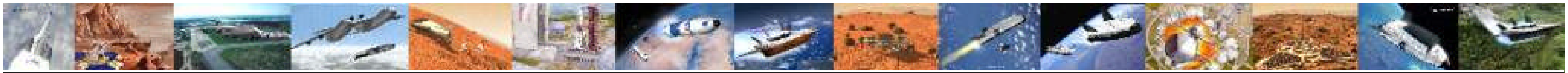


SpaceWorks Engineering, Inc. (SEI)

The League of Extraordinary Machines: A Rapid and Scalable Approach to Planetary Defense Against Asteroid Impactors

Revision B
30 March 2004

SpaceWorks Engineering, Inc.

President / CEO:
Dr. John R. Olds

Senior Futurist:
Mr. A.C. Charania

Design Products Manager:
Mr. Matthew Graham

Project Engineer:
Mr. Jon Wallace

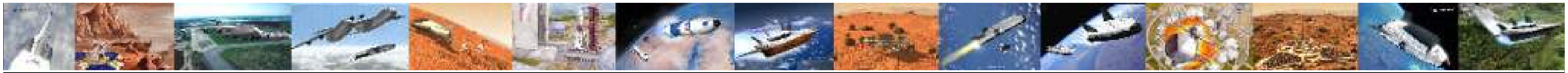
Project Overview

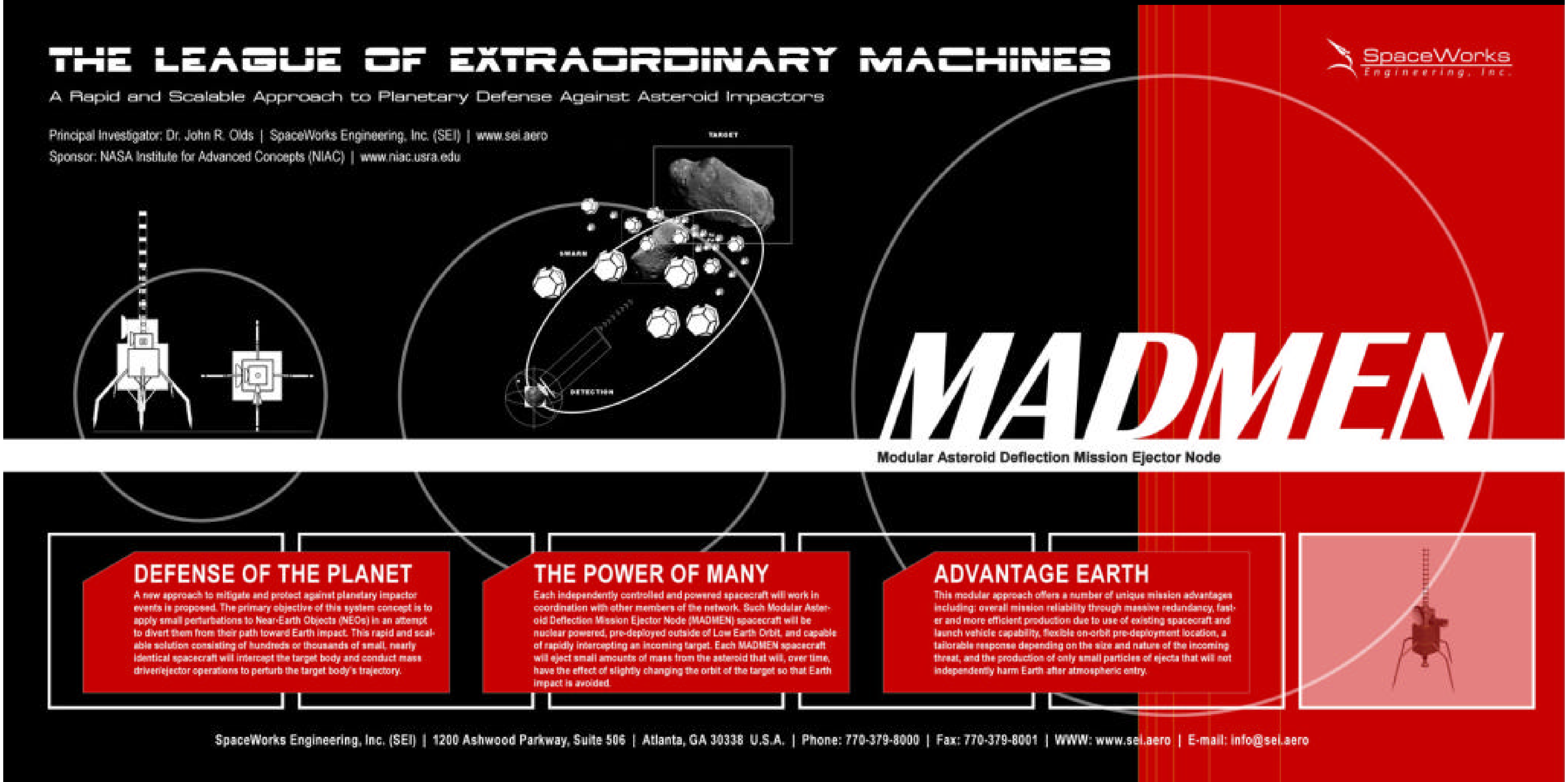
Project Purpose NASA Institute for Advanced Concepts (NIAC) Phase I grant to study new techniques to defend against threats to Earth posed by a Near-Earth Object (NEO). The study is entitled: “The League of Extraordinary Machines: A Rapid and Scalable Approach to Planetary Defense Against Asteroid Impactors.” The primary objective of this system concept is to apply small perturbations to NEOs in an attempt to divert them from their path toward Earth impact using hundreds or thousands of small, nearly identical spacecraft. Out of more than 50 proposals received by NIAC for this solicitation round (CP 02-02), only 11 were accepted, including the one from SpaceWorks Engineering, Inc. (SEI).

Scope Phase I activity involves a six-month (October 2003-March 2004) funded effort led by SpaceWorks Engineering, Inc. (SEI) to establish key quantitative data for the system concept. Presentations made at NIAC 5th annual meeting, November 5-6, 2003 (Atlanta, Georgia) and NIAC Fellows Meeting, March 23-24, 2004 (Arlington, Virginia).



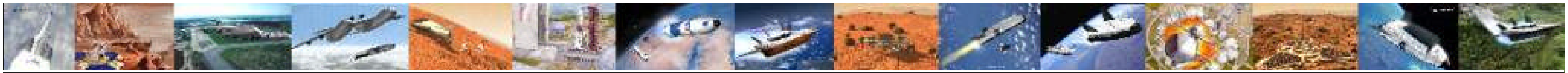

Overview of Activity




THE LEAGUE OF EXTRAORDINARY MACHINES
A Rapid and Scalable Approach to Planetary Defense Against Asteroid Impactors
Principal Investigator: Dr. John R. Olds | SpaceWorks Engineering, Inc. (SEI) | www.sei.aero
Sponsor: NASA Institute for Advanced Concepts (NIAC) | www.niac.usra.edu
SpaceWorks Engineering, Inc.
TARGET
SWARM
DETECTION
MADMEN
Modular Asteroid Deflection Mission Ejector Node
DEFENSE OF THE PLANET
A new approach to mitigate and protect against planetary impactor events is proposed. The primary objective of this system concept is to apply small perturbations to Near-Earth Objects (NEOs) in an attempt to divert them from their path toward Earth impact. This rapid and scalable solution consisting of hundreds or thousands of small, nearly identical spacecraft will intercept the target body and conduct mass driver/ejector operations to perturb the target body's trajectory.
THE POWER OF MANY
Each independently controlled and powered spacecraft will work in coordination with other members of the network. Such Modular Asteroid Deflection Mission Ejector Node (MADMEN) spacecraft will be nuclear powered, pre-deployed outside of Low Earth Orbit, and capable of rapidly intercepting an incoming target. Each MADMEN spacecraft will eject small amounts of mass from the asteroid that will, over time, have the effect of slightly changing the orbit of the target so that Earth impact is avoided.
ADVANTAGE EARTH
This modular approach offers a number of unique mission advantages including: overall mission reliability through massive redundancy, faster and more efficient production due to use of existing spacecraft and launch vehicle capability, flexible on-orbit pre-deployment location, a tailorable response depending on the size and nature of the incoming threat, and the production of only small particles of ejecta that will not independently harm Earth after atmospheric entry.
SpaceWorks Engineering, Inc. (SEI) | 1200 Ashwood Parkway, Suite 506 | Atlanta, GA 30338 U.S.A. | Phone: 770-379-8000 | Fax: 770-379-8001 | WWW: www.sei.aero | E-mail: info@sei.aero

MADMEN Lander Spacecraft and Cruise Stage

MADMEN Lander Spacecraft/Cruise Stage Cometary Approach



MADMEN Lander Spacecraft/Cruise Stage Attack

MADMEN Lander Spacecraft NEO Close-Approach

MADMEN Lander Spacecraft Surface Action

Firm Overview

Vision

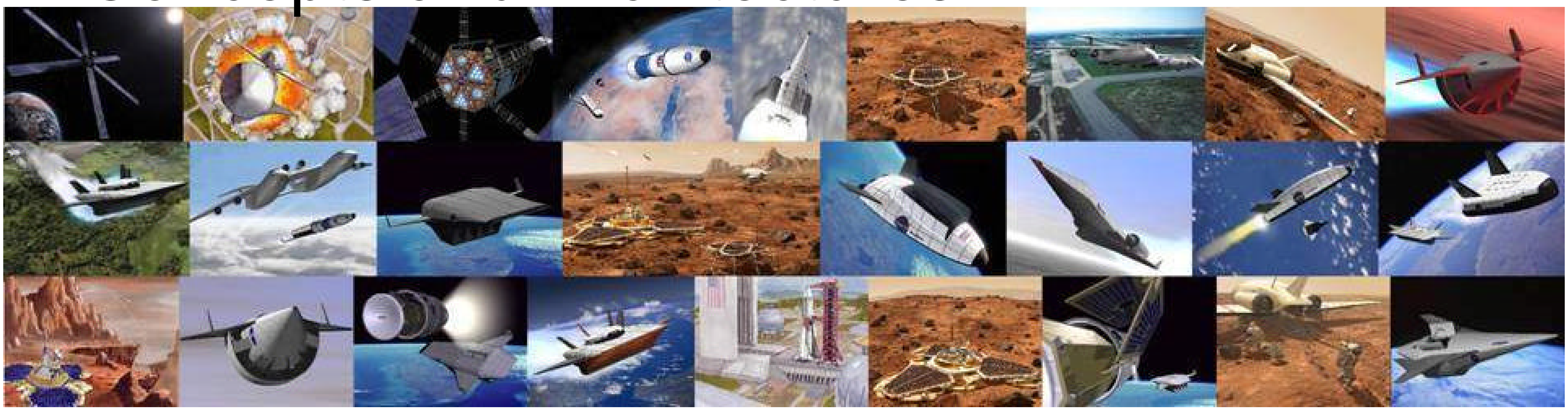
SpaceWorks Engineering, Inc. (SEI) is here to examine the imagined future with real tools.

SEI can provide consul to those seeking to exploit outer space, from transportation to infrastructure, for public and private, from science to tourism. Our conceptual level toolsets and method can help determine feasibilities of space systems, viabilities in the marketplace, and determine the temporal impacts of technology on public and private actors. We forecast future markets making determinations of future policy and media initiatives.

SpaceWorks Engineering, Inc. (SEI) is a small aerospace engineering and consulting company located in metro Atlanta. The firm specializes in providing timely and unbiased analysis of advanced space concepts ranging from space launch vehicles to deep space missions.

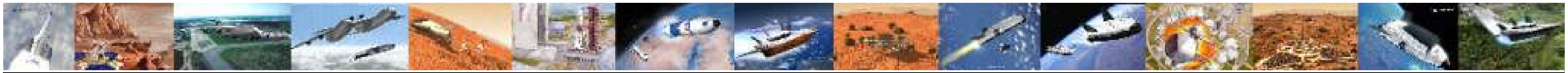
The firm's practice areas include:
- **Space Systems Analysis**
- **Technology Prioritization**
- **Financial Engineering**
- **Future Market Assessment**
- **Policy and Media Consultation**

Concepts and Architectures

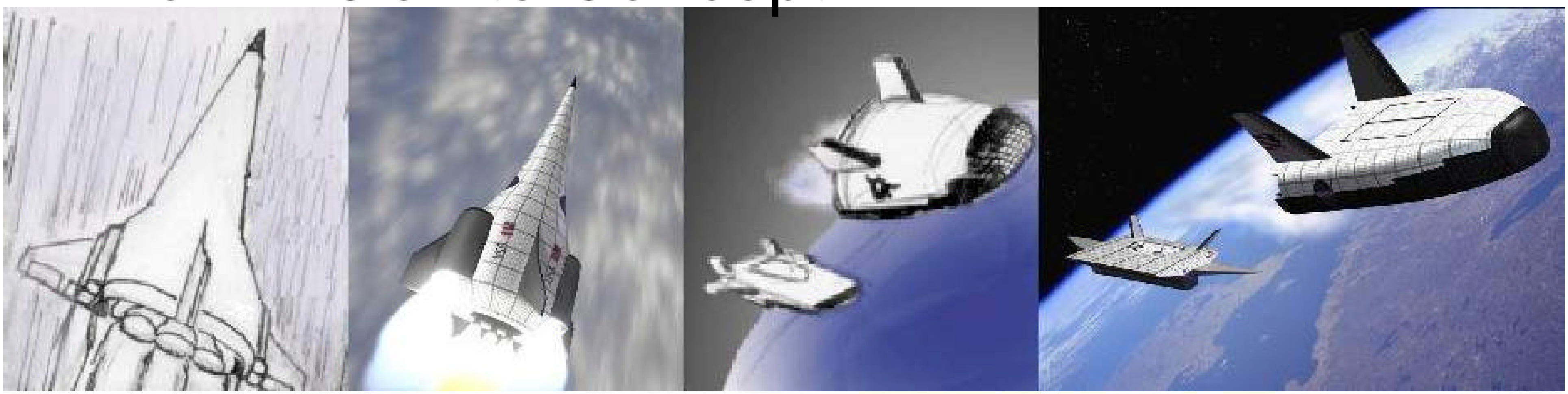


Including:
- **2nd, 3rd, and 4th generation single-stage and two-stage Reusable Launch Vehicle (RLV) designs (rocket, airbreather, combined-cycle)**
- **Human Exploration and Development of Space (HEDS) infrastructures including Space Solar Power (SSP)**
- **Launch assist systems**
- **In-space transfer vehicles and upper stages and orbital maneuvering vehicles**
- **Lunar and Mars transfer vehicles and landers for human exploration missions**
- **In-space transportation nodes and propellant depots**
- **Interstellar missions**

