performed with a solid motor for example. A more general and very flexible method, called the three-burn strategy, exists using lunar and Earth flybys.

For single or multiple burn options, the final maneuver must occur within the two week launch period. If there is a single burn it must occur near the equatorial plane to avoid a costly dogleg. Also, to avoid a severe propulsion penalty, the burn must be within about 15 degrees of GTO perigee. These two restrictions limit the availability of Mars to certain years and limits the length of the GTO launch period. Mars 2003 is available for the single burn option since certain Mars arrival dates require a near equatorial injection at Earth. In fact, by choosing the Mars arrival date judiciously, it is possible to develop a GTO launch period of about 2 months for 2003. In contrast, Mars 2001 is marginally available with Mars 2005 being not available. A brief look at following years indicates a problem for the single burn option until Mars 2013.

To alleviate this problem, a three-burn strategy has been developed (see Figure 1) which can deliver an auxiliary payload released in GTO off to Earth escape and on a path which will deliver it to Mars. In addition, this strategy is general enough to allow transfer to almost any solar system body, while accepting a GTO date which may span two or more months.

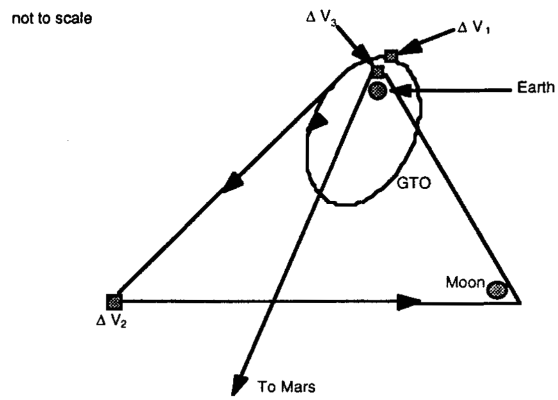

Figure 1: The Three-Burn Strategy

For Mars, the strategy requires the payload to have a multi-burn capability with a total velocity increment in excess of 1200 m/s. Also, it must be capable, with ground assistance, of precise navigation, and a thrust capability of about 0.5 g's.

Normally, the injection from low Earth orbit (LEO) to Mars requires 3600 m/s or more., however, the highly elliptic GTO provides 2400 m/s, reducing the auxiliary payload energy requirement to about 1200 m/s. The three-burn strategy requires up to an additional 300 m/s for trajectory shaping, depending on the GTO launch period desired.

The primary purpose of the three-burn strategy is to re-align the GTO major axis from its near equatorial orientation to that which would be required in LEO if a single burn were used to inject the payload directly to Mars. This is accomplished by using a single or double lunar flyby which returns the payload directly back to Earth so that it can perform this escape maneuver. This last maneuver is usually about 800 m/s, and is timed to occur on a predetermined date favorable to the Earth-to-Mars transfer. The last acceptable GTO launch date necessary to accomplish the three-burn trajectory profile is about 30 days before this final Earth flyby maneuver.

An example of the earliest and latest date for the GTO launch is presented in Figure 2 for the Mars 2001 opportunity, as viewed from the ecliptic north pole. The total ΔV required for this opportunity using a three-burn strategy is shown in Figure 3. Similarly, Figures 4 and 5 present the three-burn velocity requirement for GTO launch opportunities for 2003 and 2005 respectively.

Propellant requirements for navigation of the three-burn strategy are relatively small because of the long time interval between injection from GTO to the final maneuver to escape Earth, considerable tracking time is available to reduce the navigation requirements considerably. The first burn, injection from GTO, is the most critical. The payload, once released from the Ariane may be tracked for as little as 1-2 orbits, and a 10-m/s burn error at this time (and only the burn magnitude is important) would require about a 50-m/s correction one day out. The burn itself will be about 730 m/s. The correction may be reduced by breaking the maneuver into two parts, first getting into an intermediate orbit, say with a 5-10 day period. Then, further tracking, and better understanding of engine performance, could reduce the final burn error. Once the spacecraft is on the high ellipse toward its apogee beyond the Moon, which will take from 15 to 35 days, the remaining burns can be minimized for the existing trajectory. Tracking will be good, and correction requirements are estimated to be about 25 m/s. A final correction will be required after the escape maneuver of about 460 m/s is performed. An RMS estimate of all maneuvers required comes to about 50 m/s, and this is expected to be primarily dependent on engine performance, not tracking or attitude control.

