Preprint
UCRL-JC-141514

Overview of the VISTA Spacecraft Concept Powered by Inertial Confinement Fusion

C. D. Orth

This article was submitted to
NASA Advanced Propulsion Workshop in Fusion Propulsion,
Huntsville, Alabama, November 8-10, 2000

U.S. Department of Energy

Lawrence
Livermore
National
Laboratory

November 21, 2000

UCRL-JC-141514

Overview of the VISTA Spacecraft Concept Powered by Inertial Confinement Fusion

Dr. Charles D. Orth
Lawrence Livermore National Laboratory
L-463, P. O. Box 808, Livermore, CA 94551-0808, USA
Telephone: (925) 422-8665; FAX (925) 424-3413; E-mail: orth2@llnl.gov

Abstract:

VISTA was conceived through a detailed systems analysis as a viable, realistic, and defensible spacecraft concept based on advanced ICF technology but existing or near-term technology for other systems. It is a conical self-contained single-stage piloted spacecraft in which a magnetic thrust chamber directs the plasma emissions from inertial confinement fusion (ICF) targets into a rearward exhaust. VISTA's propulsion system is therefore unique because it is based on (1) a rather mature technology (ICF), which is known to work with sufficient driver input; (2) direct heating of all expellant by the fusion process, thus providing high mass flow rates without significant degradation of jet efficiency; and (3) a magnetic thrust chamber, which avoids the plasma thermalization and resultant degradation of specific impulse that are unavoidable with the use of mechanical thrust chambers. VISTA therefore has inherently high power / mass ratios and high specific impulses. With advanced ICF technology, ultra-fast roundtrips (RTs) to objects within the solar system are possible (e.g., ≥145 days RT to Mars, ≥7 years RT to Pluto). Such short-duration missions are imperative to minimize the human physiological deteriorations arising from zero gravity and the cosmic-radiation. In addition, VISTA offers on-board artificial gravity and propellant-based shielding from cosmic rays, thus reducing the physiological deteriorations to insignificant levels.

In this paper, we give an overview of the various vehicle systems for this concept, estimate the general missions performance capabilities for interplanetary missions, and describe in detail the performance for the baseline mission of a piloted roundtrip to Mars with a 100-ton payload. Items requiring further research include a reduction of the wet mass from its baseline value of 6,000 metric tons, and the development of fast ignition or its equivalent to provide target gains in excess of several hundred. With target gains well above several hundred, there is no other known technology that can compete with VISTA's performance.

1. Introduction

A team of physicists, engineers, and one astronaut developed the VISTA spacecraft concept through a detailed systems analysis based on advanced inertial confinement fusion (ICF) technology but existing or near-term technology for other systems. The intent was to determine a viable, realistic, and defensible concept for a self-contained single-stage piloted ICF-powered spacecraft whose performance and other design features would represent a large leap forward for interplanetary transport. Short flight durations were imperative to overcome the human physiological deteriorations from zero gravity and cosmic rays. But VISTA went beyond that requirement to provide total health for the astronauts: artificial gravity, shielding from cosmic rays, and adequate shielding from other radiations (solar flares, ICF neutron emissions). The design team considered all essential systems (e.g., engine, radiator, micrometeoroid-shield, startup-reactor, power, and distribution systems). The VISTA concept is thus the concept with the most detailed systems-analysis basis, and in addition, the one using a power source (ICF) that is known to work with sufficient energy input. Moreover, with sufficient ICF target gain, there is no other known technology that can outperform VISTA for interplanetary transport, including matter-antimatter annihilation.

In this paper, we give an overview of the various vehicle systems for this concept, estimate the general missions performance capabilities for interplanetary missions, and describe in detail the performance for the baseline mission of a piloted roundtrip (RT) to Mars with a 100-ton payload.

