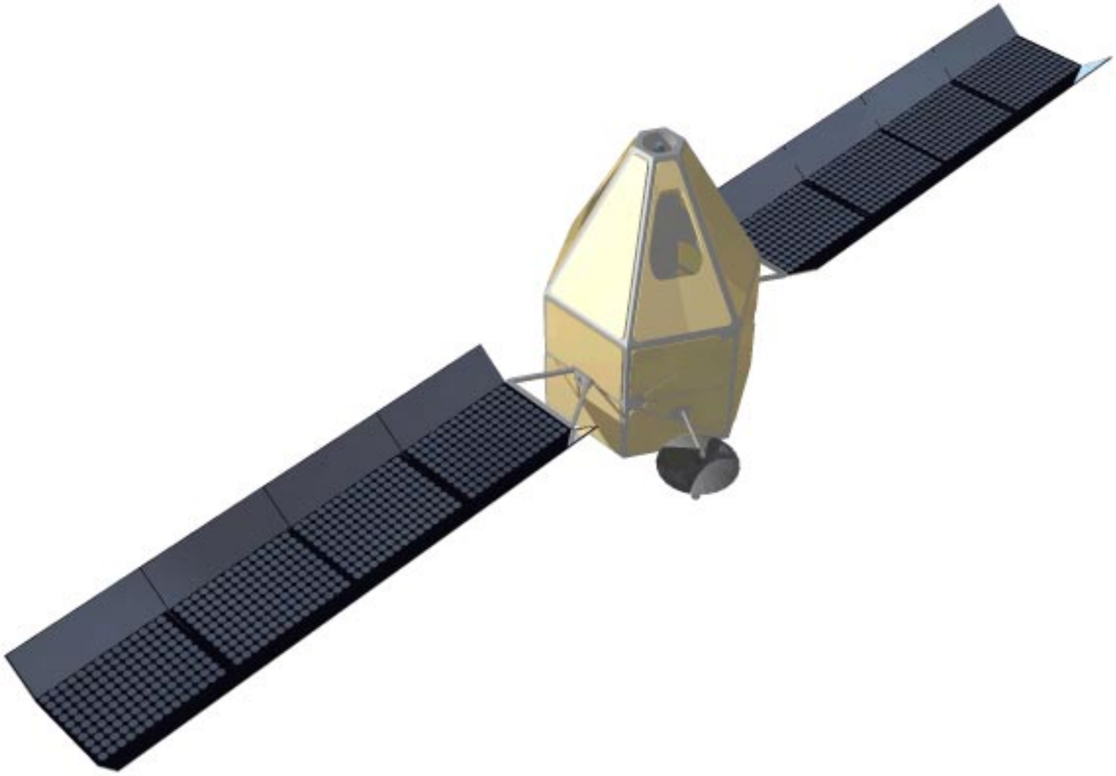


Raven Spacecraft Design

A. Scott Howe, architect
Winter 1996

Introduction

The RAVEN is an unmanned discovery class spacecraft whose mission is to approach the Wilson-Harrington comet and obtain a sample which will be returned to earth. This project was conducted by the University of Michigan AERO483 design team aerospace engineering students and faculty. The Raven project will be presented for consideration of actual deployment and use in NASA's discovery program. My participation was for presentation purposes, and to observe the overall design process. Computer graphics, modeling, and drawings were produced, as well as four animations depicting various sequences of the mission.

Mission Profile

NASA's discovery program calls for a series of scientific missions that are each not more than $150 million, which can be lifted and deployed using standard launch vehicles. The missions are in the vicinity of the Earth inside the solar system. The Raven project's mission is to visit a comet / astroid called Wilson-Harrington and bring back a sample to Earth. Specific data about Wilson-Harrington is still quite sketchy. It is uncertain as to whether it is an astroid or a comet, for at certain times in the past it has shown characteristics of both. Wilson-Harrington is thought to have a diameter of about 5Km and have a rotation period of 3.556 hours and have a mass of 2.4×10^{14}Kg.