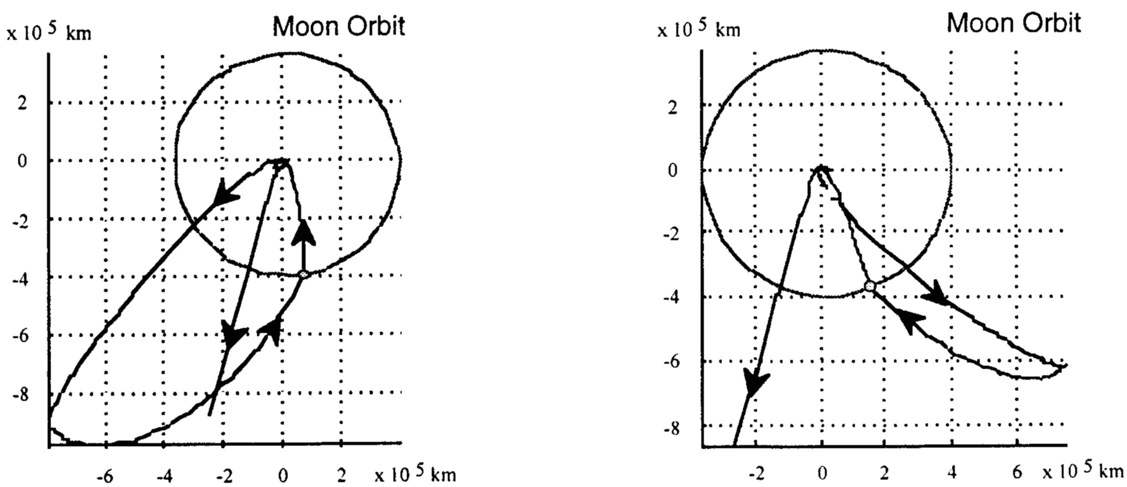

Figure 2: Earliest and Latest Ariane Launch for GTO to Mars (2001)

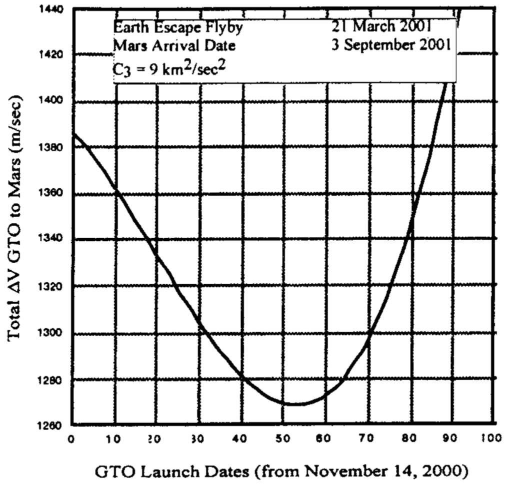

Figure 3: Mars 2001 Required ΔV

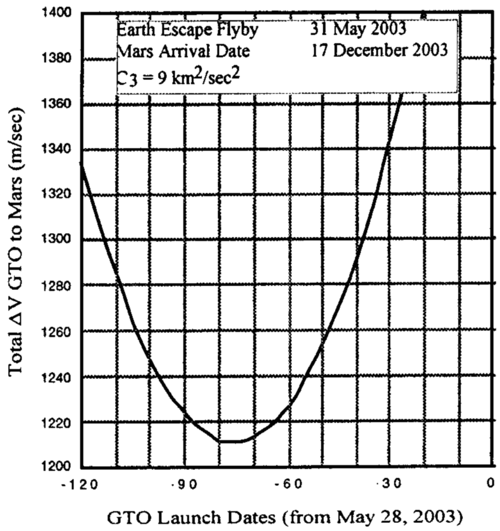

Figure 4: Mars 2003 Required ΔV

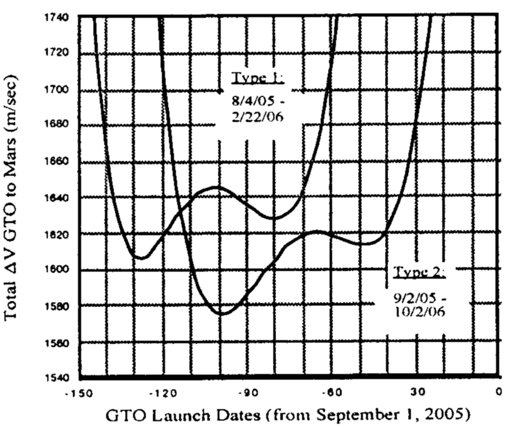

Figure 5: Mars 2005 Required ΔV

3.2 Venus

Similar mission design considerations apply to Venus except that the Earth departure asymptote tends to be opposite rather than near the sun, leading to the double lunar flyby strategy shown in Figure 6. The corresponding performance chart for the 2004 Venus opportunity is shown in Figure 7. Note that if a ΔV of 1360 m/sec is available, the Ariane launch period can be more than 4-months long.