2. VISTA's Inherent Advantages

The advantages of VISTA relative to other technologies arise from several basic physics facts. First, the efficiency of fusion for converting mass into energy (0.0038) is over four times larger than that for fission (0.0009). This advantage is lost in VISTA because VISTA uses a magnetic thrust chamber that redirects only about one-fourth of the fusion emissions in the form of a plasma consisting of charged particles. Second, however, all of the mass required to obtain a sufficient mass-flow rate for large thrust can be packaged around the ICF target in VISTA and *directly* heated by the fusion reactions to roughly 1 keV. Third, the magnetic thrust chamber isolates all spacecraft structure from the 1 keV plasma emissions, thereby avoiding the plasma thermalization and resultant degradation of specific impulse that are unavoidable with the use of mechanical thrust chambers. Consequently, VISTA has essentially no degradation of the large specific energies available from the basic fusion process (1 keV), so large specific impulses are available. Moreover, because large masses can be directly heated around the ICF target, large thrusts can be generated with no inherent reduction in jet efficiency. In this way, VISTA affords inherently high power/mass ratios and high specific impulses even though it uses only the charged-particle fusion emissions.

3. Overview of Major Systems

The baseline VISTA design uses DT fuel ignited by fast ignition with a diode-pumped solid-state laser (DPSSL) driver. A DPSSL is a space-adaptable extension of solid-state (glass) laser technology that affords high reprate and high efficiency (~12%) by replacing the flashlamp pump sources with laser diodes and replacing the glass laser media with special high-heat-conduction crystals. These laser systems are now being developed for terrestrial power-production facilities, but are still at the ~25 Hz and ~2 J level (but the LLNL laser called Mercury is supposed to generate ≥100 J at ≥10 Hz within 2 years). Non-DT fuels like DD and D^3He can be used, and are considered in our companion paper [1]. DD is in fact the fuel of choice for long missions to lessen the enroute production of tritium in the thick lithium absorption region protecting the superconducting magnet in the magnetic thrust chamber via $^7Li(n_{fast}, n' He)T$. Each target is surrounded by ~50 g of expellant. Throttling of the spacecraft can be accomplished by altering the amount of expellant per target, which varies the specific impulse, or by changing the DPSSL reprate of target firings, which directly varies the jet power.

The fast igniter is a rather speculative approach now under research at LLNL and elsewhere that might afford capsule gains of several hundred or even much more. [2] This concept employs capsule compression less sophisticated than that for a normal target, followed by a ~200-ps 10^{18} W/cm^2 laser pulse to burn through the ablated material vaporized by the compressional driver beams and create a “channel” to the fuel core. Ignition is accomplished with a ~30-ps 10^{20} W/cm^2 laser pulse directed through the channel.

The magnetic thrust chamber is the heart of VISTA’s engine, in which the charged plasma-debris energy from a target is converted into vehicle thrust. The chamber extent is defined by the envelope of particle trajectories followed by the target debris as it expands away from the target's firing position and interacts with a powerful magnetic field. As the debris interacts with the magnetic field, it is deflected rearward, creating a pulse of thrust with an effective interaction time with the spacecraft structure of roughly 50 µs. The thrust-chamber system includes the evacuated region specified as the thrust chamber, the large (13 T) warm superconducting magnet whose field determines the extent of the chamber, and all of the subsystems needed for the magnet coil: electrical charging circuitry, superconductor refrigeration equipment, thick neutron and gamma-ray shields, lithium shield coolant recirculating subsystem, shield x-ray ablation protection subsystem, and the electrical power inductor pickup probe for the induction power system. We already have a detailed design of the superconducting magnet and coil shield components. [3]

The power systems must be capable of supplying pulses to operate the laser driver (1.25 GW at 30 Hz for a 12%-efficient DPSSL driver) plus approximately 1 MW of auxiliary dc power. The power systems consist of two subsystems: a high-efficiency power-conversion system to extract ~1% of the power from the fusion process through an induction power system inherent to the structure of the superconducting magnet coil shield, and a power-conditioning system to form the proper electrical pulse shapes to operate the driver and other electrical equipment (i.e., to extend the 10 to 50 µs induction pulse to the 1 ms pulse required to operate the laser pump diodes for the DPSSL). A power flow diagram is described in our companion paper. [1]