The Raven timeline begins on 31 May 2000, where systems and components will be gathered together for assembly into the final spacecraft (see attached timeline). The launch preparations would begin 1 June 2002. Taking in the orbit of Earth, Wilson-Harrington, and other nearby bodies, an optimum launch window would be scheduled for 1 August 2002. For a period of three years, the spacecraft would ride certain orbits, firing thrusters on and off to change between orbits as necessary. On 10 August 2005 Raven would arrive at the comet, map the surface, and attempt to obtain a sample. Original designs included a detachable lander that would allow the spacecraft to set down on the comet, take a sample, and detach leaving behind a scientific package of cameras and spectrometers (see attached drawings). The final design called for a penetrator which would be launched from orbit and fired into the comet's surface, employing a winch mechanism to retrieve the sample without needing to land. The Raven would then leave the comet on 19 October 2005 and take another two and a half years to return to Earth. Splash down would occur on 16 July 2008.

Team Design

The Raven project was set up as a team design effort, with various sub-teams involved with the design of individual systems. The various teams and their members are as follows:

Administrative: Performed overall administrative activities. Team members included Professors Eisley, Gallimore, and Washabaugh and teaching assistant Miller. Project Manager: R. David Donoghue, Assistant Manager: Daniel Bonn.

Mission Planning: Determined timelines, orbits, required fuel mass, and researched specific information about individual heavenly bodies. Mission planning team utilized VARITOP, which is a computer program that would plan missions based on certain input parameters. Team members included Karen Golchert, Matt Kovacs, Markus Nee, Eng S. Tan, and Joshua Wysack.

Propulsion & Power: Designed the propulsion and power systems for the spacecraft, including the ion thrusters and solar arrays. Team members included John Barnfather, Gary Ciarkowski, Kristopher Kolman, Kevin Nemeth, and David Stanko.

Navigation, Control & Communications: Designed computer and communication systems for the spacecraft, including gyros, parabola antennas, star trackers, navigational thrusters, and onboard computer. Team members included Mark Belonio, Michael Ferrario, Justin Grinwis, Ka Fai Lau, and Scott Minder.

Scientific Instrumentation: Responsible for the selection of scientific instrumentation appropriate to complete the mission, and for defining the mission goals and priorities. Members included David Acton, Edward Hoopman, Patricia Kelly, Craig Kugel, and Alex van der Kleut.

Structures & Materials: Designed the overall spacecraft structure. The structure and materials team utilized IDEAS for modeling the spacecraft bus and for performing finite element structural analysis on each of the members. Team members included Matthew Angle, B. Todd Healey, Christopher Melus, and Michele Spannagel.