3.3 Main Belt Asteroids

Main belt asteroids can be reached by launching to Venus as described above and then using a Venus gravity assist. The ΔV required for several potential targets is shown in Table 1.

3.4 Other Targets

Other targets of interest to science are reachable from GTO by more straight-forward means, i.e., a single burn at perigee. These include the Moon and near-Earth asteroids. The ASAP is also considered to be an excellent resource for space technology demonstrations, particularly those involving Earth re-entry.

3.5 Performance Summary

Table 2 summarizes the ASAP performance for many of the cases discussed above. The figure of merit is the useful payload delivered to an Earth escape trajectory that intersects the orbit of the target body. Results are give n for both of the baseline ASAP 100-kg slot and for the "banana" assuming a 180-kg capability. Carrier spacecraft mass estimates are from a companion paper by Ken Leschly of JPL[2].

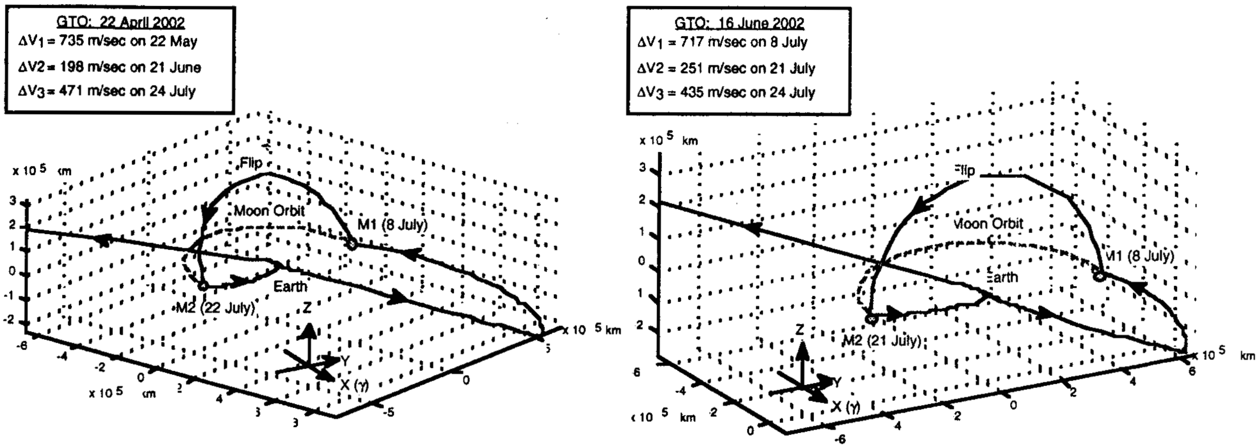

Figure 6: Earliest and Latest Ariane Launch for GTO to Venus (2002)

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Figure 7: Venus 2004 Required ΔV

4. Launch Scheduling for Planetary Opportunities

Sending an auxiliary payload to Mars or Venus necessitates changes in the Ariane manifesting process. Mars opportunities involve 3-month launch periods with abrupt termination times, after which the velocity increment from GTO to Mars rises prohibitively. While a launch to GTO is very likely in the 3-month period, it will not be known until about one year from launch who the main passenger will be. This will necessitate doing any integration analysis with more than one main passenger. Also, provisions must be made for delays to the launch vehicle or the main passenger occurring near the time of launch that would slip the Mars payload out of its launch period. Provisions should be made to transfer the Mars payload to another GTO launch (if any) within the period. Another fallback would be to revert to a Type 3 or 4 trajectory with later Earth departures (and much longer flight times).

