ATHENA: A POSSIBLE FIRST STEP IN A PROGRAM OF HUMAN MARS EXPLORATION*

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This paper introduces the "Athena" mission, a concept for an initial piloted mission to Mars that could be launched at low cost in the very near future. Athena is a double flyby, which uses two Mars gravity assist maneuvers to allow a round trip Mars mission to be performed with a single minimum energy trans-Mars injection burn. Science exploration is accomplished by taking advantage of human intelligence in the vicinity of Mars for extended periods to remotely operate rovers, balloons, or aircraft on the Martian surface with short signal time delays.

This paper discusses the trajectory and vehicle designs required to accomplish the Athena mission, modes of science exploration that it enables, and provides an estimate for total mission cost. In addition, the programmatic value of using such a minimal piloted mission to initiate human Mars exploration is also discussed.

1. INTRODUCTION

Athena is a proposal for a piloted Mars mission that could be launched as early as 2001 for a cost of about $2 billion. It is not an optimal mission plan for human exploration of Mars, but it is a way to get started at a cost at least an order of magnitude less than any alternative that has been offered to date. There is no technology employed in this plan that does not currently exist, and no hardware development required that could not be completed in time for a 2001 launch.

In Greek Mythology, Ares, or Mars, was the mindless god of war. Athena, his sister, was the goddess of wisdom and war. This mission plan is called Athena because it will bring intelligence to Mars.

2. MISSION PLAN

In the Athena plan the crew is not landed on Mars, nor do they capture into orbit. Instead, upon approaching Mars on a low-energy trajectory after a 9 month voyage, the piloted spacecraft is targeted to perform a gravity assist maneuver which changes its Earth-to-Mars elliptical orbit into a circular orbit mimicking that of Mars, but slightly

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inclined to the plane of Mars' orbit. The spacecraft will then shadow Mars for about a year, never moving much more than about one light minute of distance from the Red Planet, with several months spent within 10 light seconds. During this time the crew will be able to command a dispersed set of small rovers that have been landed on Mars, with command and response times about 100 times faster than would be possible from Earth. At the end of a year of shadowing Mars, the spacecraft's trajectory will cause it to closely approach Mars again, at which time a Mars gravity assist can be used to transform its Mars like orbit into a Mars-to-Earth transfer elliptical trajectory. Approaching Earth about 9 months later, the crew bails out in a small entry capsule modeled upon that used in the Apollo program. Deploying a parachute after entering the Earth's atmosphere, they land in the ocean and are picked up by a ship, much as was done in Apollo.

The flight plan for the Athena mission is illustrated in Figure 1.

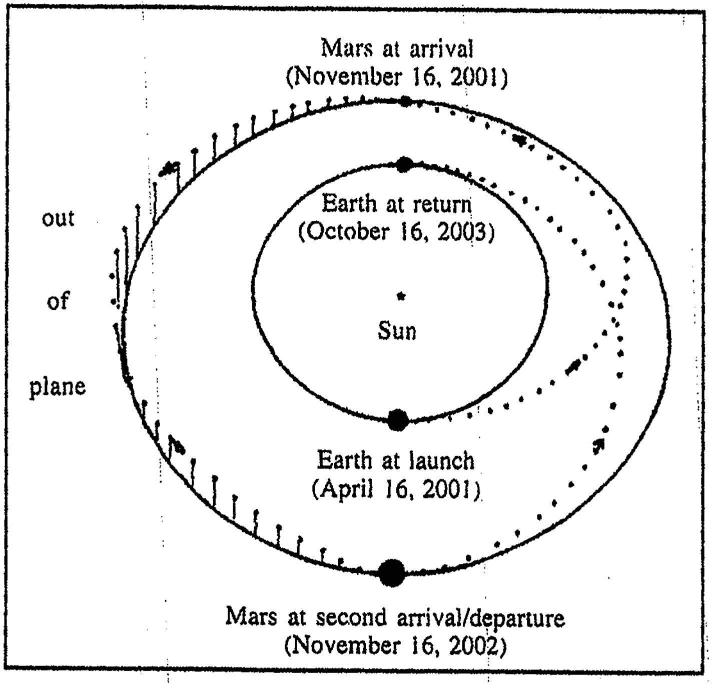

Figure 1 The trajectory for the Athena mission is a double Mars flyby. Gravity assists during each Mars approach allows a round trip Mars mission to be achieved with a single minimum energy trans-Mars injection burn.

3. MISSION FEATURES

Crew Size: Two are recommended as this imposes minimum logistics requirement. Such small crew size is feasible because crew never splits up and no surface activity specialists are needed.

Propulsion Requirements: Chemical propulsion is used for trans-Mars injection (TMI). No propulsion is needed after TMI, as the trajectory is essentially a gravity assisted free-return.