RAVEN Systems Integration Data Sheet

cost ($M)	Computer code (K words)	dimensions (mm)	Component description & category	lift-off condition		arrival condition		return condition		recovery condition		lander condition	
				Mass (kg) [alloted]	Power (w) required	Mass (kg) [alloted]	Power (w) required	Mass (kg) [alloted]	Power (w) required	Mass (kg) [alloted]	Power (w) required	Mass (kg) [alloted]	Power (w) required
			Scientific Instrumentation										
11.0	0.01	256x200x231	Remote imaging WAC	11.0	7.5	11.0	7.5					11.0	
11.9	0.01	287x200x313	Remote imaging NAC	11.9	7.5	11.9	7.5					11.9	
	0.01	200x200x200	Remote imaging electrical box										
0.9	0.01	320x160x110	Gamma ray spectrometer	0.9		0.9	3.0					0.9	
1.0	0.01	350x210x105	α / proton / x-ray spectrometer	1.0		1.0	0.5					1.0	
1.5	0.01	100x150x150	In situ imaging system	1.5		1.5	2.0					1.5	
4.0	0.01		Accelerometer	4.0		4.0	5.0					4.0	
	0.01		Calorimeter										
	0.01		Thermal probes										
	0.01		Permittivity probe										
25.0	0.01	1500x300d	Penetrator shell	30.0		30.0							
	NA	1029x150d	Sample casing	0.0				0.0		0.0			
	NA	NA	Sample					5.0		5.0			
55.3	0.11		subtotal	60.3	15.0	60.3	25.5	5.0	0.0	5.0	0.0	30.3	0.0
56.0			**allotment**	**40.0**		**40.0**		**5.0**		**5.0**		**35.0**	
			Propulsion and Power										
10.000	NA	400x400d (2)	Ion engines	14.0	1500.0	14.0	1500.0	14.0	1500.0				
	NA		Engine changer	10.0	0.0	10.0	0.0	10.0	0.0				
	NA	1160x212x634	Xenon fuel system (XFS)	19.6	0.0	19.6	0.0	19.6	0.0				
	1.00	400x79x500	Power processing unit (PPU)	14.5	0.0	14.5	0.0	14.5	0.0				
	3.30	79x158x446	Digital control Interface unit (DCIU)	6.1	0.0	6.1	0.0	6.1	0.0				
0.116	NA	NA	Xenon propellant	166.9		90.8		90.8					
0.015	NA	700x389d	Propellant tank	11.6		11.6		11.6					
0.010	NA	475x165d	Plenum tanks (2)	2.4		2.4		2.4					
0.015	NA	1590x990x220	Engine EM shielding	1.5		1.5		1.5					
0.015	NA	NA	Cabling (50% contingency)	10.5		10.5		10.5					
2.750	0.50	15m^2	Spacecraft solar arrays	40.0		40.0		21.9					
0.0	NA	163x114x32	Battery	1.6		1.6		1.6					
0.025	NA		Spacecraft thermal control	7.0	0.0	7.0	0.0	7.0	0.0				
0.0	NA		Sample package thermal control	1.0		1.0		1.0	10.0	1.0	10.0		
12.946	4.80		subtotal	306.8	1500.0	230.7	1500.0	212.7	1510.0	1.0	10.0	0.0	0.0
30.0			**allotment**	**277.0**		**152.5**		**152.5**		**1.0**		**0.0**	
			Navigation / Communication										
0.0	1.00	138x61	Sun sensors	2.0	3.0	2.0	3.0	2.0	3.0				
0.0	2.00		Reaction wheels	15.0	0.0	15.0	0.0	15.0	0.0				
0.012	1.00	116x116x116	Inertial measurement unit (IMU)	1.6	17.0	1.6	17.0	1.6	17.0				
0.015	35.00	200x250x69	Navigation computer	4.5	5.0	4.5	5.0	4.5	5.0				
0.0	0.01	229x127x102	Star trackers	0.3	9.0	0.3	9.0	0.3	9.0				
0.0	2.00		Thrusters	3.3		3.3		3.3					
0.0	NA		Thruster fuel	6.9		3.7		3.7					
0.0	0.50	1500d	Parabola	15.0	0.0	15.0	0.0	15.0	0.0				
0.3	1.00	108x188x146	Data recorder	5.9	6.0	5.9	6.0	5.9	6.0				
1.0	1.00	300x300x300	Spacecraft communications package	4.0	5.0	4.0	5.0	4.0	5.0				
0.0	1.00		Sample package recovery system	3.0	0.0	3.0	0.0	3.0	0.0	3.0	0.0		
1.327	44.51		subtotal	61.5	45.0	58.4	45.0	58.4	45.0	3.0	0.0	0.0	0.0
11.0			**allotment**	**25.0**		**21.2**		**17.5**		**3.0**		**3.7**	
			Structures & Materials										
0.0	NA		Spacecraft structure	37.0		37.0		37.0					
0.0	NA		Lander structure	30.0		30.0						30.0	
0.0	NA		Sample package structure	13.4		13.4		13.4		13.4			
0.0	0.00		subtotal	80.4		80.4		50.4		13.4		30.0	
10.0			**allotment**	**80.0**		**80.0**		**50.0**		**13.4**		**30.0**	
			Systems Integration										
0.0	NA	NA	Wiring bundles, etc	2.1		2.1		1.1		0.1		0.3	
15.0	4.9	NA	Contingency	44.0	156.0	31.2	157.1	23.6	155.5	2.5	1.0	7.6	0.0
15.0	4.94		subtotal	46.1	156.0	33.3	157.1	24.7	155.5	2.6	1.0	8.0	0.0
40.0			**allotment**	**18.0**		**18.0**		**10.7**		**2.8**		**7.3**	
84.57	54.36		TOTAL	555.1	1716.0	463.1	1727.6	351.1	1710.5	25.0	11.0	68.3	0.0
150.0			**[TOTAL allotment]**	**440.0**		**311.7**		**235.7**		**25.0**		**76.1**	