Thermal control systems are required to remove waste heat generated from inefficiencies in the driver and power systems, and from the deposition of target emissions in the coil shield. Thermal control (refrigeration) is required to maintain the temperature of the superconductor for the magnet, and the temperature of the propellant tanks (especially the tritium tank). We chose heat-pipe radiators to radiate the waste heat because of their conservative design, although there are many other types of radiators. The heat-pipe radiators are overlaid with sufficient micrometeoroid shielding to cut the thermal efficiency of the heat-pipe radiators in half. We also assumed a loss rate given by a micrometeoroid model that is 10% worse than that given by the 1970 NASA model. That is, we assumed that excess heat pipes are installed at the beginning so that 10% can be lost to micrometeoroid damage during operation. In contrast with (e.g.) the SP-100 radiator design, however, our design allows the feed-to-heatpipe transfer region to enclose the main feed lines, thereby offering micrometeoroid protection for the main lines without added mass.

The optimum spacecraft geometry (Fig. 1) is determined by the size of the magnet coil and the positioning of the target relative to the plane of the magnet coil. The size of the magnet is subject to two constraints: 1) the magnet structure and shield must be far enough away from the target so that material is not ablated by target emissions; and 2) the magnet must not be so far away that the expanding target debris plasma cools enough to lower its conductivity sufficiently to allow significant recombination until after being deflected by the magnet (lowered conductivity allows the magnetic field to penetrate the plasma, which causes drag upon decoupling in the rearward exhaust). The first constraint requires the coil shield to be roughly 15 m from the target, assuming use of the most resistant materials (e.g., Be, C, B_4C); the second constraint is not well understood at this time. We positioned the target relative to the plane of the coil to maximize the jet efficiency, and the result is a 50-degree half-angle between the axis of the magnet coil and the coil ring, as viewed from the target location.

The layout for the rest of the spacecraft equipment is determined by the neutron/gamma-ray shield for the magnet's superconductor (i.e., the coil shield). This shield must be located on the interior side of the coil, facing the target, to shield the magnet superconductor from neutron and gamma-ray heat depositions. The coil shield is sized in angular extent (as seen at the target) for minimal neutron impingement consistent with neutron scattering in the shield itself; that is, the shield is sized first by line-of-sight considerations from the target to the angular limits set by the coil windings and associated hardware. The shield is then enlarged slightly to protect the superconductor from neutrons that might scatter in the edges of a smaller shield and still penetrate the superconductor. The shield design that satisfies these constraints fills 3.93% of the solid angle seen by the target, and has been specified in detail. [3]