Launch Requirements: A piloted Mission can be launched using either one Energia-A, or, two STS launches plus four Proton D-1's. Auxiliary science landers delivering 4 rovers to the surface can be launched using two Delta 7925 or Molniya launch vehicles.

Risk factors: Lack or propulsion requirement after TMI or need to cope with Mars landing, ascent, or human operations in the Martian environment makes the engineering aspects of the mission very low risk. Exposure to space environment for 2.5 years will create about a 2% statistical risk of cancer later in life on each crew member due to cosmic rays. Health effects of zero-g exposure for two years would be significant; therefore it is recommended that artificial gravity can be incorporated into mission design.

4. EXPLORATION FEATURES

The crew will approach and depart Mars twice with a hyperbolic velocity of about 4 km/s. Table 1. shows the amount of time the crew will spend within specified distances from Mars.

Table 1

TELOPERATION TIME LAG OF ATHENA MISSION

Total Duration	Distance	Signal Delay Time
1 hour	< 36,00 km	< 0.012 seconds
10 hours	< 36,000 km	< 0.12 seconds
1 day	< 86,000 km	< 0.29 seconds
10 days	< 860,000 km	< 2.9 seconds
20 days	<1,720,000 km	< 5.9 seconds
50 days	<4,300,000 km	< 12 seconds
100 days	< 8,600,000 km	< 24 seconds
200 days	< 16,000,000 km	< 47 seconds
300 days	< 24,000,000 km	< 70 seconds
400 days	< 32,000,000 km	< 93 seconds

By comparison, the signal delay time between Earth and Mars varies between 360 seconds and 1,200 seconds, making remote controlled driving of rovers moving on the surface of Mars extremely difficult if conducted from Earth. Taking 900 s as typical of Earth-Mars signal times, we see that the response time of the crew of the Athena mission in controlling rover vehicles operating on Mars will be 100 times faster (9 s or less) for about 40 days. This will give them a substantial amount of time during which they can drive the rovers significant distances over the Martian surface, search for fossils or for other scientific objectives.

Other forms of teleoperated exploration systems are also possible. For example, the response time of the crew is also fast enough during much of the mission to allow them to fly subsonic remotely piloted airplanes through the canyons of Mars. The deployment of such drone aircraft from aeroshells launched directly to Mars by Delta Class vehicles is feasible, with each aircraft probably adding about $100 million to the mission cost, including launch. Alternatively, the astronauts could actively command balloons equipped with an imaging system and a rover. The balloon could be brought down to low altitude, at which time the rover, suspended from the balloon by a tether, could be commanded to grab a rock and moor the balloon. Then the rover would separate from the tether, and be used to explore the locality, until the time came when the crew would direct it to re-attach itself to the tether and take off and fly with the balloon to another distant location.

5. HABITAT DESIGN

The habitat design for the Athena mission is shown in Figure 2. It is a simple can with some attached solar panels and an escape capsule, 5 m in diameter and 15 m long, so it would be small enough to launch in the Shuttle payload bay. At 4 rpm it generates lunar gravity; at 6 rpm it generates Mars gravity. The delta-V required to spin it up to 6 rpm is only 6.3 m/s, so even with a small hydrazine system it could be spun up and down many times. The spin axis would point at the Sun, so the solar panels can remain fixed. If used in deep space, the antenna used would have to track the Earth. But this antenna could be small, for since the spacecraft has 5 to 10 kilowatts of power, its communication system really doesn't need much gain. The Hab is designed for a mass of 20 tonnes, so that it can be launched in one piece by the Space Shuttle, a Titan IV, or a Proton.

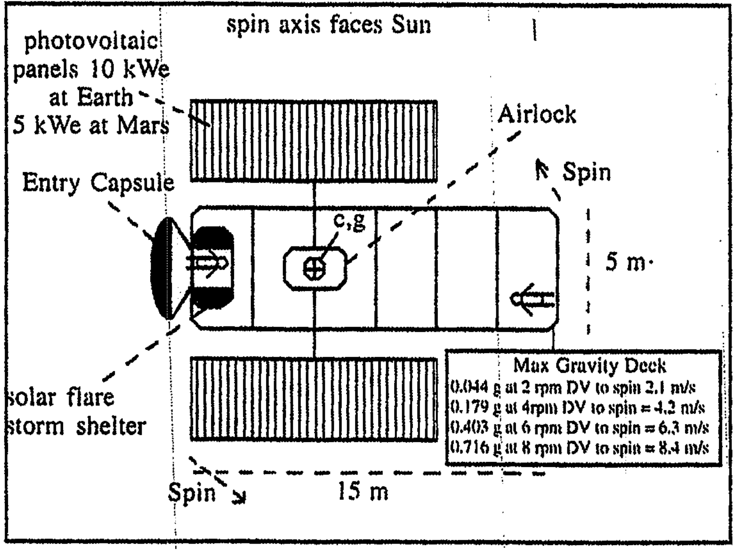

Figure 2 Artificial gravity habitat for the Athena mission.