This spread sheet maintained by A. Scott Howe e-mail: ash@ipc.kajima.co.jp

Systems Integration: Responsible for selection of launch vehicle, allocating mass budgets to each team, and integrating all the systems into the final spacecraft (see attached spreadsheet). Systems integration team used FORM-Z and STRATA to produce computer graphics, drawings, and computer animations of the spacecraft and major events of the mission. Team members included A. Scott Howe, Thuan Lieu, Jason Miller, and Jacob Stam.

Aerospace Design

The design process in the aerospace industry appears to be strongly systems oriented, with major concern for overall size and mass of the craft. A major factor effecting the design is the requirement that the craft escape the gravity well formed by the Earth. In order to do this, various private contractors have devised standard launch vehicles designed to carry a range of payloads. The standard launch vehicles include modular farings which have specific limits to volume within which payloads must be contained. In addition, the range of launch vehicles each have capacities for carrying certain mass limits to various orbits. The orbits include escape from Earth's gravity well, but also include low Earth orbits for satellite deployment. The same launch vehicle may be capable of carrying a certain mass payload into a stable low Earth orbit, but would only be able to carry a tenth of the same mass all the way to escape. In addition, calculating the capacity of a vehicle to escape velocity is usually insufficient where an interplanetary mission is concerned, for escape merely leaves the payload in a parked orbit exactly sufficient to counteract Earth's gravity well. For the sake of conservation of fuel on the spacecraft itself, it is usually advantageous to require a launch vehicle to go beyond escape velocity in order to assist the spacecraft along on its initial leg of the journey. This decreases the allowed mass even more.

Launch Vehicles

Vehicle	Low Earth Orbit (kg)	Polar Orbit (kg)	Geosynchronous Transfer Orbit (kg)	Escape (kg)	Launch cost
Atlas I	5580	4670	2250		$70m
Atlas II	6395	5400	2680		$75m
Atlas IIA	6760	5715	2810		$85m
Atlas IIAS	8390	6805	3490		$115m
Conestoga 1229	665	500			$15.5m
Conestoga 1679	1500	1250			
Conestoga 1620	1980		960		$18m
Taurus	1770	1435	445	295	
Taurus / SSRM	2180	1750	640	380	
Delta Lite	1930	1463	650	426	$25m
Delta Lite / SSRM	2540	1968	837	560	$25m
Delta II 7325	2865	2095	1004	732	
Delta 7326	2865	2095	950		
Delta 7925	5045	3830	1820		$50m
Delta III			3800		
LLV-1	795	515			$16m
LLV-2	1985	1490	593		$22m
LLV-3	3655	2855	1136		

Computer Coding Resources

SUBSYSTEM NAME		CODE (K words)	DATA (K words)	
APPLICATIONS				
Power & Propulsion				
DCIU		0.6	0.4	
PPU		1.2	0.5	
Thermal control		0.8	1.5	
Electrical power management		1.2	0.5	
Navigation / Communication				
IMU		20.1	6.3	
Navigation computer		23	27.5	
Thrusters		0.6	0.4	
Reaction wheel system		3	0.9	
Star tracker		2	15	
Communication system		8	1	
a) subtotal		60.5	54	
OPERATING SYSTEM				
COTS software				
Run-time Kernel		8	4	
b) subtotal		8	4	
Non-COTS software				
Executive		3.5	2	
I/O device handlers (5)		10	3.5	
Test & diagnostics		0.7	0.4	
Math utilities		1.2	0.2	
c) subtotal		15.4	6.1	
d) O/S subtotal	(b+c)	23.4	10.1	
e) total software	(a+d)	83.9	64.1	
MARGIN CALCULATIONS				
f) Uncertainty	1.0x(a+c)	75.9	60.1	
g) On-orbit spare	1.0x(e+f)	159.8	124.2	
TOTAL REQUIREMENTS	(e+f+g)	319.6	248.4	= 568 K words