Table 1: Examples of Main Belt Asteroid Opportunities

Asteroid	No.	Radius	Earth Departure	C_3	Carrier ΔV	Flight Time	Approach Velocity	Earth Range
		(km)		(km^2/sec^2)	(km^2/sec^2)	(years)	(km/sec)	(AU)
Ceres	1	466	Aug-2002	11.9	1.6	3.2	8.6	3.4
Pallas	2	263	Jul-2002	10.3	1.5	2.6	14.5	1.5
Egeria	13	104	Aug-2002	8.0	1.4	3.2	10.6	3.6
Amphitrite	29	106	Aug-2002	7.8	1.4	2.5	5.8	2.1
Hestia	46	62	Aug-2002	9.9	1.5	2.8	4.2	1.7
Juno	3	134	Mar-2004	8.7	1.4	2.5	6.8	3.6
Vesta	4	255	Mar-2004	9.1	1.4	2.7	5.4	3.0
Parthenope	11	77	Mar-2004	9.3	1.4	2.3	6.7	3.6
Psyche	16	126	Mar-2004	8.7	1.4	2.9	4.6	2.3
Fortuna	19	100	Mar-2004	8.7	1.4	3.0	6.1	1.8

Table 2: ASAP Performance Summary

	Mars		Mars		Mars		Venus		Venus	
EARTH DEPARTURE	3/01		6/03		8/05-9/05		7/02		3/04	
ARIANE LAUNCH	11/00-2/01		2/03-5/03		4/05-8/05		4/02-6/02		.	
C3 (M^2/S^2)	9		9		17		9		9	
DELTA V FROM GTO (M/S)	1400		1400		1650		1400		1400	
LAUNCH WINDOW (DAYS)	90		110		105		LARGE		LARGE	
APPROACH VELOCITY (KM/S)	5.1		2.8		3.2		5.4		5.6	
LAUNCH MASS (KG)	100	180	100	180	100	180	100	180	100	180
CARRIER DRY MASS	20-30	35-45	20-30	35-45	20-30	35-45	20-30	35-45	20-30	35-45
PROPULSION SYSTEM	60	95	60	95	65	105	60	95	60	95
PAYLOAD	**10-20**	**40-50**	**10-20**	**40-50**	**5-15**	**30-40**	**10-20**	**40-50**	**10-20**	**40-50**
	Moon		L1		Main Belt Asteroid					
EARTH DEPARTURE	-		-		-					
ARIANE LAUNCH	-		-		-					
C3 (M^2/S^2)	-2		.		8-12					
DELTA V FROM GTO (M/S)	800		1000		1200-1600					
LAUNCH WINDOW (DAYS)	.		.		LARGE					
APPROACH VELOCITY (KM/S)	.		.		.					
LAUNCH MASS (KG)	100	180	100	180	100	180				
CARRIER DRY MASS	20-30	35-45	20-30	35-45	20-30	35-45				
PROPULSION SYSTEM	35	55	40	65	45-60	80-105				
PAYLOAD	**35-45**	**80-90**	**30-40**	**70-80**	**10-35**	**30-65**				

5. Mission Concepts

Most of the work on potential planetary utilization of ASAP has been targeted at Mars and some of the more promising concepts are discussed here and summarized in Table 3.

5.1 Aerobot Concepts

The exploration of Mars with aerobots is one type of a mission concept under consideration as an Ariane 5 auxiliary payload. The use of aerobots in Mars exploration has several advantages over landers, rovers, and orbiters. Whereas landers and rovers have limited range and imaging perspective, the use of an aerobot moving above the Martian surface at several kilometers in altitude will have substantially greater mobility and area coverage capability. Furthermore, the collected data taken by an aerobot will bridge the resolution gap between data obtained by an orbiting satellite and that from a ground-limited rover. The development, testing, and use of aerobots to explore the Martian surface relies first on demonstrating key technologies and then progressing to missions with greater capability. Two mission concepts under consideration are the Aerobot Technology Experiment and the Solar Heated Montgolfiere/Wind Sail Rover.