Image sources: SpaceWorks Engineering, Inc. (SEI), Space Systems Design Lab (SSDL) / Georgia Institute of Technology



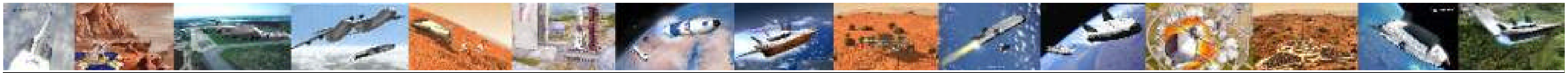
From Vision to Concept



Including:
- Engineering design and analysis
- New concept design
- Independent concept assessment
- Full, life cycle analysis
- Programmatic and technical analysis

Including:
- Storyboards
- Technical concept illustrations (marker and pastel in B&W and color)
- 2-D line engineering drawings with technical layouts and dimensions
- 3-D engineering CAD models of concept designs
- High-resolution computer graphics imaging (renders)
- Concept / architecture summary datasheets and single page handouts / flyers

Introduction to the Threat



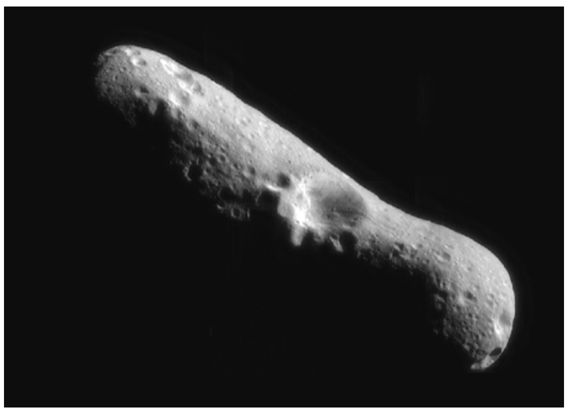
Definitions

NEO Near Earth Object (within 0.3 AU)

PHO Potentially Hazardous Objects (within 0.025 AU)

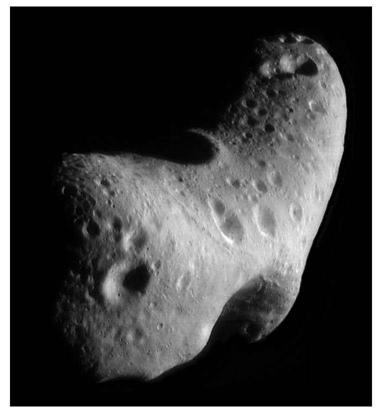
Types of NEOs Asteroids or Comets

Amount 50,000 fragments of NEOs fall on Earth as meteorites each year but are too small to cause much damage. Forty thousand tons of dust, much from NEOs, also lands on Earth every year. This is nearly 100 billion particles.



Asteroid 433 Eros (NEAR Shoemaker)

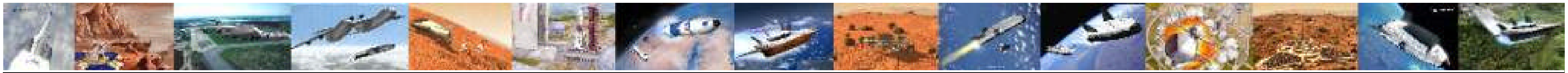
Asteroid 433 Eros (NEAR Shoemaker)



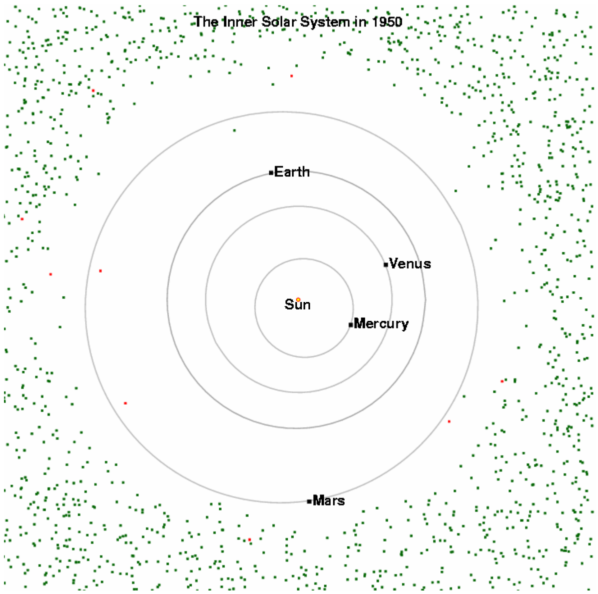
Asteroid 433 Eros (NEAR Shoemaker)

Comet Wild 2 (Stardust)

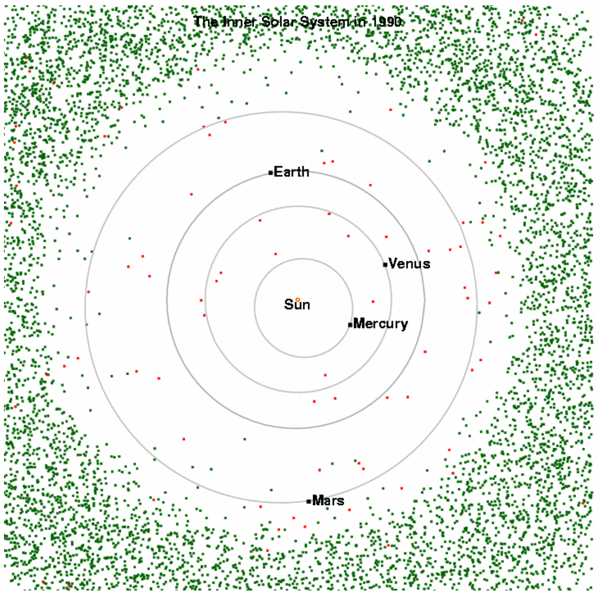
Sources: http://nssdc.gsfc.nasa.gov/planetary/mission/near/near_eros_approach.html, http://stardust.jpl.nasa.gov/photo



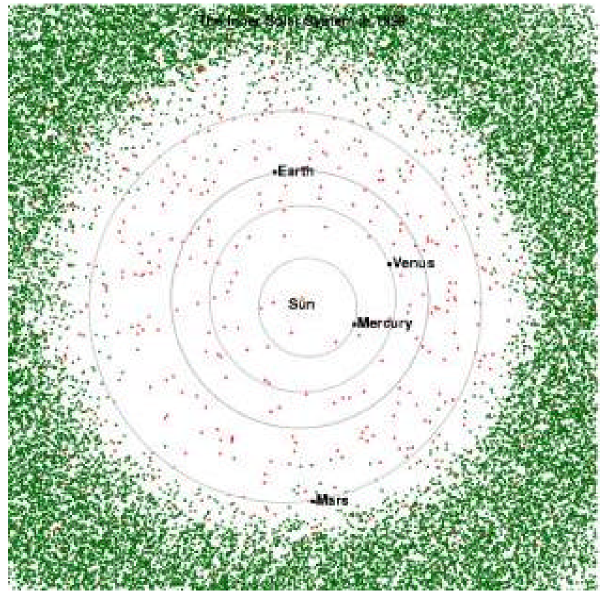
1950



1990

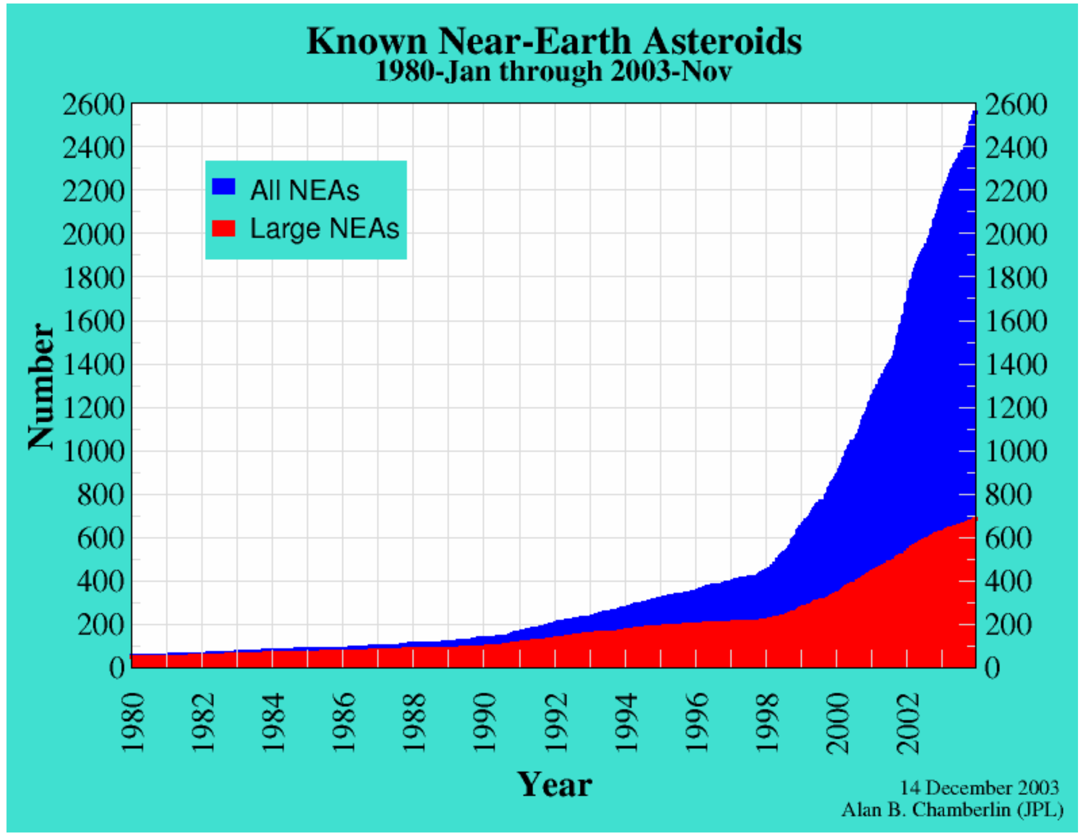


1998



Near Earth Object Maps of the Inner Solar System

Source: http://www.arm.ac.uk/neos/

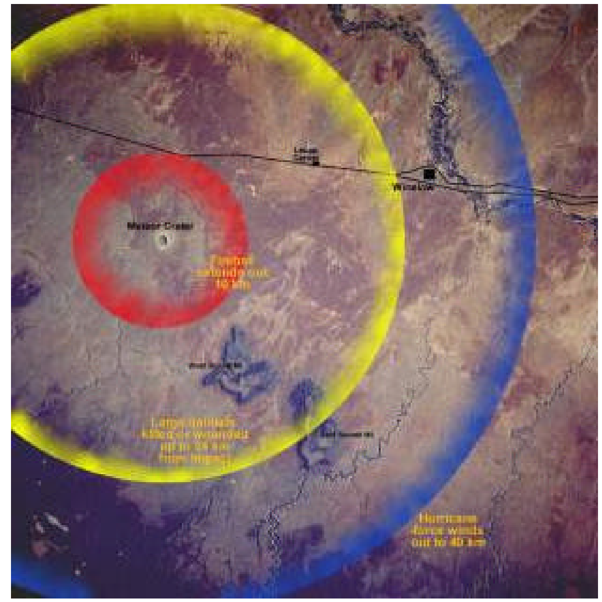


Known NEOs

Source: http://neo.jpl.nasa.gov/stats

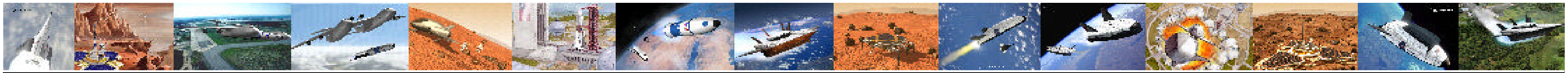
Tunguska
1908
~60m diameter

Meteor Crater
20k-50k years ago
~30m diameter



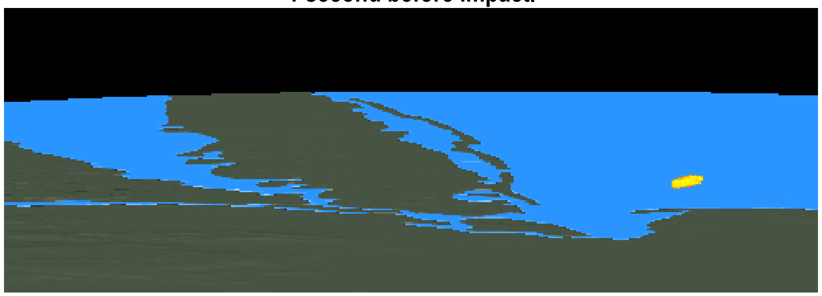
Terrestrial Meteor Evidence

Source: http://www.lpl.arizona.edu/SIC/impact_cratering/Enviropages/Barringer/effectsmappage.html

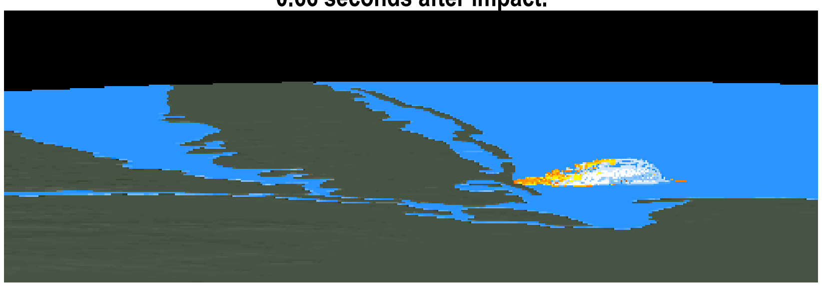


The Impact of a 1.4 km Diameter Asteroid off the New York Coast

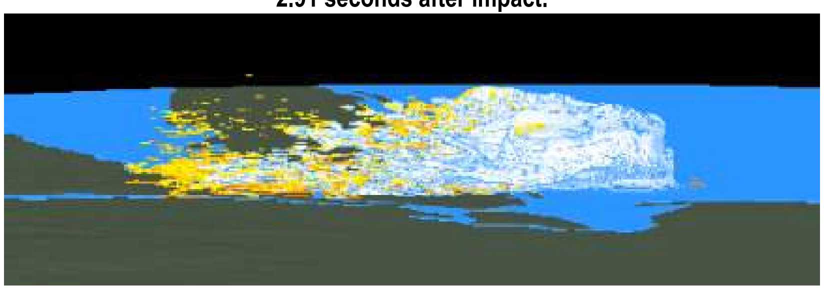
1 second before impact.