In the design process, a cheaper launch vehicle is initially chosen, and its mass capacity budgeted out among all the various teams. Since the launch vehicle cost is directly proportional to its capacity for lift, the cheaper vehicles have very small mass capacity. The various teams attempt to design their various systems within the alloted mass, sometimes haggling with other teams to gain a few grams here and there. In this way questions of how to divide up the mass among the teams usually answer themselves in the design process. Teams which were overbudgeted give mass to others which were underbudgeted in an attempt to even out misappropriations. In the case where there is no more mass to give and still one or more of the teams comes in over their allotment, either a new launch vehicle is chosen which has a slightly larger mass capacity, or the mission is trimmed and proposed instrumentation cut out. There is a constant balancing act between keeping the launch vehicle smaller and cheaper, and keeping the goals of the mission. If finally it is determined that the mission cannot be accomplished as a discovery class due to the fact that larger launch vehicles or more expensive instrumentation is needed, the mission is either cancelled or must be reconsidered in another context.

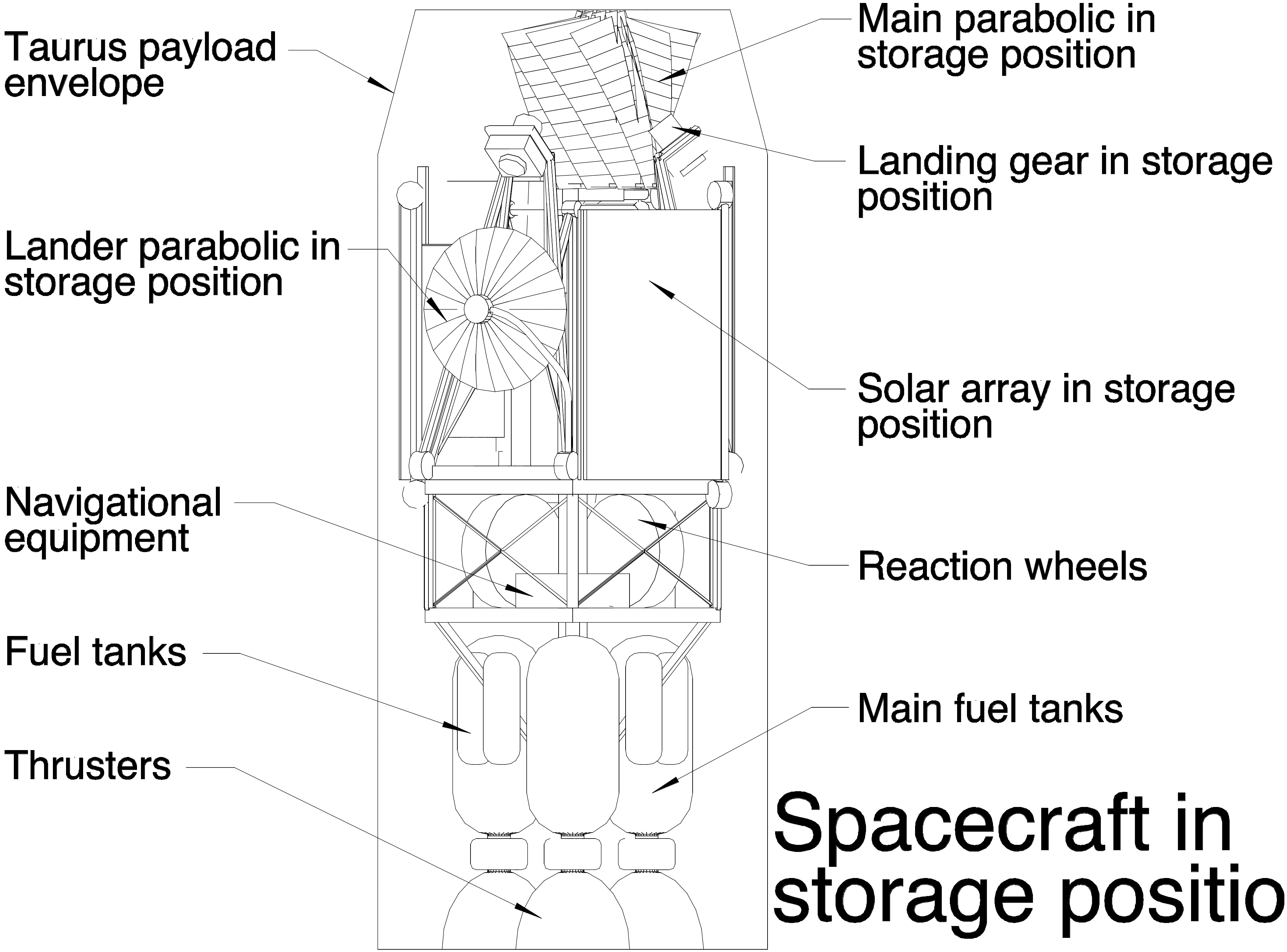
In the Raven project, the decision to attempt a penetration of Wilson-Harrington from orbit rather than land on the comet was the result of the balancing act between launch vehicle size and mission goals. It was decided that the additional mass a lander would consist of would require the use of a larger launch vehicle and therefore endanger the mission from a monitary standpoint. Since the goal of the mission was to gain a sample of the comet (even though making an actual landing was indeed desirable and possible), an alternate method requiring less mass was devised, where a rocket-fired penetrator would be deployed from orbit.