Overall mass allocations for the Athena mission is given in Table 2. Consumable mass allocations are shown in Table 3.

6. MISSION LAUNCH

Energia can lift and throw 30 tonnes onto trans-Mars injection. Thus, if Energia is available, the entire mission can be launched in one piece. If Energia is not available, the mission can be conducted as follows:

1. The Hab can be delivered to orbit complete except for re-entry capsule by one STS launch.
2. Four Protons are then used to lift to orbit and mate with the Hab four storable propulsion stages, each with a propellant mass of 18 tonnes and a dry mass of 2

tonnes, and an Isp of 326.5 (i.e. Russian RD-0210 N_2O_4/UDMH engines). This combination can throw 26 tonnes onto TMI with a C3 of 18 km^2/s^2.

3. The capsule, together with the crew and final supplies can be delivered to the Habitat by another STS launch shortly before trans-Mars injection.

Table 2
MASS ALLOCATIONS FOR ATHENA MISSION

Hab Structure	4.0 tonnes
Life support system	2.0
Consumables	7.7
Electrical Power (5 kWe solar)	1.0
Reaction Control system	0.5
Comm and Information Management	0.2
Science Equipment	0.2
Crew	0.2
(4) EVA Suits	0.4
Furniture and Interior	0.5
Re-entry Capsule	4.0
Spares and Margin (25 percent)	5.2
Hab total	25.9 tonnes

Table 3
CONSUMABLE REQUIREMENTS FOR ATHENA MISSION WITH CREW OF TWO

Item	Need/ man-day	Fraction Recycled	Wasted/ man-day	Crew Requirements 900 day mission
Oxygen	1.0 kg	0.8	0.2	360 kg
Dry Food	0.5 kg	0.0	0.5	900
Whole Food	1.0 kg	0.0	1.0	1800
Potable Water	4.0 kg	0.8	0.0**	0
Wash Water	26.0 kg	0.9	2.6	4680
Total	32.5	0.87	4.3	7740 kg

*** Potable water loop is closed by wastage from whole food.*

7. SAMPLE TRAJECTORIES

Table 4 shows a set of sample trajectories which can be used to accomplish the Athena plan in 2001, 2003, or 2005. In all cases the spacecraft approaches and leaves Mars with a hyperbolic velocity of 4 km/s and uses Mars's gravity to shift into an orbit with the same orbital elements of Mars but with its orbital plane tilted about 9.5 degrees with respect to that of Mars.

8. ESTIMATED COST

The estimated cost of the Athena mission is about $2 billion. The basis for that estimate is shown in Table 5. It should be noted that about $700 million could be saved from the launch costs shown here if Energia were made available. Also, we have included the entire cost of the surface component of the mission and mission operations without taking any credit for the existing Mars Surveyor robotic lander program.

Table 4
TRAJECTORIES FOR ATHENA MISSION

Event	2001	2003	2005
Depart Earth	April 16, 2001, C3=12	July, 20, 2003, C3=18	Aug. 29, 2005, C3=16
Arrive Mars	Nov. 16, 2001, Ls=28	July 15, 2004, Ls=90	Oct. 1, 2006, Ls=135
Depart Mars	Nov. 16, 2002, Ls=100	July 20, 2005, Ls=270	Aug.15, 2007,Ls=315
Arrive Earth	Oct. 16, 2003,Vh=4 km/s	May 15, 2006,Vh=5 km/s	May 5, 2008,Vh=3.5 km/s

Table 5
COST ESTIMATES FOR ATHENA MISSION

Shuttle Launches:	Two needed at $300 million each	= $600 million
Proton Launches :	Four needed at $70 million each	= $280 million
Delta Launches:	Two needed at $55 million each	= $110 million
Hab development :	(use Space station technology)	= $400 million
Re-Entry Capsule:	(use State Station ACRV)	= $100 million
Rover landers:	Four Mars Surveyor landers at $50 million each	= $200 million
Mission Operations		= $100 million
Reserves and Contingency (20%)		= $358 million
Total Cost		= $2148 million

It will be noted that the only major piece of hardware that needs to be developed to perform the Athena mission is the Hab, whose cost we have estimated at $400 million. This amounts to $20,000/kg on a cost per kilogram basis, which is consistent with most development cost estimates in conservative space system hardware costing models. However, rather than leave such estimates to be a point of contention between battling computer costing algorithms, the simplest way for NASA to verify such an estimate would be for NASA to put out an RFP for Hab development with a maximum acceptable price tag for responsive proposals set at $400 million. Given the fundamental simplicity of the Hab as a piece of space hardware, we believe that many qualified bids would be received by NASA under such conditions.