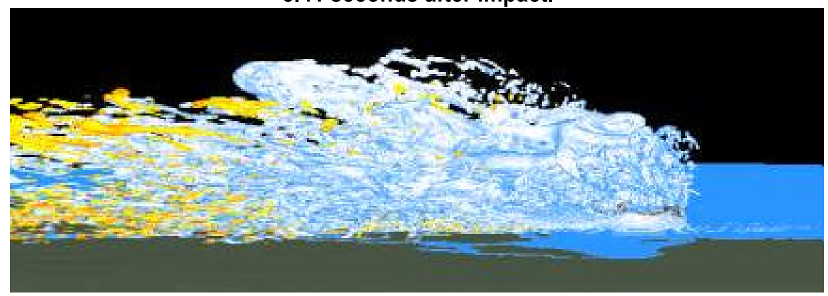
0.66 seconds after impact.

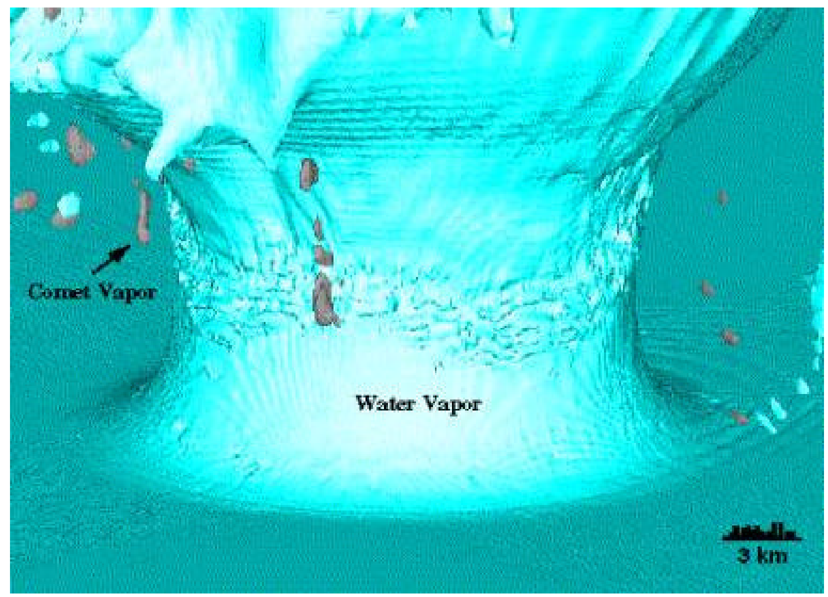


2.91 seconds after impact.

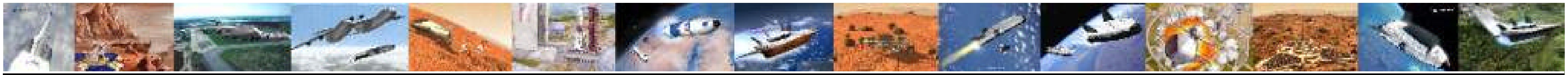


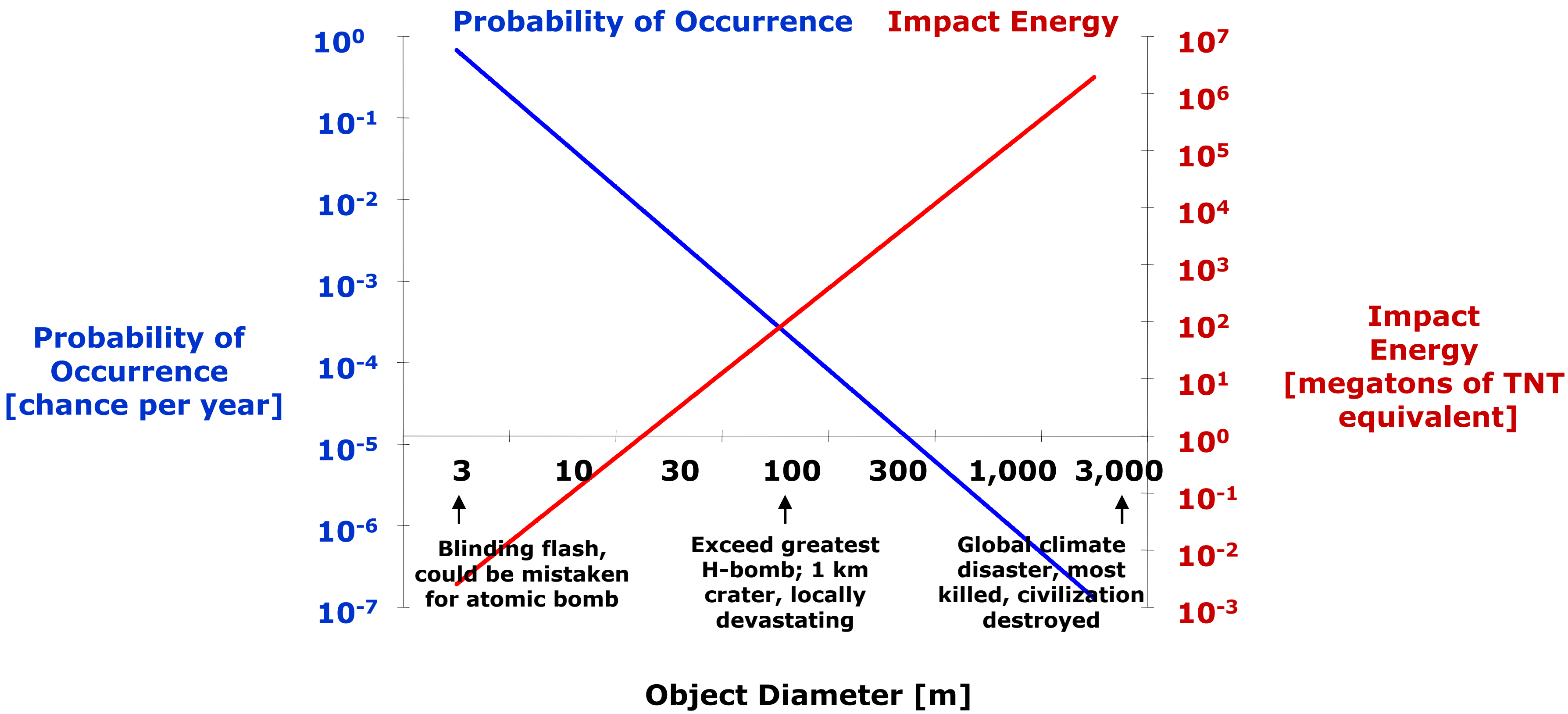
8.41 seconds after impact.





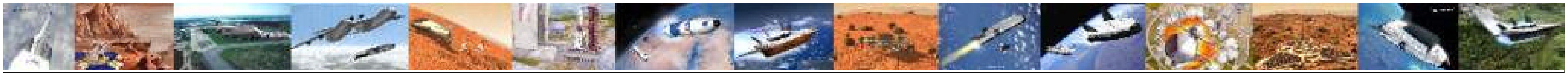
Source: Sandia National Lab, http://sherpa.sandia.gov/planet-impact/asteroid, “This simulation depicts the impact of an asteroid into the Atlantic Ocean about 25 km south of Brooklyn, New York. This is an example of a near grazing impact: the asteroid approaches the ocean at an angle of only 15 degrees from horizontal. The simulation starts out with the asteroid 50 km south of the impact point, at an altitude of 14 km above the surface of the water. It is 1.4 km in diameter, traveling 20 km/s. (The same impact energy as Shoemaker-Levy 9 on Jupiter.) An impact of this magnitude can be expected to occur on Earth about once every 300,000 years and is just at the "global catastrophe threshold".”

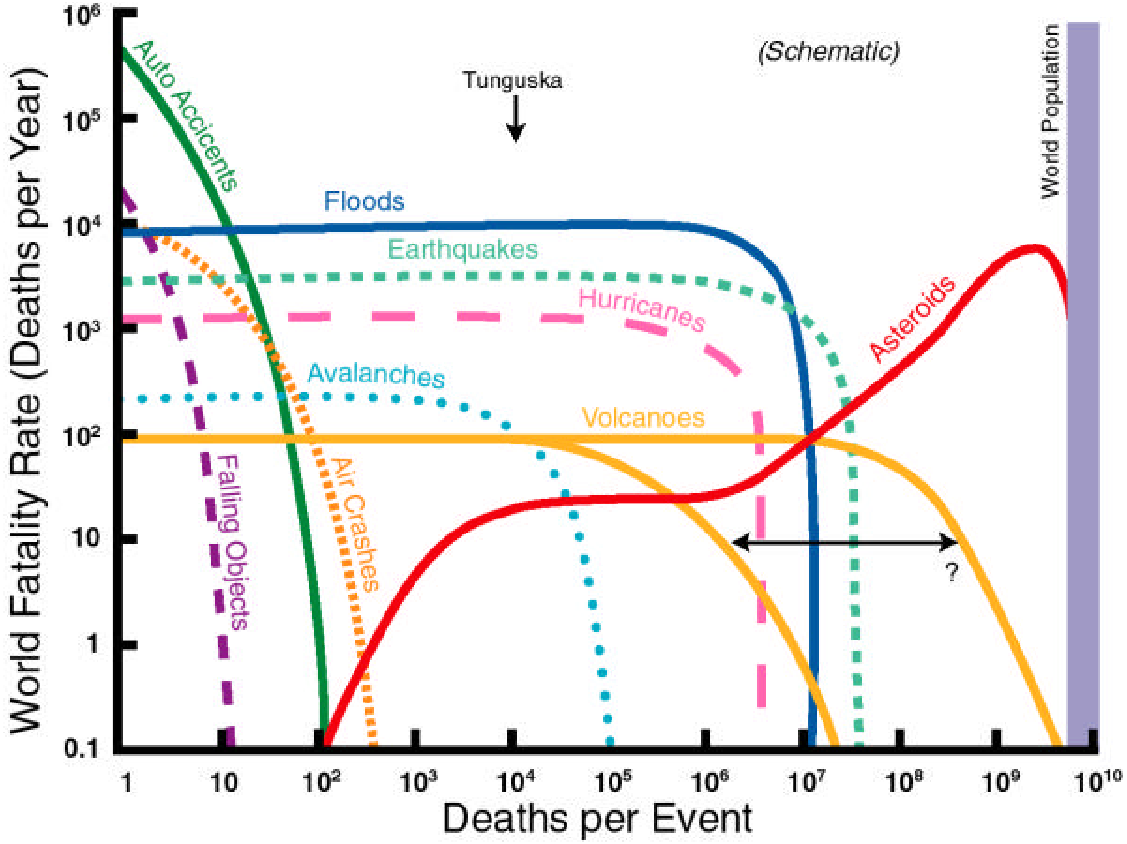




Impact Potentials

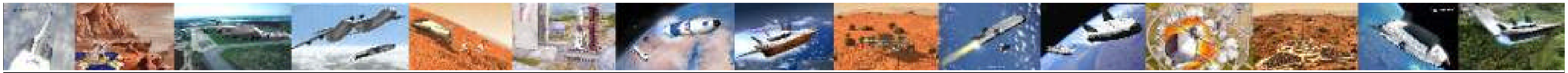
Source: "How a Near-Earth Object Impact Might Affect Society", Commissioned by the OECD Global Science Forum, Clark R. Chapman, Southwest Research Inst., Boulder, Colorado, USA, Workshop on Near Earth Objects: Risks, Policies, and Actions, Frascati, Italy, 20 January 2003.



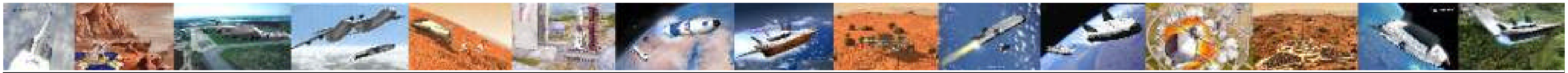


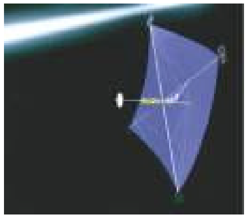
Fatality Rates Compared with Accidents and Natural Hazards

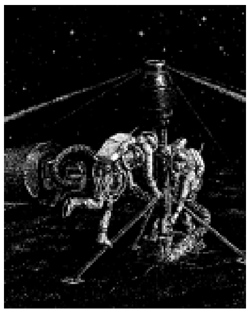
Source: "How a Near-Earth Object Impact Might Affect Society", Commissioned by the OECD Global Science Forum, Clark R. Chapman, Southwest Research Inst., Boulder, Colorado, USA, Workshop on Near Earth Objects: Risks, Policies, and Actions, Frascati, Italy, 20 January 2003.



MADMEN Lander Overview







Solar Sails The orbit of a Near Earth Object (NEO) could be altered by attaching sails designed to catch the Solar Wind streaming from the Sun. For large asteroids, however, the size of sail required may be too large to be realistic.

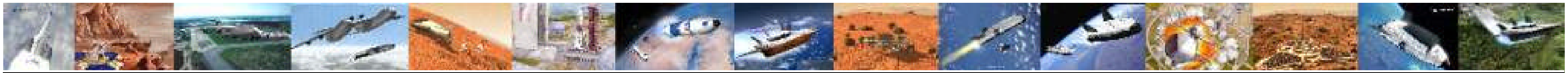
Mass Driver A device that ejects materials from the surface of an object that would slowly change its orbit.

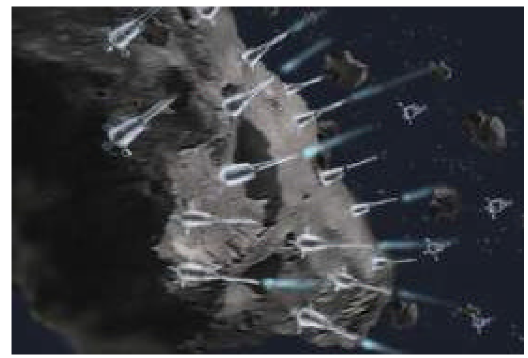
Solar Mirrors The orbit of a Near Earth Object could be changed by focusing sunlight (or artificial laser light) onto the surface of the object. The jet of gas produced would change the path of the object particularly if it contains abundant water or carbon such as a C-type asteroid.

Engines Engines, either attached to the NEO or on a spacecraft, could be used to move the object. On some NEOs water locked up in their minerals could be used as fuel.

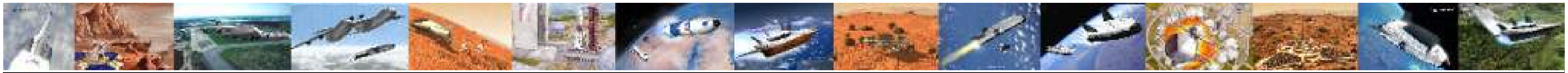
Impactor/Explosives These (chemical or nuclear) could be used to generate a crater on an NEO. The ejection of materials from the asteroid will change its motion. For comets a crater could form a new active area producing a jet of gas which will change the orbit still further.