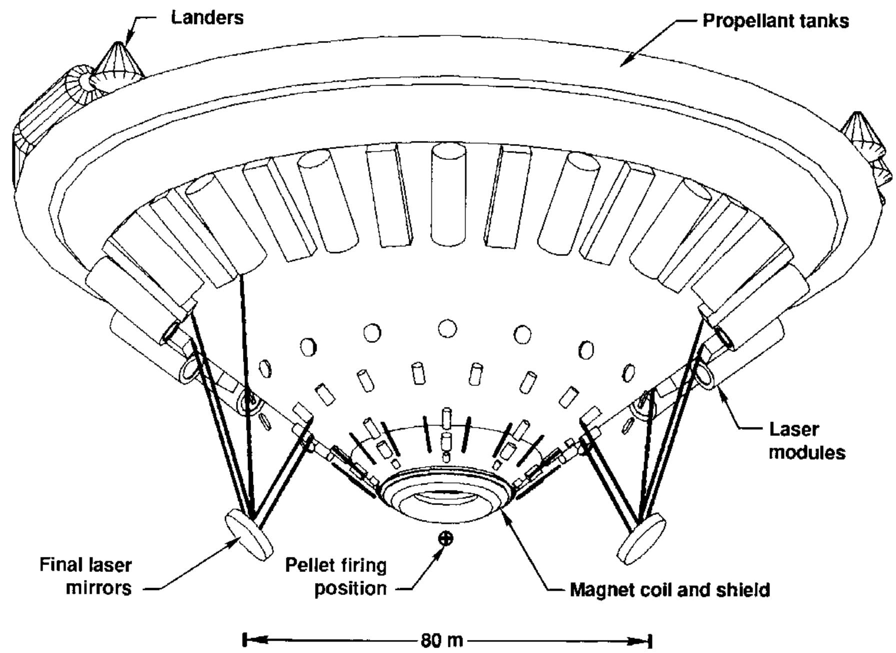

Figure 1: The VISTA Spacecraft Configuration. Appropriately stiffened heat-pipe radiators form a conical surface with the ICF target position at its apex. DPSSL and other structure is attached to the conical surface.

This shield casts a conical shadow that is free of all direct target emissions, because material thick enough to stop neutrons and gamma rays will certainly stop the x-rays (and any stray debris). All spacecraft systems are located within this shadow and thereby protected from target emissions. In fact, it is this shadow concept that determines the conical shape of VISTA. The conical design minimizes the fraction of fusion neutrons that are intercepted by the spacecraft, thus minimizing both the amount of heavy shielding and the amount of spacecraft heating (and therefore the resultant mass in waste-heat radiators). In addition, the cone produces a stable mechanical structure and affords a mobile vehicle with a stable thrust vector under steerage.

The conical surface is the primary load-bearing structure, onto which must be attached the driver systems, target injector, power processors, et cetera. Local stiffening is provided as needed to support mounted components and provide structural attachment points. The conical surface is composed of many heat-pipe radiators and micrometeoroid shielding integrated together and spaced between the longitudinal load members of the cone.

The torroidal propellant tank, which is mounted on the base of the cone to minimize its field of view to the hot radiator surfaces, also serves dually as a stiffening ring for the conical structure. The payload is mounted topside (or even perhaps inside) these propellant tanks, minimizing its radiation exposure, minimizing its thermal loading from the heat-pipe radiators, and providing maximum structural isolation from the pulsed fusion drive.

The fully assembled spacecraft does not have the configuration or the structural integrity for an earth-surface launch. Thus, VISTA is a “mother ship” that transports astronauts and their payloads, but does not itself land on any planet. We assume that the ship would be assembled from sections launched into low earth orbit (LEO). After assembly, the ship would be translated into an orbit above the radiation belts (e.g., a 700-km nuclear-safe orbit). At this higher orbit, fueling and final checkout would be performed by remote handling techniques. During these procedures, only the small fission reactor for auxiliary power would be activated. Only after final checkout would the ship be piloted.

The crew systems consist of a spacecraft portion, and a portion for experiments and experiment probes deployed during the mission. The spacecraft portion includes the Mission Module (MM) and the Mars Excursion Module (MEM). The MM includes 3 Space-Station (SS)-type modules consisting of 2 Habitability Modules and a Laboratory/Logistics Module, as modified for the Mars mission. The MEM consists of a descent stage that stays on the Mars surface, and an ascent stage for return of the crew and samples to Mars orbit for rendezvous with the MM.

4. Hazards Analysis

A detailed analysis of onboard and other hazards is given in the VISTA final report. [3] Here we merely summarize the findings.

There is no hazard to crew members from onboard tritium while they are in their space suits, because the emitted beta ray cannot penetrate even one layer of thin clothing. However, systems must be included to prevent any tritium from getting into the food or water ingested, or from getting into the gases breathed by the crew members. In either case, the tritium could end up in a water state inside the human body, and could thereby cause serious consequences. Nevertheless, a modification of procedures used at terrestrial laboratories (e.g., LLNL) should suffice for adequate crew protection.