Not only is mass a critical component in the design process, but size is also very important. Since faring sizes and shapes are determined by aerodynamics, balance, and probable mass & size, spacecraft design must adhere to these requirements in order to achieve a safe deployment in space. For this reason the spacecraft must be designed to be compact for shipping. The compact form must stand tremendous strains at liftoff and should have a balanced mass distribution as much as possible in order to not impede the navigational capacity of the launch vehicle. An eccentric load may ever so slightly use up more fuel which could be more efficiently used in sending the spacecraft along its journey. Having a compact shape for shipping purposes requires ingenuity for the design of various deployable systems once the spacecraft is placed in orbit. Fold out solar arrays and parabola antennas require mechanisms which drive the deployment and take into account both shipping shape and final shape. As a matter of common sense, the mechanisms should be of robust design that has either redundant configurations or is little likely to fail under most circumstances. The more sophisticated the mechanisms, the higher the cost for manufacturing them. A rule of thumb could be “the simpler thebetter”, and oftentimes the use of simple machines (wedge, wheel, pulley, screw, etcetera) decreases the chance of failure rather than depending on motors and powered drivers.

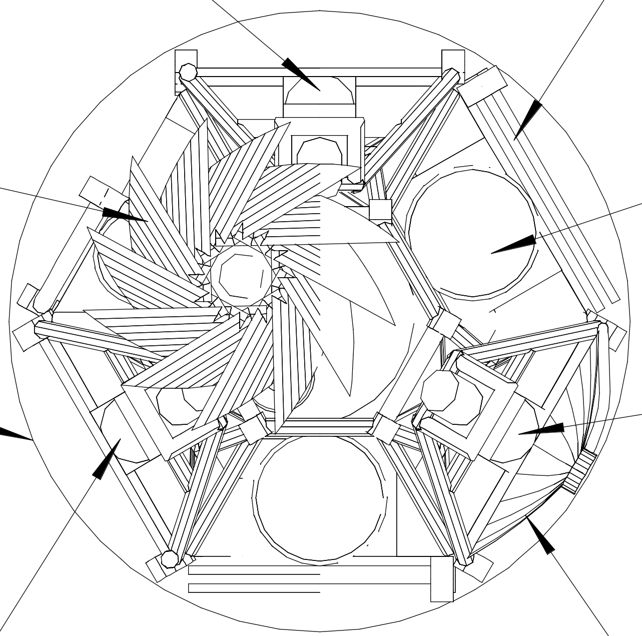
Application to Architecture

Aerospace design decidedly deals with higher cost hardware than architectural design, as far as a comparison of the artifacts pound for pound is concerned. The tremendous requirements imposed on the aerospace industry by the very nature of the harsh environment and context (i.e. the Earth’s gravity well) focuses the attention of the design on mass and size more than function, structure, and aesthetics as is the case with architecture. Nevertheless, the very exercise of participating in the aerospace design process places a new perspective on how artifacts can be designed. In architecture, though not so critical, mass and compactness are also important factors of the building which influence foundation size and shipability of components. This is especially true when it comes to the design of kit-of-parts building systems where shipability and size become some of the most important factors.