Alternate Mitigation Techniques





Modular Asteroid Deflection Mission Ejector Node (MADMEN)



A **modular/swarm spacecraft architecture**, based upon existing spacecraft buses and launch vehicles, is proposed to mitigate near-Earth object (NEO) planetary threats.

Each spacecraft that is part of this swarm would utilize **mass driver technology** to remove mass from the object to yield an Earth-avoiding trajectory.

Such a design philosophy focuses on developing **rapid and scalable** NEO mitigation plans incorporating the world's current launch vehicle/spacecraft bus manufacturing capability.

Potential advantages envisioned in such an architecture design include: integrating the analysis of spacecraft development/deployment/launch, ability to complete the mission given the loss of part of the swarm, scalability of response for different size threats, and flexibility to initiate an immediate response leaving the option to develop more advanced systems.

Inspiration: **Gerard K. O'Neill (Space Studies Institute) mass drivers**
NASA ANTS (Autonomous Nano-Technology Swarm)

Overview

NEO + Swarms: Examples of Consensus

Aerospace Corporation

AIAA 2204-1454 “Deflecting a Near-Term Threat Mission Design for the All-Out Nuclear Option”: One of the main conclusions of this Aerospace Corp. study was the need to incorporate redundancy into the mission design given the uncertainty in various aspects of the mission. This included both spacecraft and launch pads (launch failures taking out a pad). They included some preliminary estimates for multiple small spacecraft and launch vehicles.

Current Designs

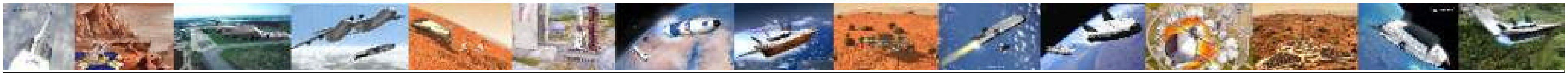
U.K. QinetiQ’s Smallsat Intercept Missions to Objects Near Earth (SIMONE) mission utilizing a fleet of low-cost microsatellites that will individually rendezvous with a different Near Earth Object (NEO), (AIAA 2004-1425). http://www.esa.int/gsp/completed/neo/simone.html

Policy Experts

“Project CARDINAL-A Policy Relevant NEO Hazard Mitigation System”: As presented by G. Somer from RAND, the Project CARDINAL reference design included a swarming approach to the mitigation architecture (AIAA 2004-1463).

Community

Swarms repeatedly mentioned at 1st Planetary Defense Conference: Protecting Earth from Asteroids, Orange County, California, February 24-27, 2004.



Components Equipped with a power source, a drilling/pulverizing mechanism, landing anchors, a mass driver accelerator, and associated subsystems

Mass Driver Propellant-less operation uses asteroid's material as ejecta to deliver sustained impulse to the target without the requirement to provide and manufacture additional propellant.

On-board Power Baseline power source is nuclear power for long life and deep space compatibility. Consider solar power as a trade study.

System Modularity Allows massive system redundancy and increases overall mission reliability. Individual spacecraft can fail and still have mission success.

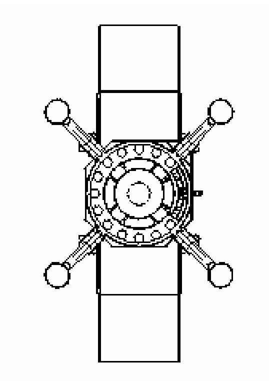
Design Commonality Ensures high production rates and economies of scale during production. Opens competition to a vast array of spacecraft bus manufactures.

Small Design Allows launch and deployment on a variety of domestic and international launch vehicles. Launch of multiple MADMEN on small or large launchers can be accommodated. Lower launch costs and faster response time.

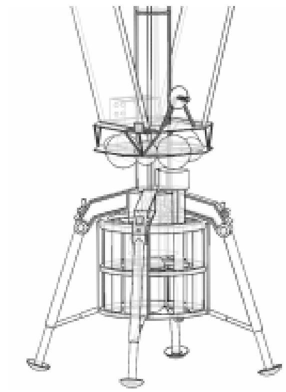
Small Ejecta Mass Creates smaller objects in ejecta debris field that are unlikely to survive entry into Earth's atmosphere

MADMEN Lander Characteristics

Components of MADMEN Spacecraft



Mining system with coring drill tube attachments



Ejecta bucket and ore processing

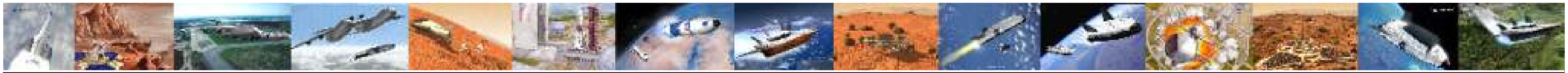
Nuclear reactor power system with high power capacitors

Self-Assembling Mass Ejection Tube

Radiators

Attitude and landing propulsion system

Note: Landing legs, mass ejection tube, and radiators collapse for launch vehicle packaging



Key Trade Offs

DESIGN TRADE-OFFS

Item	Main Effects
Ejection Velocity	Launch Energy Down Force Launch Power
Ejecta mass per shot	Launch Energy Hole Size Total Mass Ejected
Operating Time on Target Body	Number of Landers Public Confidence
Mass Driver Track Length	Launch Power Down Force
Shot Frequency	Reactor/Capacitor Size Trade Number of Landers

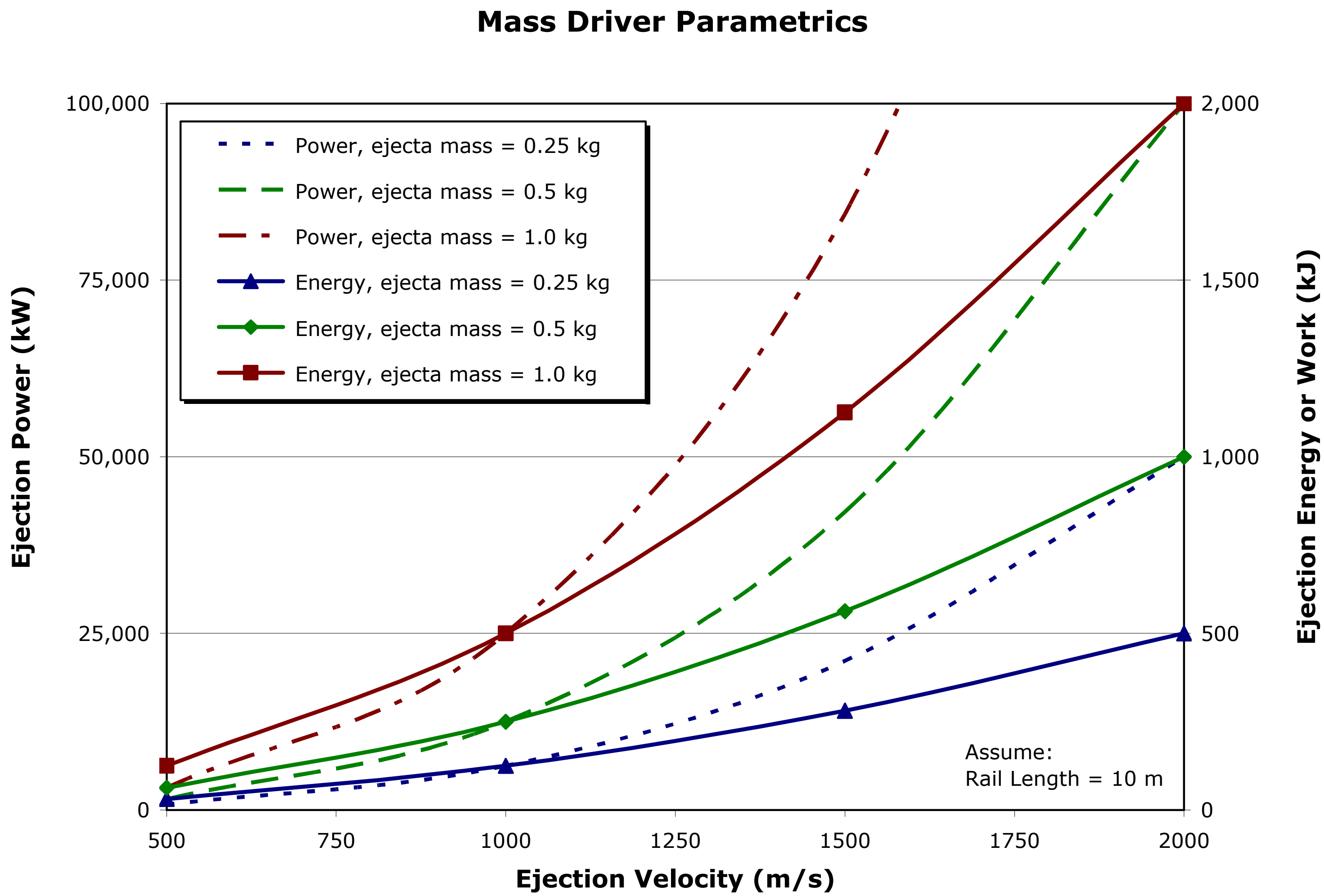
CONSTRAINTS

Item
Operating Time on Target Body
Launch Vehicle Packaging
Limit on Ejecta Size
Mass Driver Track Length
Launch Vehicle Mass to C3 = 0

OBJECTIVE

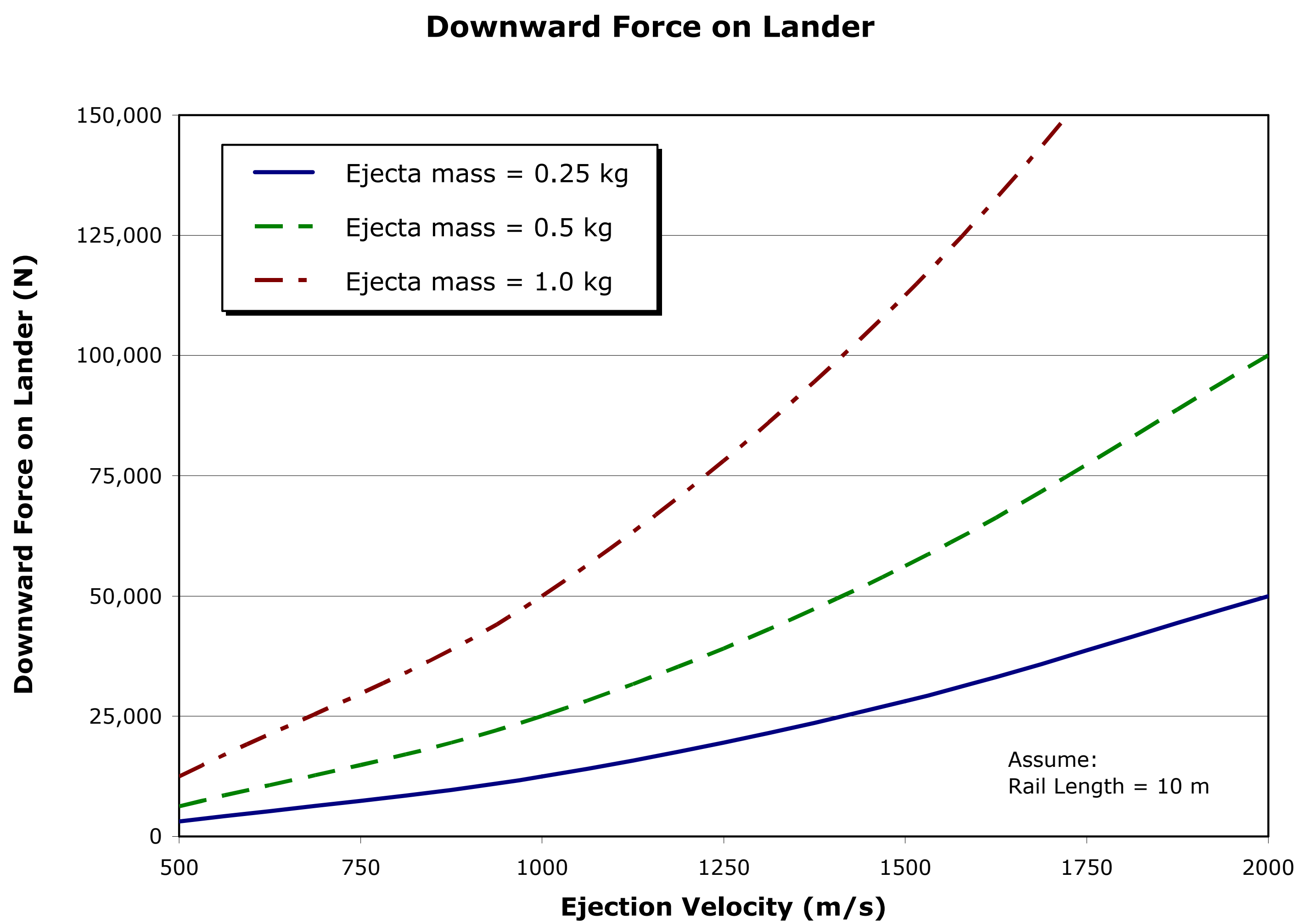
Item
Minimize the total number of spacecraft required for the particular target (uses multidisciplinary Genetic Algorithm optimizer)

Sensitivity (1)