There are two types of neutron activation of spacecraft components. One is the direct activation of components (such as the coil shield itself and the final turning mirrors) that are situated near the target and not shielded by the superconducting-magnet coil shield. The direct activation of these components could be significant, and would constitute a hazard if refurbishment of these components becomes necessary. The other type of neutron activation is the minimal activation of almost all components resulting from neutrons scattering from the coil shield so as to be redirected to strike components that would otherwise be shielded. The treatment of this activation and its effects on refurbishing operations must await future investigation, but is not considered to be significant.

At peak engine output (30 Hz) for DT fuel and a target gain of 1000 (i.e., a target yield of 5,000 MJ), VISTA creates nearly 6×10^{22} 14-MeV neutrons every second. These neutrons leave the engine compartment isotropically (in all directions) at nearly the speed of light. In order to reduce the flux of neutrons to a level between 3×10^{8} and 3×10^{9} MeV-neutrons $m^{-2}s^{-1}$ to avoid hazardous radiation exposures to astronauts, VISTA must be at least 8,000 to 36,000 km from exposed personnel. Thus, astronauts on nearby spacecraft must hide behind their solar-flare shields for 6 to 12 hrs while VISTA accelerates 8,000 to 36,000 km away. This hazard is only moderately reduced by using advanced targets fuels such as DD or $D^{3}He$. [1] There is no hazard for terrestrial beings, however, because the atmosphere is roughly seven neutron mean free paths thick. Further study is required to evaluate the hazard for high-flying aircraft.

5. Mission Performance to the Planets with Advanced ICF Technology

Using our IFRTRIP code [1] and the parameters shown in Table 1 for what we call the advanced-technology case, we estimate the performance to the planets shown in Table 2 for a total wet mass of 6,000 metric tons. Table 3 displays the mass distribution for all systems for the RT to Mars, which is a 145-day mission using pure DT fuel. DD is a better fuel choice, however, to reduce the startup tritium mass from metric tons to kilograms. [1] If we add a 30% contingency to the dry mass and account for propellant reserves and losses, then the RT mission duration becomes 183 days and the performance parameters change as shown in Table 4. Table 5 shows the breakdown of masses with contingencies using the standard generic mass template adopted this year by a NASA Technical Interchange Meeting.

Table 1: Parameter Values Assumed for the Advanced-Technology Case

Parameter	Value	Parameter	Value
Driver energy	5 MJ	Extra kg/kW_{th} for micrometeoroid shield	0.007
Driver efficiency	12%	Induction electrical system efficiency	50%
Expellant density, g/cm^3	0.077	Jet efficiency (calculated)	32%
Expellant type	H_2	Magnet coil radius (m)	13.0
Fuel type	DT	Maximum pulse rate (Hz)	30
Fuel compressed $\rho\Delta r$ (g/cm^2)	5.0	Radiator T, coil (K)	1500
Fuel capsule gain	1500	Radiator T, driver (K)	900
Heat-pipe radiator kg/kW_{th} @ 1000 K	0.07	Radiator Temperature, thermal systems (K)	1000
Specific impulse with engine on	constant	Gravity	included

Table 2 Minimum VISTA roundtrip mission durations for Advanced-Technology Case

Destination Planet	***RT Time (days)***
Mercury	160
Venus	108
Mars	145
Jupiter	422
Saturn	735
Uranus	1425
Neptune	2134
Pluto	2692

6. Critical Development Issues and Technological Readiness Levels

The critical development issues are listed in Ref. [3], where technology readiness and current status are discussed in detail. Here we mention only the major items.

The most critical development issue that needs further study is to determine the rate of decrease of plasma plume conductivity, and its effect on the jet efficiency through drag effects. The only other critical issue is the maximum target gain that will be available.

Another issue of importance is the total wet mass, because VISTA was designed under the assumption that there was no inherent limit to wet mass. No one has yet studied how much VISTA's 6,000 metric tons can be reduced to save the cost and time of launch systems (i.e., the dependency of VISTA on the development of "heavy-lift" launch vehicles). Although other concepts claim to have much lower wet masses, it remains to be seen whether credible systems analyses for these other concepts can actually achieve such small launch masses and still maintain small enough values of the ratio of dry mass to jet power to achieve a mission performance exceeding that expected with fission systems. We invariably found that the more the design of each subsystem was clarified, the more massive VISTA became (there is simply no substitute for a detailed systems analysis). We even changed the one-way distance to a planet depending on how fast VISTA could get there with a given set of parameters, in comparison to how fast the planet moves (e.g., see Table 4).