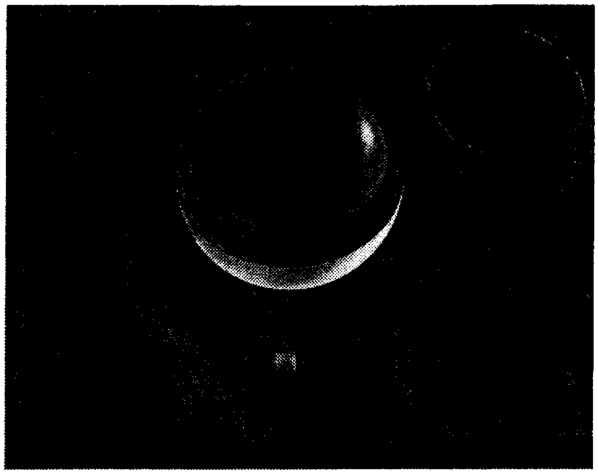

Figure 8: Aerobot Experiment

The Aerobot Technology Experiment (see Figure 8) will be a low-cost flight experiment designed to demonstrate the key technologies for the exploration of Mars with aerobots and to demonstrate the feasibility of an airborne platform at Mars for scientific exploration. The payload, weighing between 25 to 32 kg, is inserted into the Martian atmosphere via an aeroshell delivery. Next, a drogue chute is deployed which extracts the main parachute that is connected to the main balloon. The balloon inflates in 60 seconds or less. The balloon will carry an instrument payload that includes a miniature wide angle camera, spot spectrometer, and magnetometer. The mission lifetime is approximately 7 days.

Table 3: Mission Concepts

	Entry/Descent/Landing							Micro-satellite Payload Quantity & Mass					Micro-banana Payload Quantity & Mass					
	AeroCapt	Aeroshell	Parachute	Airbag	Balloon	Penetrator	Carrier	EDL (kg)	Instr (kg)	Unit P/L (kg)	Quan.	Total P/L (kg)	EDL (kg)	Instr (kg)	Unit P/L (kg)	Quan.	Total P/L (kg)	Mounting
Seismic Net		X				X	C	3	1	4	2	8	3	1	4	4	16	S
Climate Net		X	X				C	5	2	7	2	14	5	2	7	4	28	S
Scout		X	X				C	6	4	10	2	20	6	4	10	4	40	S
Science Lander		X	X				C						12	8	20	2	40	S
Science Lander		X	X		X		C						35	10	45	1	45	A
Balloon Experiment		X	X		X		C						35	10	45	1	45	A
Wind Rover		X	X		X		C	6	4	10	1	10	6	4	10	2	20	S
Nano-rover		X	X	X			C	4	1	5	2	10						
Com. Orbiter	X							-	-	100	1	100	-	-	120	1	120	S
Science Orbiter	X							-	-	100	1	100	-	-	120	1	120	S

Carrier: C = cruisecraft (spinner) S = sciencecraft
Banana mounting: S = symetrical about thrust axis A = asymetrical

The Solar Heated Montgolfiere/Wind Sail Rover mission concept (see Figure 9) is designed to take advantage of the fact that a Montgolfiere, or hot air balloon, can make multiple soft landings and deliver a payload, such as a wind sail rover, to the surface. The payload weighs approximately 10 kg and includes a 4-kg instrument payload. After insertion into the Martian atmosphere, the solar heated balloon delivers a wind rover to the surface. The rover will carry out soil and rock sample analysis and will acquire high resolution images over many kilometers. The balloon will then rise to a low altitude and acquire high-resolution stereoscopic surface images over a 12-hour period, the expected lifetime of the balloon. The mission lifetime of the wind rover is approximately 30 days.

5.2 Network Concepts

There are several network-type mission concepts that benefit from a very low-mass (less than 10 kg), 40-cm aeroshell design similar to that being developed for Deep Space 2. In these concepts, the objectives are carried out with two or more probe deliveries to the Martian surface. Targeting of the probes to specific interesting sites or to cover a given area depends on the mission science requirements. For example, the site selection may be based on geology, mineralogy, or imaging requirements.

A long-term (approximately 20 years) investigation of the nature and variability of the Martian climate system is considered to have high priority in the Solar System Exploration Road Map*. A network of probes on the surface of Mars will define the climate nature and variability. In addition, these probes will collect data on the thermal structure of the red planet's atmosphere during probe entry. A current probe design includes a 4.7-kg entry, descent, and landing package and a 2.1-kg instrument within a 40-cm diameter aeroshell. Ideally, the probes are distributed across the Martian surface for climate monitoring purposes. Each probe operates autonomously and communicates through a relay satellite. Options exist for long-term data storage over several years in the event that no orbiter is available.