9. GENERAL DISCUSSION

What is the purpose of the Athena mission? Clearly, the notion of flying all the way to Mars without landing is unsatisfactory. Furthermore, while robotic exploration can clearly be enhanced by having humans in the vicinity of Mars to shorten the signal control time delay, from a pure science standpoint it is questionable whether the cost incurred by the manned flight systems could not be better spent buying large numbers of robotic missions and simply accepting the operational disadvantages of the long signal time delays incurred by controlling them from Earth. So why do Athena?

The answer is this: Athena is an *icebreaker* mission. Since the end of Apollo, Mars has been staring NASA in the face as the next challenge for human exploration. The public knows this, and no amount of dancing around the issue can hide it.

Two things, however, have kept NASA from sending human explorers to Mars. The first is the notion that such missions must be incredibly expensive. The second is fear of the risks involved. These two factors have fed off each other, for example, in the case of the 90 Day Report, where fear of long duration space voyages made NASA put the Mars mission at the end of an impossibly expensive 30 year series of preparatory activities.

The debilitating effects of long duration spaceflight are not caused by radiation. No astronaut or cosmonaut has ever received a radiation dose during flight large enough and prompt enough to create any visible effects. Cosmic ray doses in interplanetary space are similar to those in LEO, and the magnitude (50 Rem/year) of such doses are only sufficient to incur a statistical risk of cancer of 1 to 2% on a round-trip Mars mission. Rather, all the well-known ill effects of space flight are due to long duration zero gravity exposure and ensuing complications.

Currently, some people in NASA propose to address this problem by using the Space Station to continue the Soviet program of research quantifying the debilitating effects of long duration zero gravity exposure on human experimental subjects. This prospect has aroused considerable revulsion in the astronaut corps, and will arouse much more among the American public once it comes to be understood. It is one thing to endure risk and hardship in order to reach some great objective; it is another altogether to do so simply as a test. The man who takes a bullet wound in battle for his country is a hero; the man who takes a bullet wound in an experiment to test a new kind of bullet is a fool. If they are to endure the effects of long-duration zero-g, most astronauts would much rather take his or her lumps in the course of performing a mission to Mars than as a test subject on the Space Station.

It should also be noted that the proposed prolonged program of zero-g research will not reduce the total risk to human life posed by a human exploration program. Shuttle missions are risky. Flying enough of them to carry out the zero gravity research program will incur a very high probability of losing crew—much more than an actual Mars mission itself. NASA lost more men in T-38's and training exercises during Apollo than in spaceflight.

So NASA is left with basically left with three choices:

1. *Forget about deep space missions (asteroids included).* If this option is selected, the space program will continue its downward spiral. NASA was chartered to storm heaven. When it did so, in the 1960's, it enjoyed broad public support. Continued confinement of operations to a sphere established a generation ago is trying the patience of the American people.

2. *Go regardless of the effects of zero g.* This is doable in the short run because the effects, while bad, have been shown to be endurable. Crews, while coming home in poor shape, can function well enough while in space. However, in the long run it is undesirable.

3. *Use artificial gravity.* Zero-g life sciences organizations in NASA raise strong objections whenever this suggestion is advanced, because it is orthogonal to their current research program. However, the fact of the matter is that in their arguments against artificial gravity they make much of potential, but unproven, ill-effects due to coriolis forces and such, while ill-effects caused by zero-g are very real and their mitigation proven intractable despite 30 years of research. Every astronaut the author has ever discussed the issue with would *much* rather go to Mars in artificial-g than zero-g.

The simple artificial-g habitat used in the Athena mission can, if launched as a stand alone payload, serve as a variable gravity test facility, and a prototype piloted interplanetary spacecraft.

Demonstration of such a prototype piloted interplanetary spacecraft would be a visible step that NASA could take now, within current fiscal constraints, that would directly enable sending humans on deep space missions. It could be used to kill forever the dragon of zero-g space sickness that is barring us from the solar system. It would directly accomplish most of the non-recurring development that needs to be done prior to either an Athena-type Mars mission or a piloted asteroid mission. With the actual spacecraft built and demonstrated, we would know the mission's mass requirements to the kilogram, which would allow us to quantify precisely the mission propulsion requirements, and therefore the launch requirements. With this data in hand, NASA would be able to go forward to congress or the administration with a plan for a human Mars or asteroid missions whose risk is low and whose cost can be shown to be both low and known accurately.

Once the fundamental feasibility (both fiscal and technical) of human interplanetary spaceflight has been demonstrated by the Athena mission, there would be little standing in the way of follow-on Mars exploration missions in which humans travel to and explore the Red Planet on its surface.

Before Copernicus, Ptolemaic astronomers believed that humanity was walled off from the heavens by a set of crystal spheres. In a way those spheres are still there, made not of glass but of fear. It's about time we smashed them.