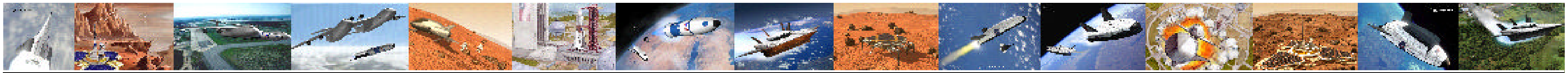


* Note: Based upon baseline lander/impactor scenario

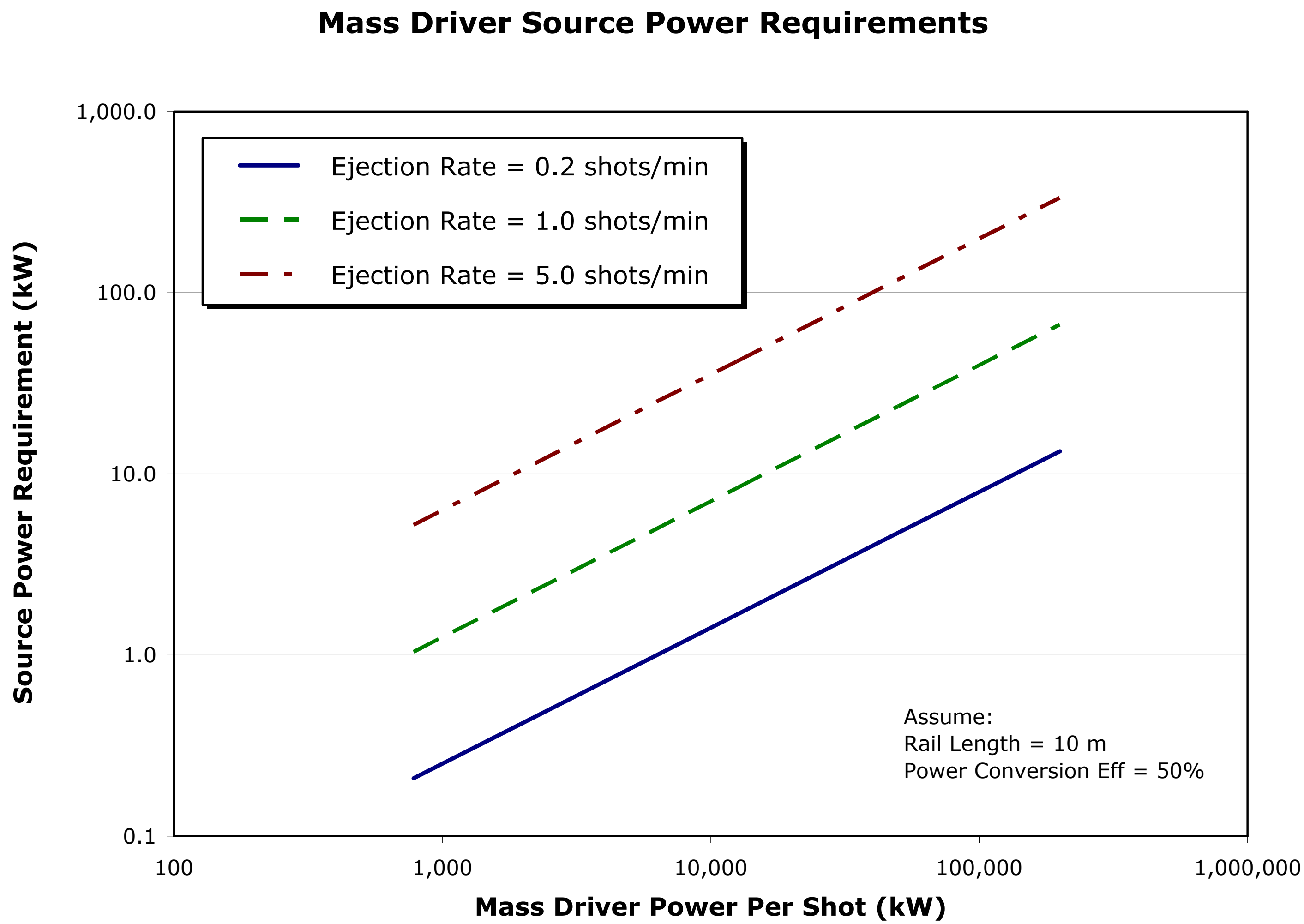
Sensitivity (2)



* Note: Based upon baseline lander/impactor scenario

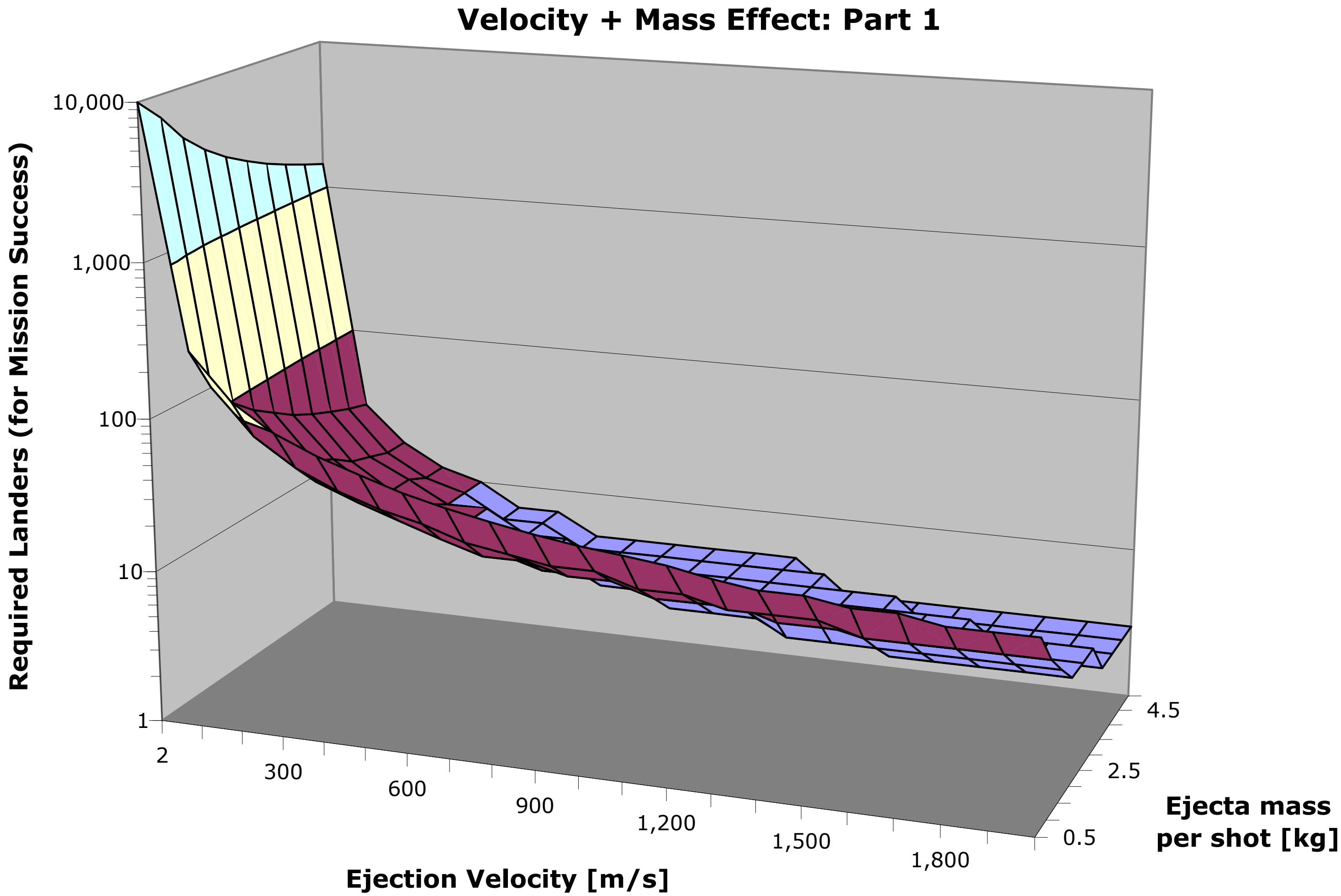


Sensitivity (3)



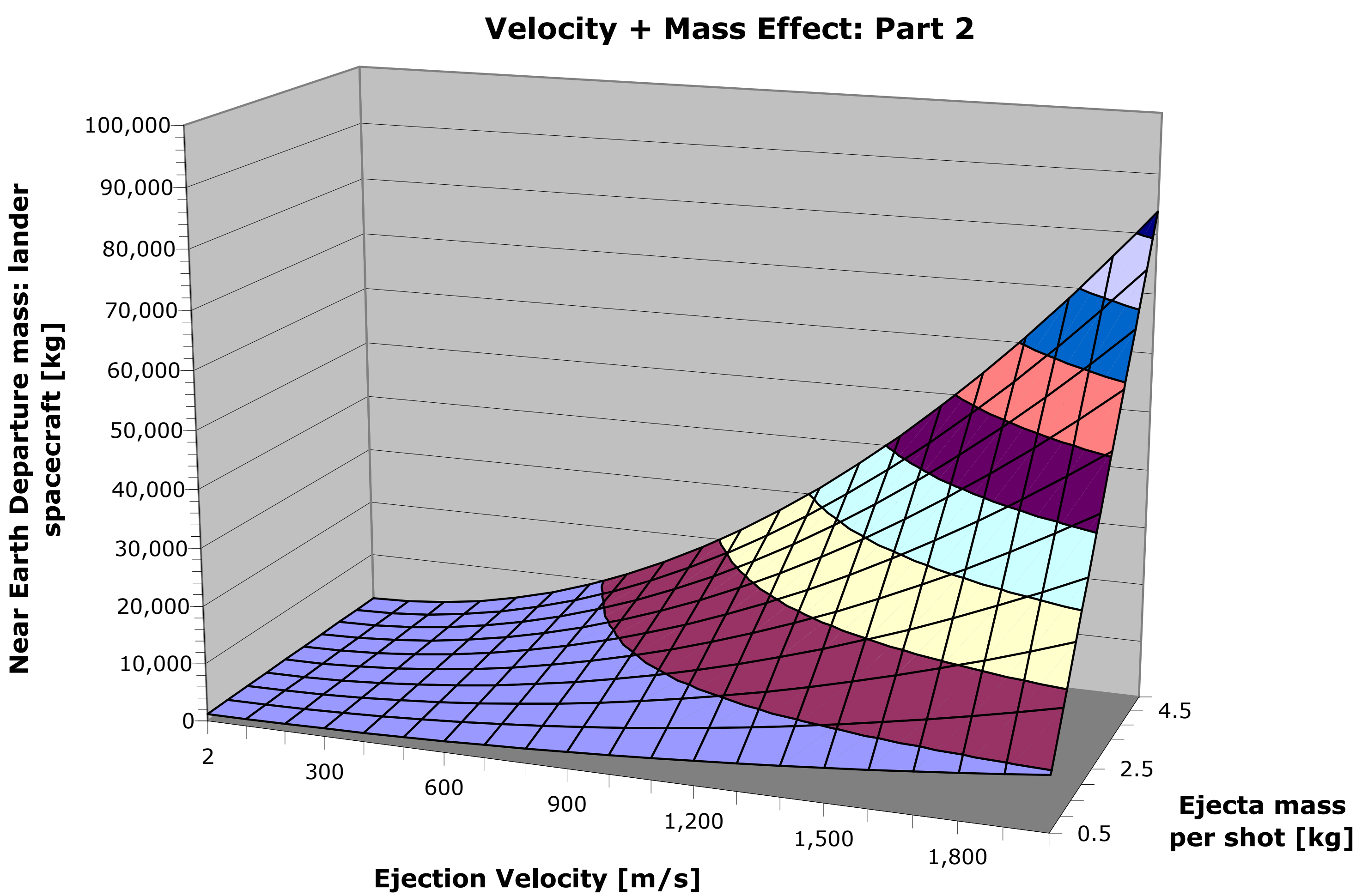
* Note: Based upon baseline lander/impactor scenario

Sensitivity (4)

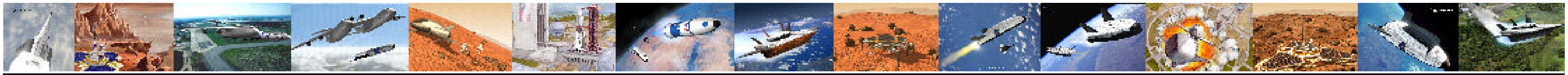


* Note: Based upon baseline lander/impactor scenario

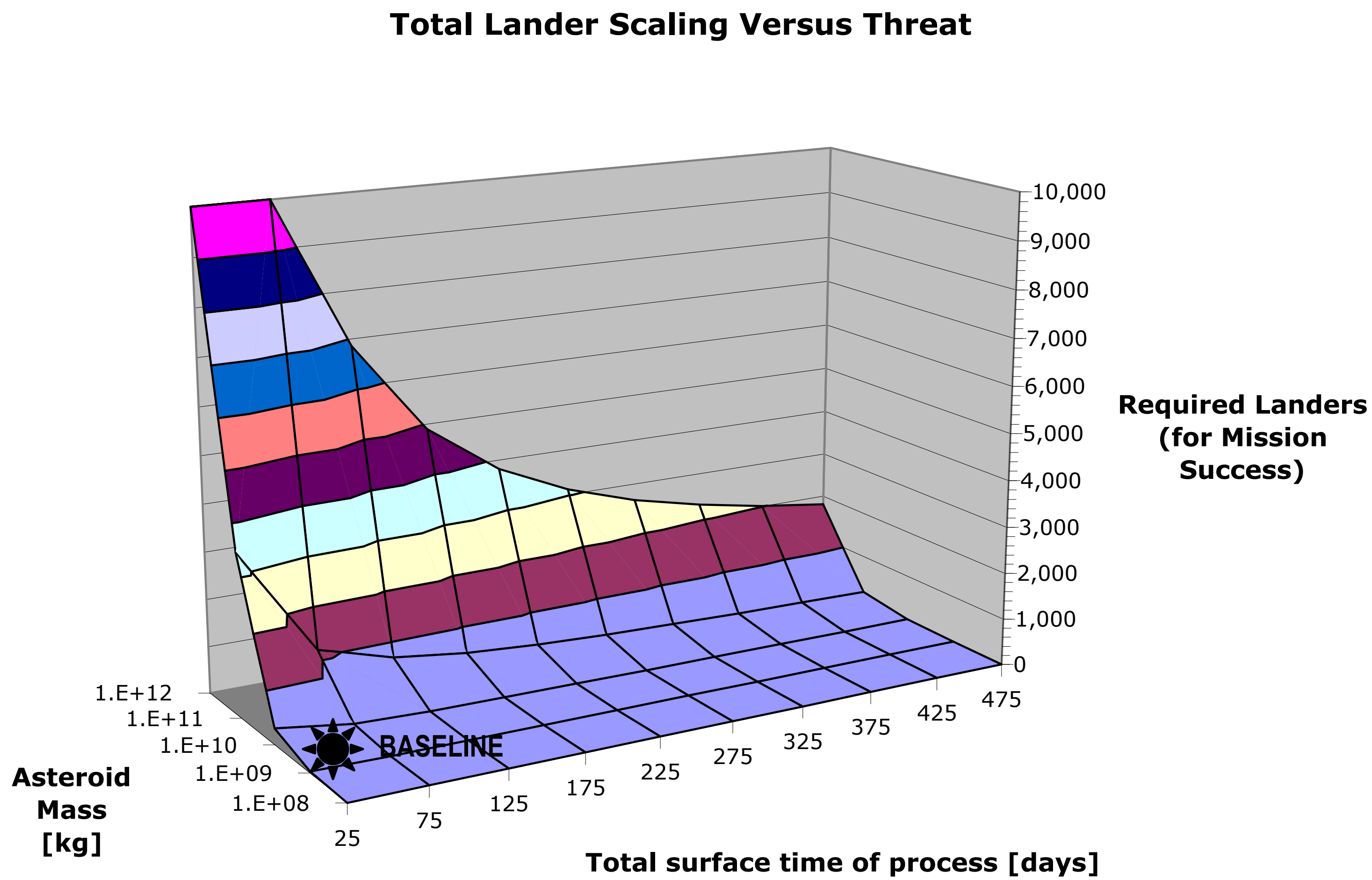
Sensitivity (5)