7. Conclusions

The VISTA concept is perhaps more advanced than any other fusion concept for space propulsion, not only because it is rests on a more mature base for its engine technology, but also because it was established through a detailed systems study that focused on minimizing the hazards to astronauts from zero gravity and the cosmic radiation. The result was a stably steerable conical craft with inherently high power/mass ratios and high specific impulses (provided that adequate ICF target gain can be developed) and a craft that can be throttled.

We extend special thanks to Gail Klein, Joel Sercel, Nathan Hoffman, Kathy Murray, and Franklin Chang-Diaz for their participation in the original (1987) VISTA systems design study.

Table 3 Summarized distribution of mass in VISTA's metric tons for advanced-technology mission to Mars

Subsystem	Mass	Total Mass
Payload System		289
Payload	100.	
Payload Shield	189.	
Propellant System		4458
Non-fuel target mass	36.5	
DT fuel	3.72	
Expellant (0.077 g/cc H2)	4100.	
Tritium refrigerator	50.	
Propellant tanks	207.	
Tritium tank	61.	
Driver System		268.
Laser driver	150.	
Driver radiators	118.	
Thrust Chamber System		**805.**
Coil	216.	
Coil shield + structure	523.	
Radiators	66.	
Auxiliary Systems		180.
Startup reactor equipment	5.	
All radiator shields	18.	
Trusses	42.	
Inductor-coil power system	115.	
Total DRY mass		1860.
Total WET mass		6000.

Table 4 Effect of mass contingencies on performance parameters for Mars RT with advanced technology

Performance Parameter	*Value With Mass Contingency*	*Value Without Mass Contingency*
Jet efficiency (%)	32.	32.
Specific impulse, I_{sp} (s)	2.72×10^4	2.72×10^4
Effective I_{sp}, = $I_{sp}(\varepsilon_{jet})^{0.5}$ (s)	1.55×10^4	1.55×10^4
Mass flow rate (kg/s)	1.36	1.54
Thrust (N)	2.06×10^6	2.35×10^6
Jet power (GW)	15.65	17.80
One-way distance (cm)	2.718×10^{13}	2.423×10^{13}
Alpha (kg/kW)	0.151	0.104

Table 5 Distribution of mass in metric tons for VISTA's advanced-technology mission to Mars including contingencie

(ia. = included in value above; ib. = included in value below)

Mass Property Item	Mass Value	Section Subtotal
I. Fusion Engine		
A. Input power systems		
Input power generators (Laser Driver)	150.	
Power transfer systems	ia.	
Radiators & Thermal Systems (including direct structure / pipes, heat exchangers, coolant, pumps, refrigeration, insulation)	104.	
B. Fusion Chamber Wall systems	0.	
Vessel Wall systems		
Radiators & Thermal Systems (including direct structure / pipes, heat exchangers, coolant, pumps, refrigeration, insulation)		
C. Magnet systems (Thrust Chamber System)		
Magnets (Superconducting Coil)	216.	
Direct support structure	16.	
Radiation shielding	505.	
Thermal shielding	ia.	
Radiators & Thermal Systems (including direct structure / pipes, heat exchangers, coolant, pumps, refrigeration, insulation)	58.	
D. Magnetic Nozzle systems	0.	
Nozzle		
System for adding expellant in nozzle		
Diverter & other magnet systems		
Thrust vector control system		
Radiators & Thermal Systems (including direct structure / pipes, heat exchangers, coolant, pumps, refrigeration, insulation)		
E. Fusion fuel systems	5.	
Target assembly		
Injector / Positioner		
Tritium breeding systems		
Radiators & Thermal Systems (including direct structure / pipes, heat exchangers, coolant, pumps, refrigeration, insulation)		
F. Concept-specific systems	0.	
Other acceleration / grid systems		
Radiators & Thermal Systems (including direct structure / pipes, heat exchangers, coolant, pumps, refrigeration, insulation)		
Fusion Engine Subtotal		1054.
II. Fluids		
A. Main Propellants / Expellants		
Main impulse	3835.	
Flight performance reserve (~1% of Main)	ib.	
Boiloff / residuals / losses (~3% of tankable)	271	
B. Stage dry (≥10% of tankable cryogenic propellants)	ia.	
C. Adapter (~3% of Main)	ia.	
D. Fusion fuels	3.5	
E. Other fluids	34.	
Fluids Subtotal		4144.
III. Reaction Control Systems (included in fusion fuel sys)		
A. Control System		
B. Reaction control fluids (~2% of Main propellant)		
C. Radiators & Thermal Systems (including direct structure / pipes, heat exchangers, coolant, pumps, refrigeration, insulation)		
Reaction Control Systems Subtotal		0.
IV. Tanks		