* Available at http://eis.jpl.nasa.gov/roadmap/site/slide_destiny.html

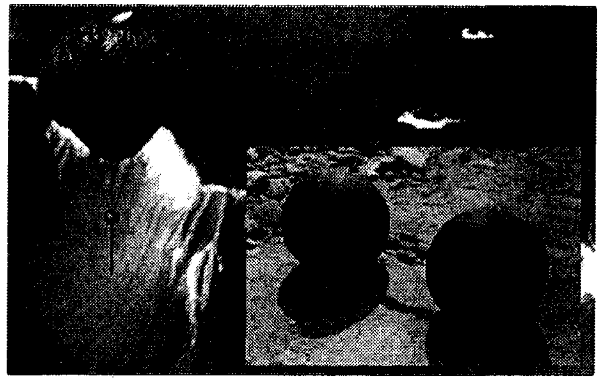

Figure 9: Solar Heated Montgolfiere/Wind Sail Rover

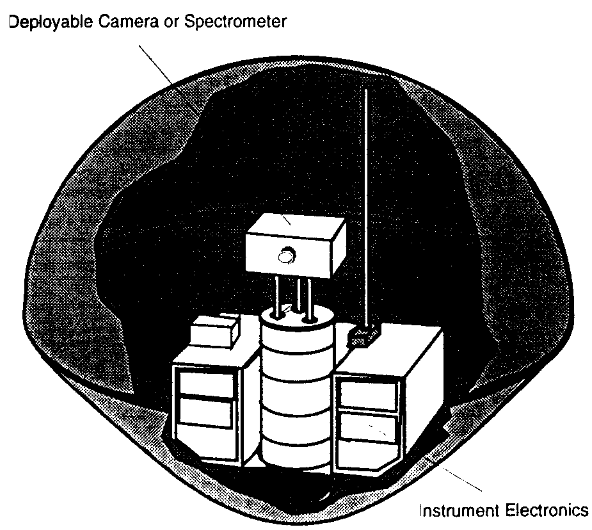

Figure 10: Probe with Various Payloads

Another mission concept will investigate the Mars surface with various payloads. In this low-mass payload design, less than 10 kg, there exists the opportunity to send two or more probes to the planet's surface, each with a different instrument payload such as a deployable camera or spectrometer (see Figure 10). The current mission design will require a relay orbiter for communications.

The seismicity and internal structure of Mars can also be investigated with a network-type mission. In this concept, multiple probes are delivered to Mars, impact its surface, and lodge beneath the surface. These probes are very low-mass, approximately 3.3 kg and are designed to self-right themselves during entry. The ideal mission design includes a network of microprobes and may utilize a modified New Millennium Program Deep Space 2 microprobe. Each probe will communicate through a relay orbiter and will last approximately one year.

5.3 Orbiters

Many of the mission concepts under consideration require the use of a relay orbiter for communications. Ideally, such a satellite in orbit around Mars will benefit all Mars exploration missions. One such design is the Multiple Relay Satellite (see Figure 11), a 100-kg Mars orbiter that uses the ASAP launch capability. The current design includes a 5-year in-orbit lifetime.

6. Conclusion

Ariane 5 auxiliary payload capability to GTO could be available as early as mid-1999 and will be routine by 2003. This capability coupled with the trend toward smaller, smarter science spacecraft provides exciting and

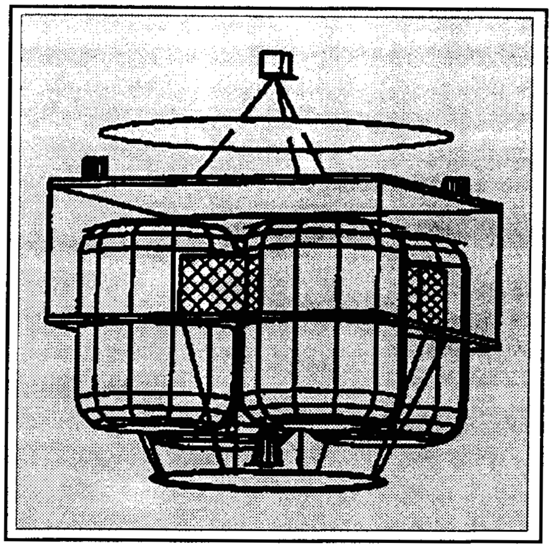

Figure 11: Mars Relay Satellite

challenging new opportunities for planetary scientists and mission designers.

7. Acknowledgment

Special acknowledgment is due to Jacques Blamont of CNES who first suggested the use of ASAP for planetary missions and created the "banana" concept. We also acknowledge the contributions and support many of our colleagues at JPL, CNES, and Arianespace, particularly John Beckman who started JPL down this track and Kim Leschly who has turned these ideas into credible spacecraft concepts.

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8. References

1. *Ariane V ASAP User's Manual,* published by Arianespace, 1997.

2. K. Leschly & G. Sprague, "Carrier Spacecraft Using the Ariane 5 GTO Secondary Launch Opportunities," this conference.