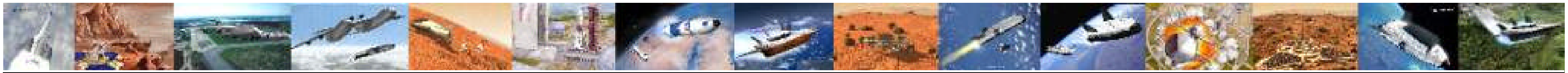
* Note: Based upon baseline lander/impactor scenario



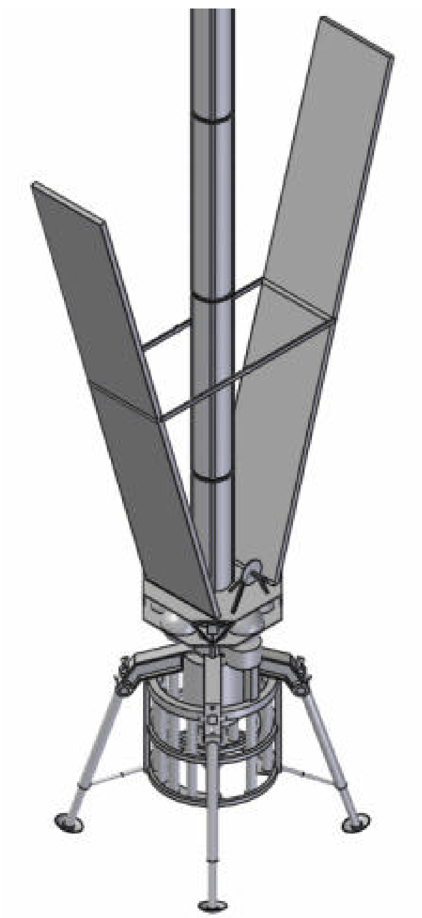
Sensitivity (6)

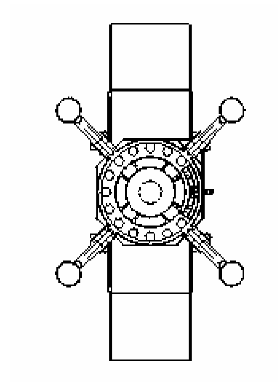


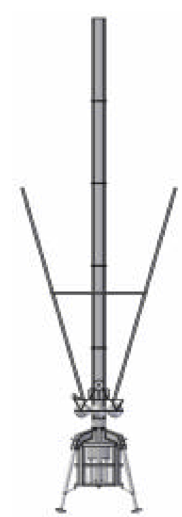
* Note: Based upon baseline lander/impactor scenario



Overview: Modular Asteroid Deflection Mission Ejector Node (MADMEN) Spacecraft







BASELINE MADMEN LANDER SPACECRAFT PARAMETERS

Item	Value
Ejection Velocity	187 m/s
Ejecta mass per shot	2 kg
Rail Length	10 m
Shot frequency (per minute)	1 per minute
Total surface time of process	60 days
Total Power Required	42.2 kW
Dry Mass / Gross Mass	**1,503 kg / 1,621 kg**

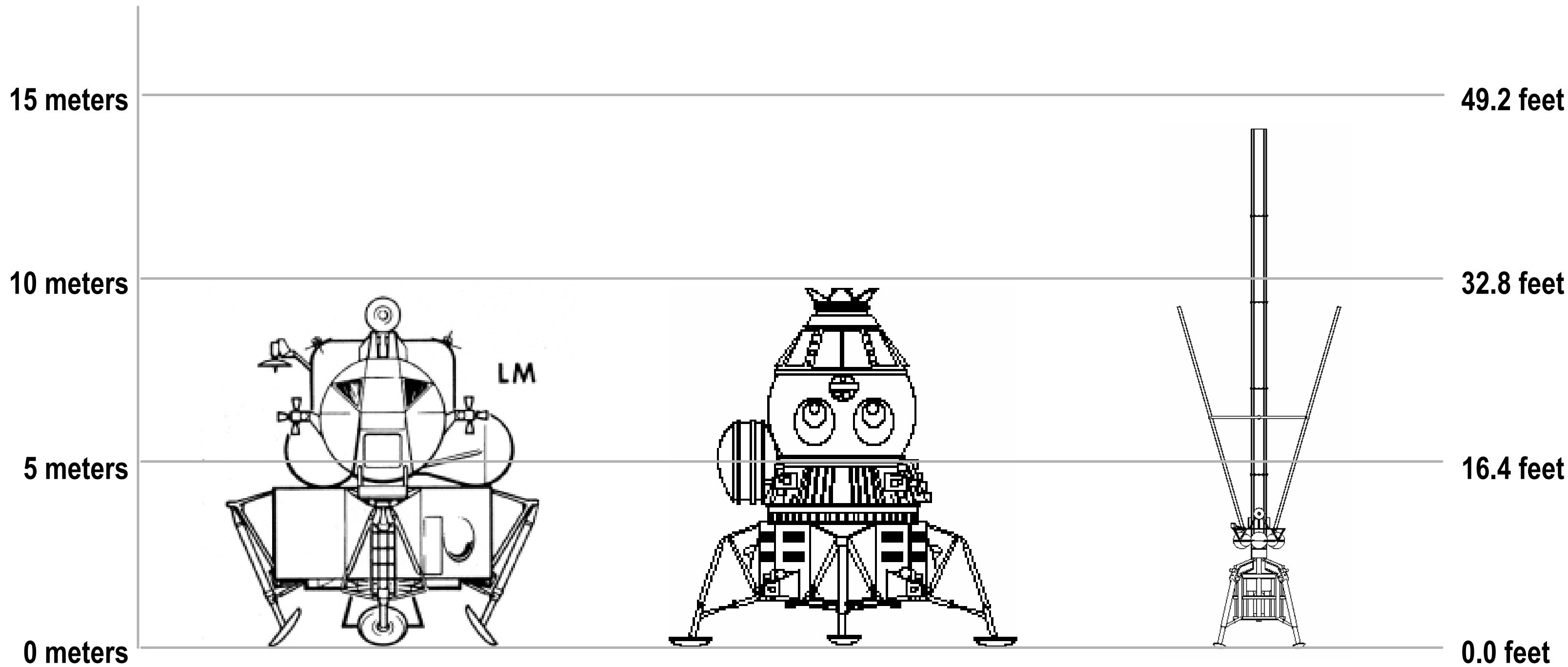
* Note: Reflects optimized spacecraft parameters based upon Delta-IV Heavy launch constraint and goal for lowest number of spacecraft for particular asteroid threat

BASELINE MISSION AND IN-SPACE-TRANSFER STAGE PARAMETERS

Item	Value
Delta-V imparted to Impactor	0.2 m/s
Impactor Mass / Diameter	2.7×10^9 kg / 130 m
Delta-V to get to Impactor	5,423 m/s
Dry Mass / Gross Mass (with Payload)	**2,207 kg / 8,816 kg**

* Note: Upper stage consists of conventional LOX/LH2 stage using RL-10A-4-2 engine performing a two-burn, Earth escape + Impactor capture, lander spacecraft has additional propulsive capability of 175 m/s

MADMEN Lander Scale Comparison



Apollo LM	LK Energia	MADMEN Lander	VEHICLE NAME
15,100 kg	**10,300 kg**	**1,502 kg**	**DRY MASS**
9.39 m	9.81 m	13.97 m	Length
6.37 m	9.51 m	2.54 m	Height
9.39 m	9.51 m	2.54 m	Width

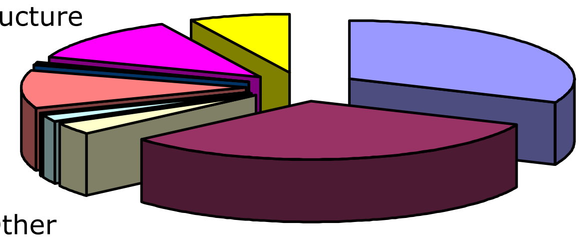
Mass Breakdown Statement (MBS): MADMEN Lander Spacecraft

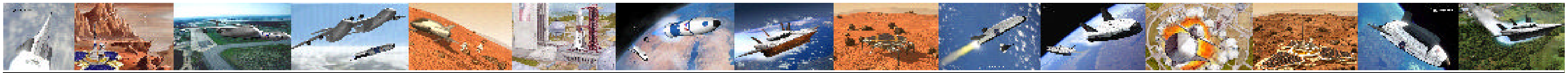
TWO-LEVEL MASS BREAKDOWN

Item	Mass [kg]
1.0 Power System	514
2.0 Mining System	517
3.0 Ejection System	54
4.0 Propulsion	31
5.0 Thermal Control	2
6.0 Main Structure	172
7.0 Data Processing	8
8.0 Navigation Sensing/Control	4
9.0 Telecom and Data	4
10.0 Dry Mass Margin (+15%)	196
Dry Mass	**1,502**
11.0 Propellants (cruise egress + landing)	118
Near Earth Departure Mass: lander spacecraft	**1,620**

* Note: Any errors due to rounding, propellants include reserves, residuals, unusable, and in-flight losses/venting

TOTAL MASS BREAKDOWN





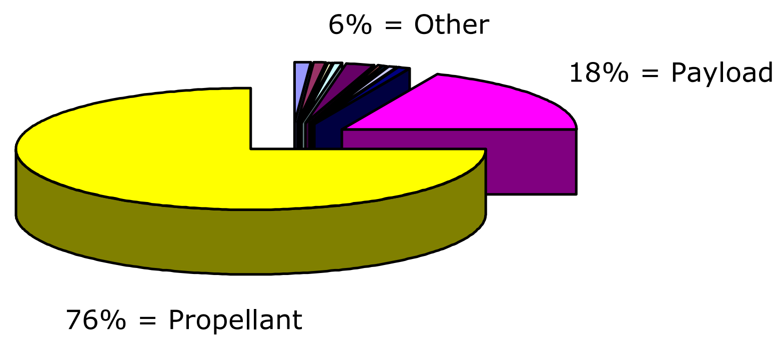
Mass Breakdown Statement (MBS): In-Space-Transfer Stage (ISTS)

TWO-LEVEL MASS BREAKDOWN

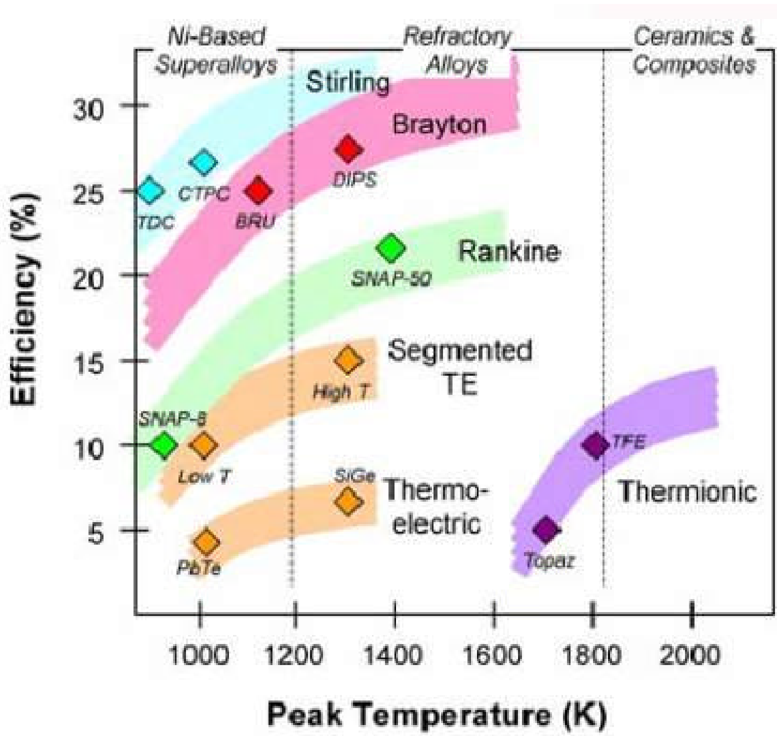
Item	Mass [kg]
1.0 LH2 Tank Structure	98
2.0 LH2 Tank Insulation	70
3.0 LOX Tank Structure	33
4.0 LOX Tank Insulation	37
5.0 Propulsion	187
6.0 Telecom	4
7.0 Subsystems	40
8.0 Other Structure	47
9.0 Dry Mass Margin (+15%)	70
Dry Mass	**586**
10.0 Payload	1,621
Impactor Arrival Mass	**2,207**
11.0 Propellants	6,609
Pre-Injection Mass: ISTS and Payload	**8,816**

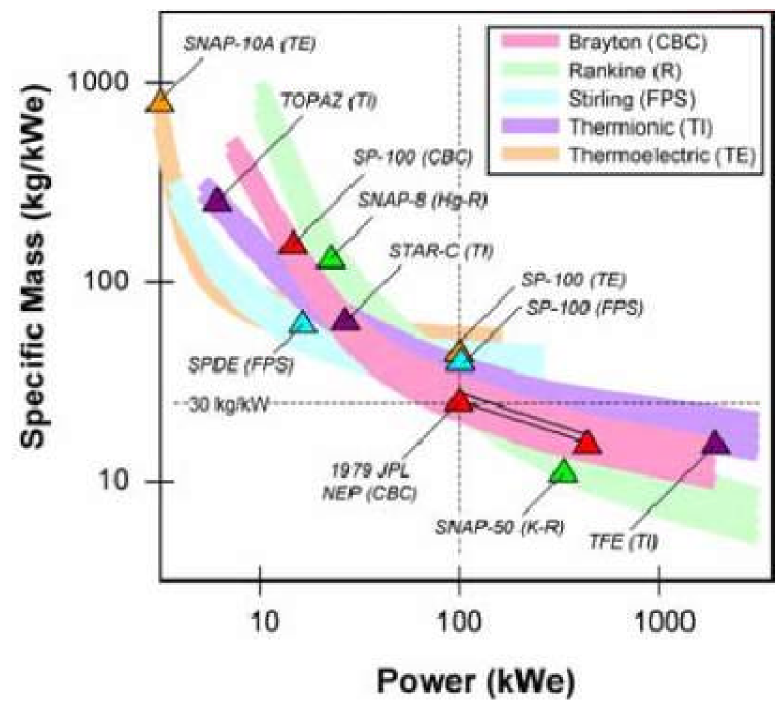
* Note: Any errors due to rounding, propellants include reserves, residuals, unusable, and in-flight losses/venting

TOTAL MASS BREAKDOWN



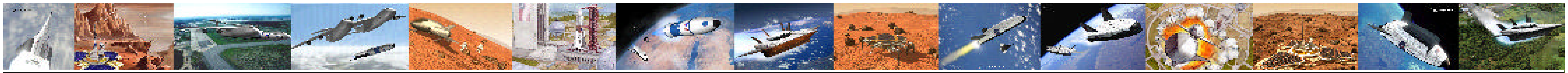
Boeing EELV Delta IV Heavy 4050-H
Earth Escape Capability = 9,306 kg
(5m x 19.1m composite dual manifest fairing, c_3=0 km^2/s^2)