A. Tanks (normally ~15% of propellant [incl. tritium tank = 56.)	263.	
B. Insulation	ib.	
C. Refrigeration systems (including radiators)	50.	
D. Pumps (including radiators)	ia.	
E. Power systems (including radiators)	ia.	
Tanks Subtotal		313.
V. Structural Components		
A. Primary structure (trusses, etc.)	37.	
B. Micrometeoroid shields (all systems)	16.	
C. Interface hardware	ia.	
Structural Components Subtotal		53.
VI. Payload Systems		
A. Payload	100.	
B. Payload radiation & thermal shields	ib.	
C. Crew quarters	ib.	
D. Solar-flare shields	172.	
E. Avionics & communications (~0.2%)	ia.	
F. Radiators & Thermal Systems (including direct structure / pipes, heat exchangers, coolant, pumps, refrigeration, insulation)	ia.	
Payload Systems Subtotal		272.
VII. Power (Electrical) Systems		
A. Power conversion system	90.	
B. Power conditioning / processing system	25.	
C. Energy Storage systems	ia.	
D. Distribution systems	ia.	
E. Direct support structure	ia.	
F. Radiators & Thermal Systems (including direct structure / pipes, heat exchangers, coolant, pumps, refrigeration, insulation)	ia.	
Power (Electrical) Systems Subtotal		115.
VIII. Startup / Restart Power System		
A. Reactor	5.	
B. Electrical storage systems	ia.	
C. Power conditioning / processing system	ia.	
D. Radiators & Thermal Systems (including direct structure / pipes, heat exchangers, coolant, pumps, refrigeration, insulation)	ia.	
Startup/Restart System Subtotal		5.
IX. Shutdown and Disposal		
Shutdown and Disposal Subtotal		0.
X. Total Masses (metric tons)		
A. Total dry mass		1813.
B. Total non-dry mass		4143.
C. Mass growth contingency (30% of dry mass)		544.
TOTAL WET MASS at launch		6500.

This work was performed under the auspices of the US DOE by LLNL under Contract -7405-Eng-48 f the NASA Advanced Propulsion Workshop in Fusion Propulsion, Marshall Space Flight Cen November 8–10, 2000.

References

[1] C. Orth, “Parameter Studies for the VISTA Spacecraft Concept,” in this Workshop.

[2] Max Tabak, J. Hammer, M. Glinsky, W. Kruer, S. Wilks, J. Woodworth, E. M. Campbell, M. Perry, and R. Mason, “Ignition and High Gain with Ultra-Powerful Lasers,” *Physics of Plasmas*, Vol. 1 # 5, pp. 1626–1634 (1994); and Max Tabak, private communication (1998).

[3] C. Orth, “VISTA: A Vehicle for Interplanetary Space Transport Application Powered by Inertial Confinement Fusion,” University of California, Lawrence Livermore National Laboratory, Report UCRL-LR-110500, in final preparation.