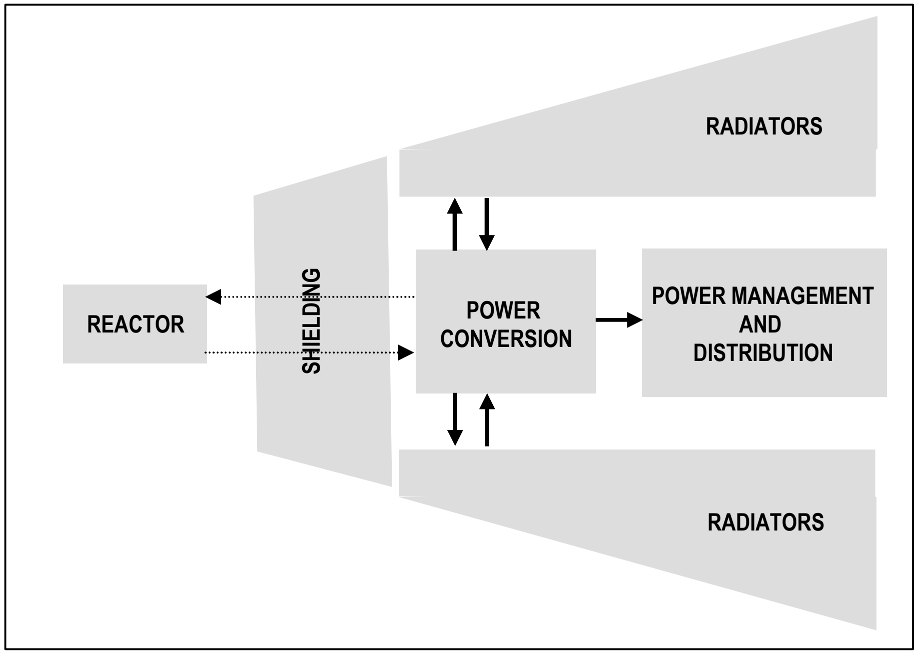
Thermo-Electric Conversion Options

Source: Two-Phase Flow, Fluid Stability and Dynamics Workshop, Steve Johnson, Power Implementation Manager, May 15, 2003, PROJECT PROMETHEUS



Power Budget: MADMEN Lander Spacecraft

POWER SCHEMATIC



TWO-LEVEL POWER BUDGET

Power Item	Power [kW]
Thruster Power Required	0.010
Propellant Feed System Required	0.010
Mining Power Required	10.000
Driver Power Required	0.798
Hotel Load Required	0.025
Science Load Required	0.010
Communication Load Required	0.025
Total Load Required	10.878
Total loss: other	0.537
Total loss: cabling	0.535
Total loss: shielding	0.418
Total loss: power-conversion	28.685
Total loss: power-conditioning	0.609
Total loss: propellant-feed-system	0.001
Total loss: mining	0.526
Total loss: driver	0.042
Total losses: all	31.353
Total Power Required from Reactor	**42.231**

Power Efficiency Chain: MADMEN Lander Spacecraft

TOTAL REACTOR POWER
42.23 kW (thermal)

TOTAL POWER AVAILABLE
11.56 kW (electrical)

Reactor

100.0% 42.2307 kW
99.5% ηother
99.5% ηcabling
99.0% ηshielding
98.0% Total

Shielding

98.0% 41.3914 kW
99.5% ηother
99.5% ηcabling
30.0% ηpower-conversion
29.7% Total

Power Conversion

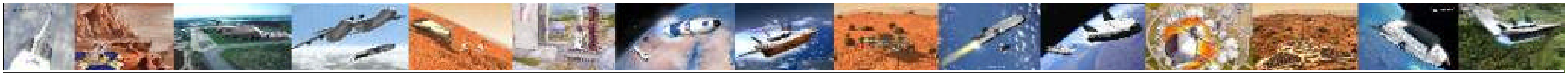
29.1% 12.2936 kW
99.5% ηother
99.5% ηcabling
95.0% ηpower-conditioning
94.1% Total

PMAD / Power Cond.

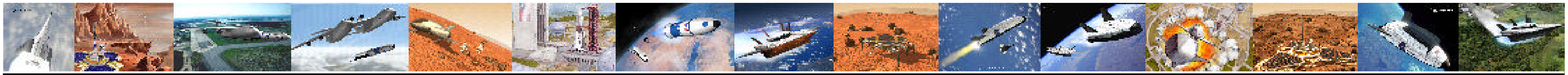
27.4% 11.5624 kW

Efficiency	Value
η–other	99.5%
η–cabling	99.5%
η–shielding	99.0%
η–power-conversion	30.0%
η–power-conditioning	95.0%
η–propellant-feed-system	95.0%
η–mining	95.0%
η–driver	95.0%

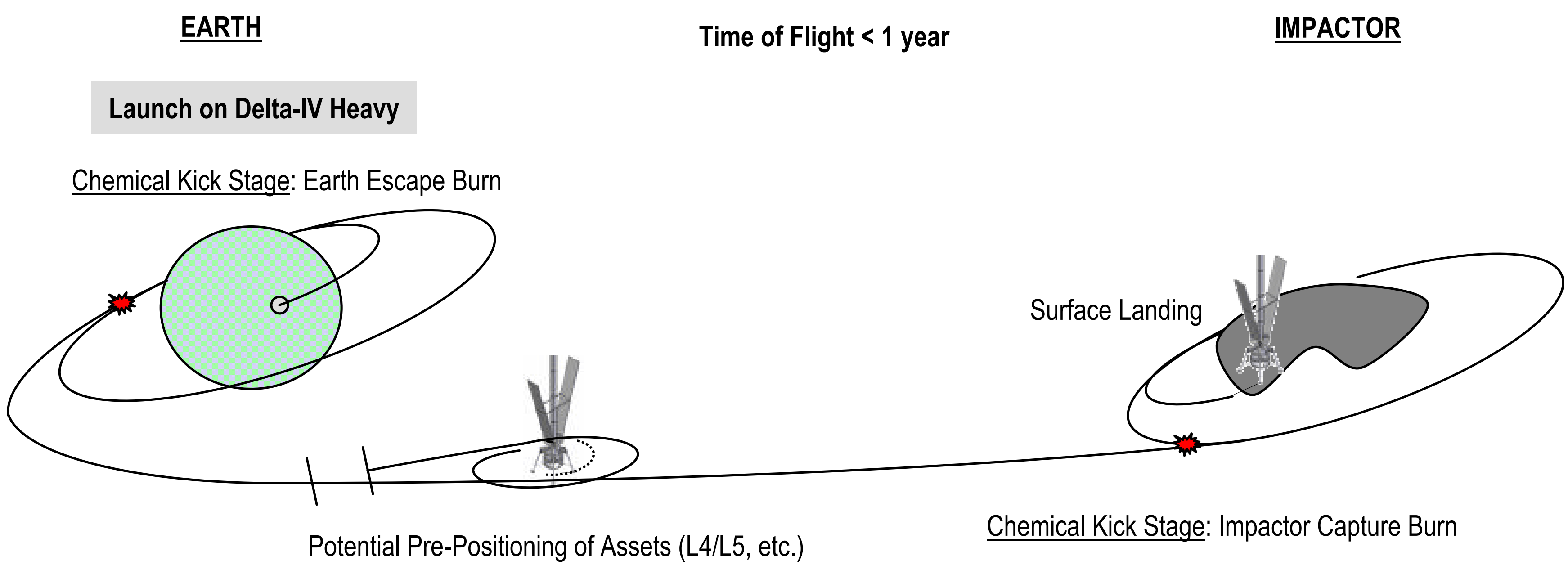
	Thrusters	Propellant Feed System	Mining	Driver	Hotel Loads	Science Loads	Communication Loads
Input	0.0100 kW	0.0106 kW	10.6324 kW	0.8487 kW	0.0253 kW	0.0101 kW	0.0253 kW
Efficiencies	99.5% ηother 99.5% ηcabling 99.0% Total	99.5% ηother 99.5% ηcabling 95.0% ηpropellant-feed-system 94.1% Total	99.5% ηother 99.5% ηcabling 95.0% ηmining 94.1% Total	99.5% ηother 99.5% ηcabling 95.0% ηdriver 94.1% Total	99.5% ηother 99.5% ηcabling 99.0% Total	99.5% ηother 99.5% ηcabling 99.0% Total	99.5% ηother 99.5% ηcabling 99.0% Total
Output	27.1% 0.0100 kW	25.8% 0.0100 kW	25.8% 10.0000 kW	25.8% 0.7982 kW	27.1% 0.0250 kW	27.1% 0.0100kW	27.1% 0.0250 kW



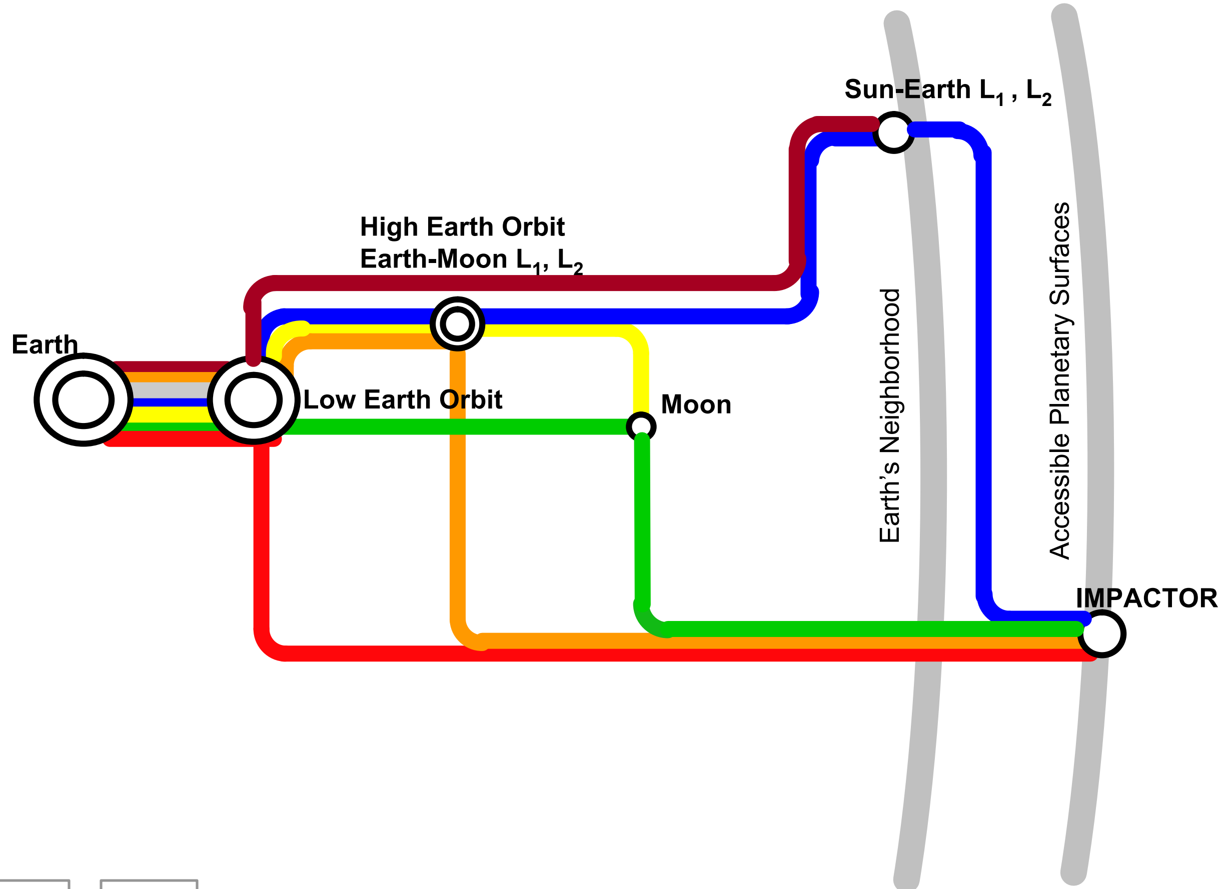
Architecture Overview



Mission Profile and Concept Of Operations

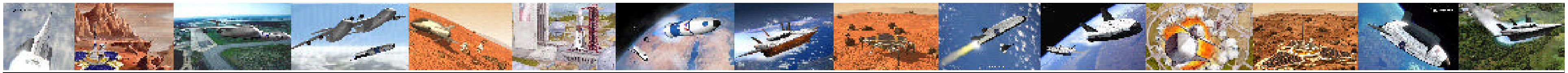


- Manufacture an adequate number of MADMEN spacecraft. Likely done before the identification of a specific threat.
- Deploy the MADMEN to an orbital assembly point. Tradable location but likely somewhere above LEO. Perhaps an Earth-Moon or an Earth-Sun libration point.
- Identify a target planetary impactor on a collision course with Earth.
- Dispatch an adequate number of MADMEN toward the target (a response swarm with redundancy). Chemical boost stages can be used to decrease trip time.
- MADMEN work as a team to affect the orbit of the asteroid so that its new trajectory does not intercept Earth.

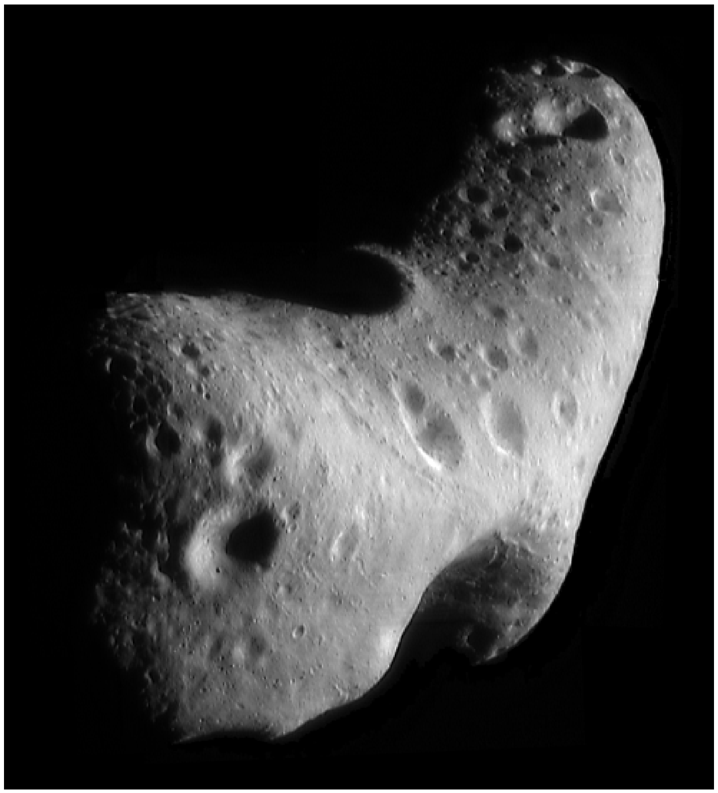


Pre-Positioning

Source: Gary L. Martin, Space Architect, National Aeronautics and Space Administration, "NASA's Strategy for Human and Robotic Exploration", June 10, 2003



Hypothetical Impactor Specifications

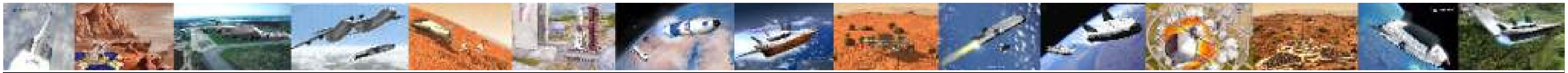


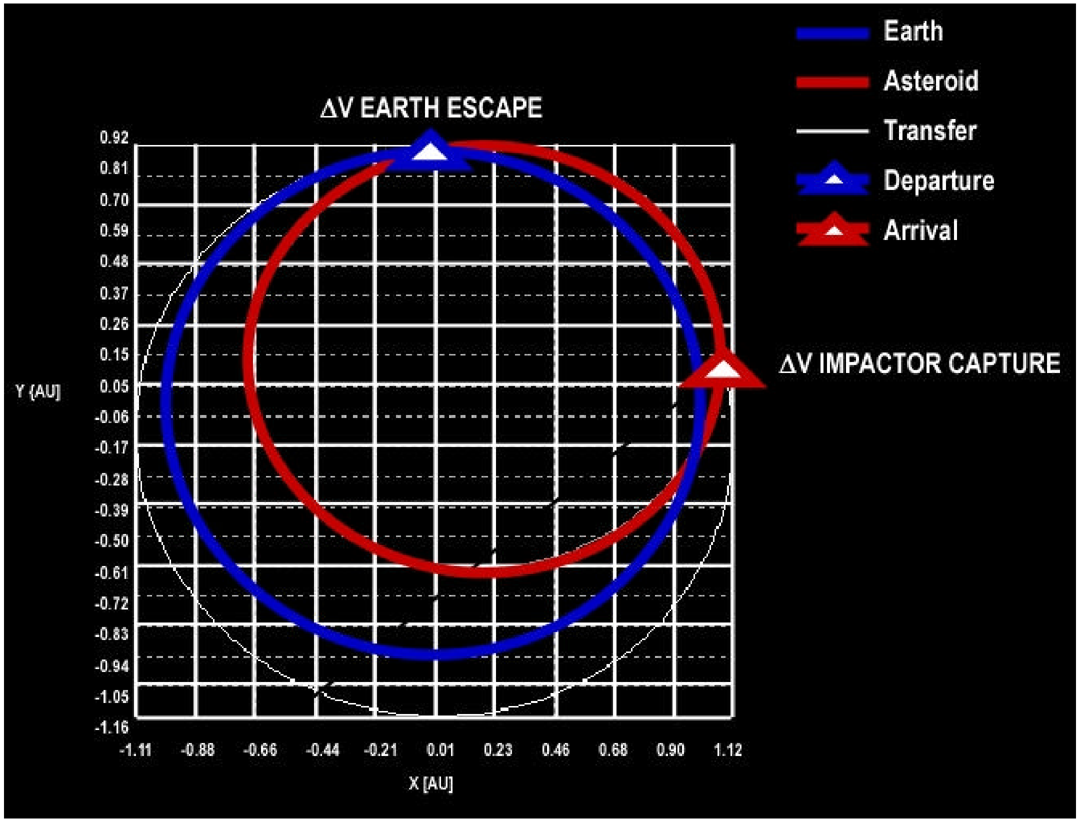
Asteroid 422 Eros (NEAR-Shoemaker)
Sources: http://nssdc.gsfc.nasa.gov/planetary/mission/near/near_eros_approach.html

DEFINED THREAT SPECIFICATIONS FOR D'ARTAGNON

Item	Value
Time/Date of Detection	February 22, 2004 00:00:00: UT
Expected Date of Impact	September 14, 2009 11:04:26.117 UT
Approximate orbital elements at time of detection	q (perihelion distance) = 0.639030 AU e (eccentricity) = 0.288063 i (inclination) = 4.788754 degrees Ω (right ascension of ascending node) = 350.540144 degrees ω (argument of perihelion) = 230.750220 degrees M (mean anomaly at time of detection) = 254.275083 degrees Period = 0.849613 years
Type	Type S Asteroid
Size	130 m x 120 m x 110 m
Mass	**2.7×10^{12} g $\pm$40%**
Density	3 ± 1 g / cm^3

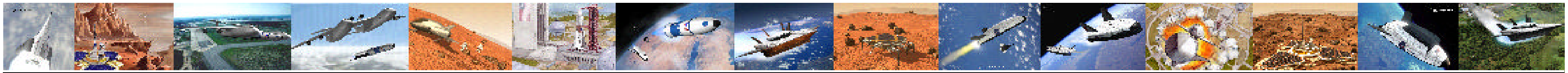
* Note: David K. Lynch, Ph.D. and Glenn E. Peterson, "Athos, Porthos, Aramis & D'Artagnon: Four Planning Scenarios for Planetary Protection", http://www.aiaa.org/images/pdf/Impact_Scenarios.pdf.





Item	Value
Departure Year	2/26/2008
Time of Flight	367 days
Approximate ΔV	5.42 km/s

In-Space Transfer to D'Artagnon



System Reliability and Robustness To Achieve Mission Success

- With the survival of thousands or millions of humans at stake, the reliability of proposed asteroid deflection system cannot be compromised
- Similar to the Borg collective on the Star Trek series, parts of the swarm can be destroyed yet the remaining assets in the swarm fleet can still accomplish the mission
- These swarms are robust enough (through design and embedded intelligence) to complete the objective. Even excluding failures on the outbound journey, the harsh circumstances of the environment near potential NEO threats themselves dictate multiple backups.

OVERALL SUCCESS

TRANSFER SUCCESS BASED UPON
Launch (includes stage separation)
In-Space Earth Assembly
Earth Escape Burn
In-Space Trajectory
Impactor Capture Burn
Transfer Stage Separation
Transfer Stage Egress Burn
Impactor Landing Burn
Impactor landing

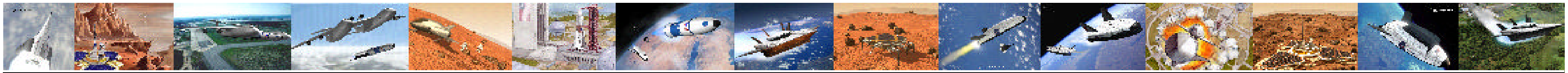
ACTIVATION SUCCESS BASED UPON
Rail extension
Reactor power
Drilling Activation
Driver Activation

OPERATIONS SUCCESS BASED UPON
Surface operations
Swarm communication

OVERALL SUCCESS RATE: 0.4371

Total Number of Spacecraft Required at Full Functionality for Full Lifetime to Perform Mission: 17

Total Number of Spacecraft Required Given Likelihood of Failure: 39



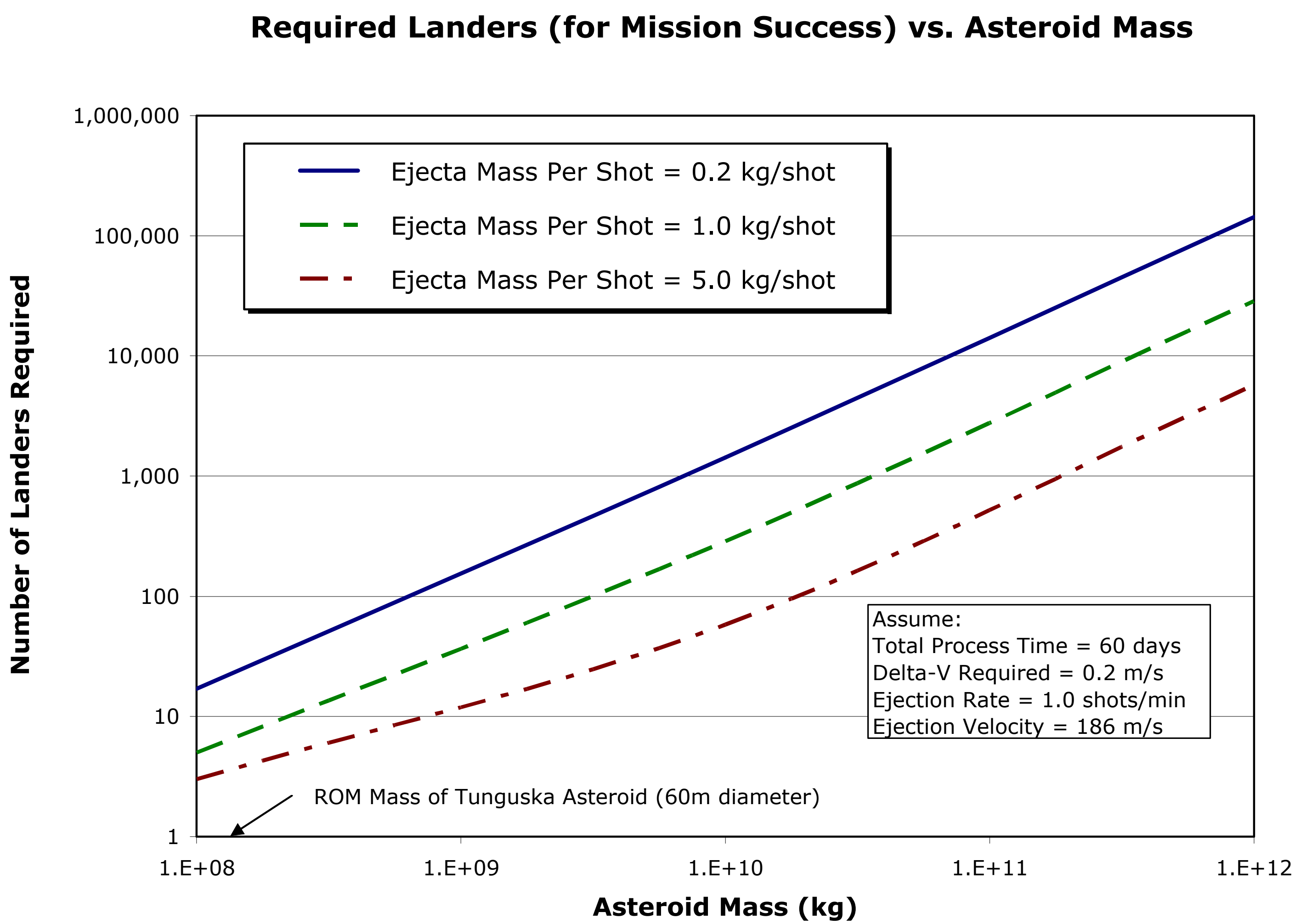
Life Cycle Cost Summary

MADMEN Lander Spacecraft Units: 39 Units
In-Space Transfer Stage Units: 39 Units

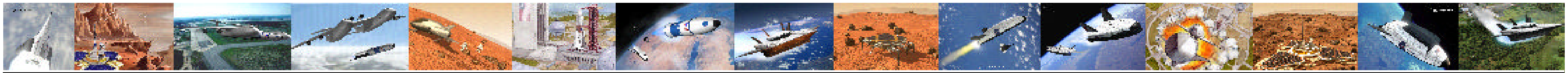
Cost Item	Total Cost [$M]: FY$2004	Cost / Lander Spacecraft [$M]: FY$2004
TOTAL	**$12,603 M**	**$323 M**
DDT&E	**$1,178 M**	**$30 M**
MADMEN Lander Spacecraft	$1,178 M	$30 M
Acquisition	**$5,419 M**	**$139 M**
MADMEN Lander Spacecraft	$4,475 M	$115 M
In-Space-Transfer Stage (ISTS)	$944 M	$24 M
Facilities	**$220 M**	**$6 M**
Operations Cost	**$78 M**	**$2 M**
Launch Cost	**$5,708 M**	**$146 M**

† - rounded FY2004 US$; assuming a 2.1% inflation rate; 98% rate effect on launch vehicle purchase (Boeing Delta-VI Heavy at $165M/launch, FY2004); 95% rate effect learning on MADMEN and upper stage acquisition

Sensitivity (7)

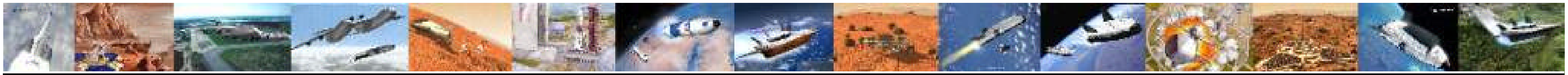


* Note: Based upon baseline lander/impactor scenario



Phase 1 NIAC Summary

- This analysis has presented a novel and potentially valuable technique for NEO deflection
- The potential solution described here considers not only the need to move a specific impactor's orbit, but also the need to have a highly reliable, robust, and scaleable architecture that is cost effective, easy to manufacture, easy to launch, and practical to intercept most incoming threats
- This preliminary assessment has indicated that several tens to hundreds of MADMAN lander spacecraft, each with a mini mass driver system, can deflect a local/regionally-devastating incoming asteroid that is in an orbit generally close to the Earth
- Substantial reductions can be made in the total number of spacecraft and/or spacecraft mass if both surface operation time and deflection distance are traded-off in the analysis
- Specific use was made of fictional threat scenarios to present a case study of this planetary defense architecture
- Additional work TBD in Phase I on variations on in-space transfer stage architecture and power systems
  - Nuclear electric propulsion (NEP)-based transfer stage (mass savings vs. reactor size, political concerns, and trip time)
  - Mass-driver and Miner utilizing alternative power sources (avoid fission reactor)



Potential Project Showstoppers

Drilling Uncertainty of drilling/mining in near zero g/no atmosphere

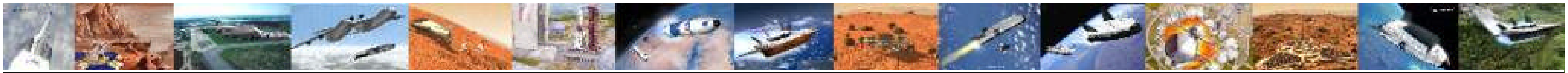
Rotation Effect of asteroid spin/movement on shot direction

Landing Safe landing and attachment dilemma

Intercept Time Intercept times are significantly different depending upon target body, intercept depends upon observation date, sometimes optimally better to wait

Composition Suitability if approach to rock pile versus stony-type asteroid impactor

Orbital Parameters Uncertainty in actual impact location or certainty, will problem be exacerbated?



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