The next few pages contain drawings of an early design of the spacecraft.



Spacecraft in storage position



Gamma ray spectrometer in storage position on landing gear

Main parabolic in storage position

Taurus payload envelope

Alpha / proton / X ray flourescence spectrometer in storage position on landing gear

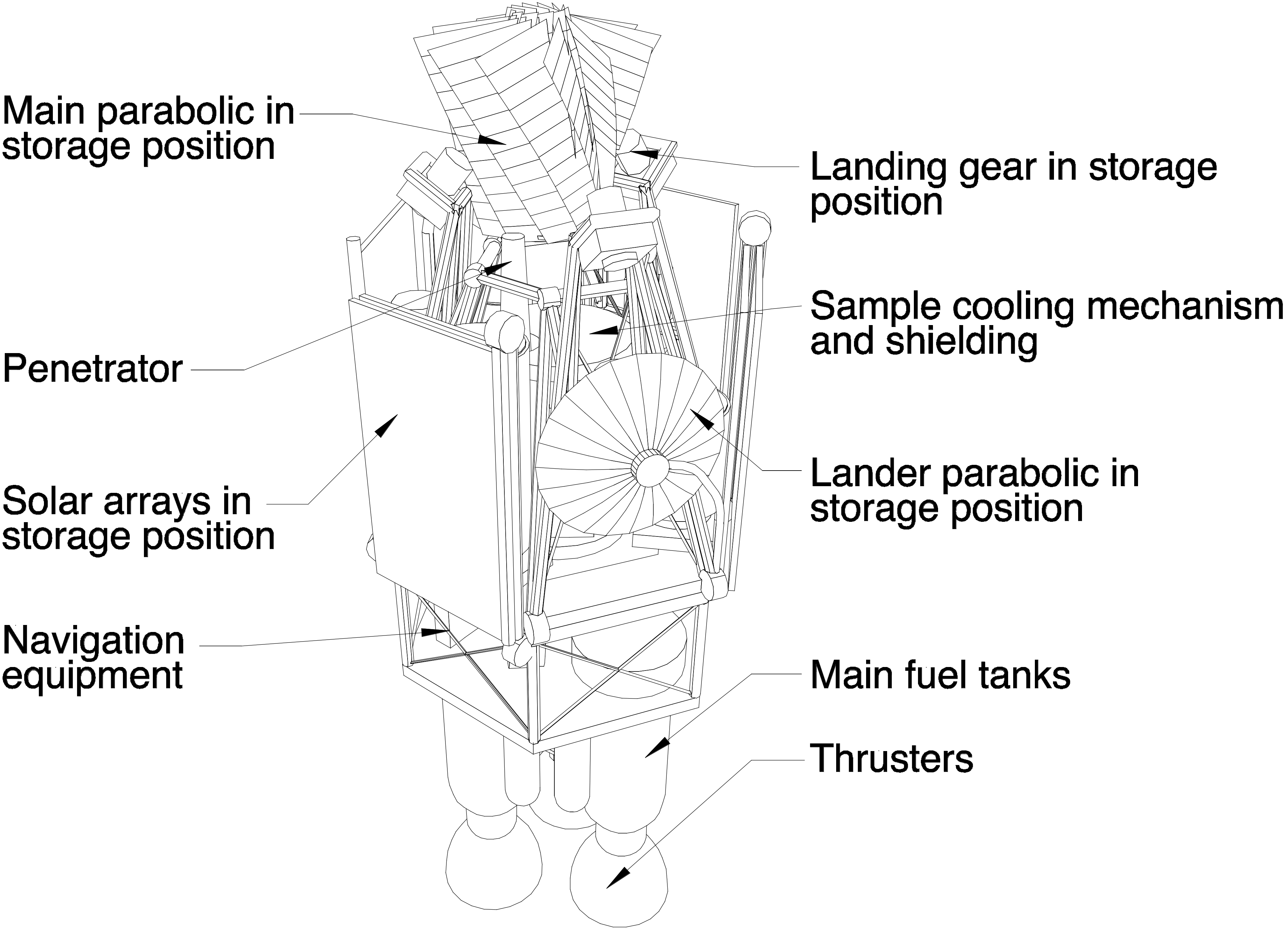
Solar array in storage position

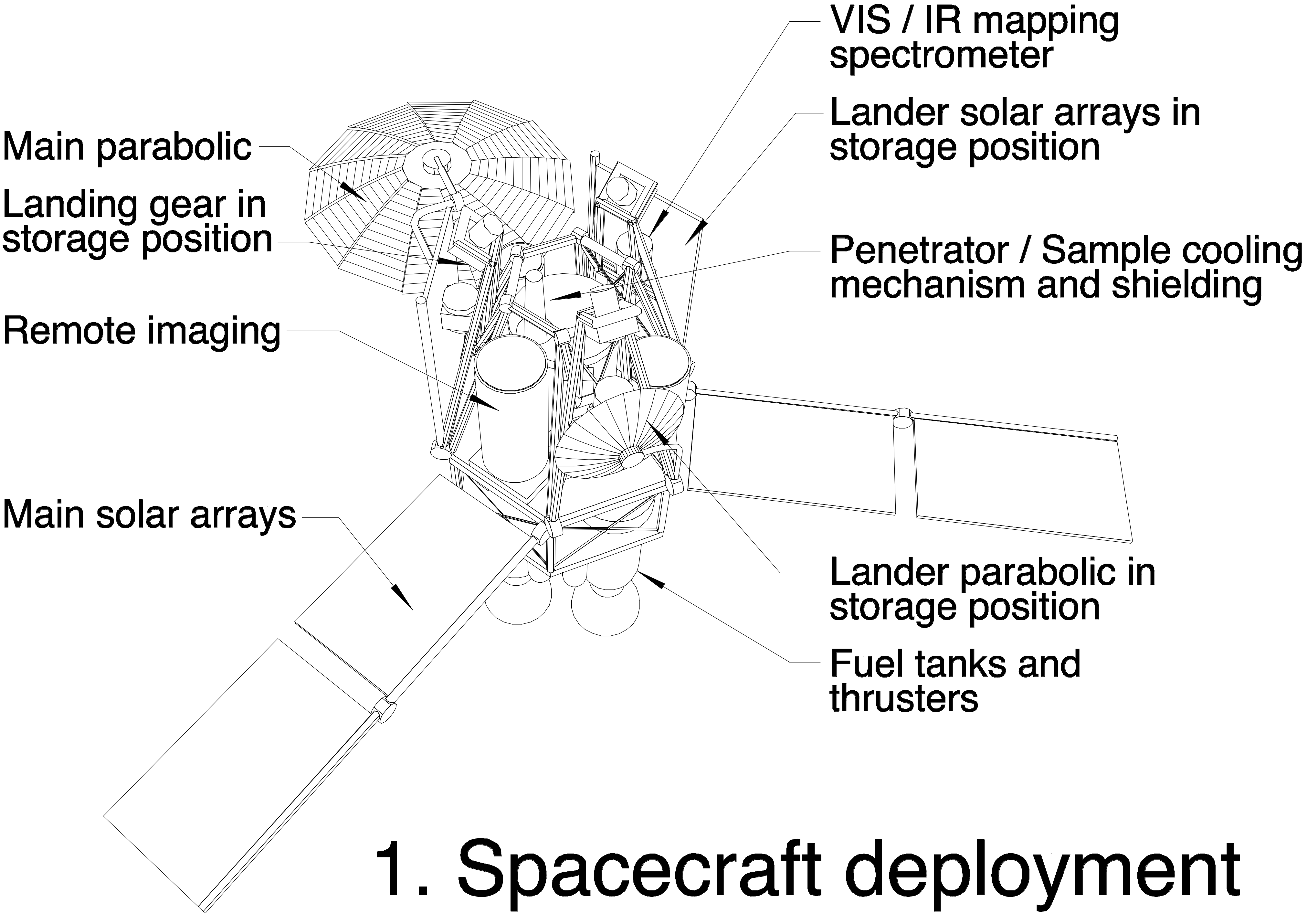
Remote imaging system

Neutron spectrometer in storage position on landing gear

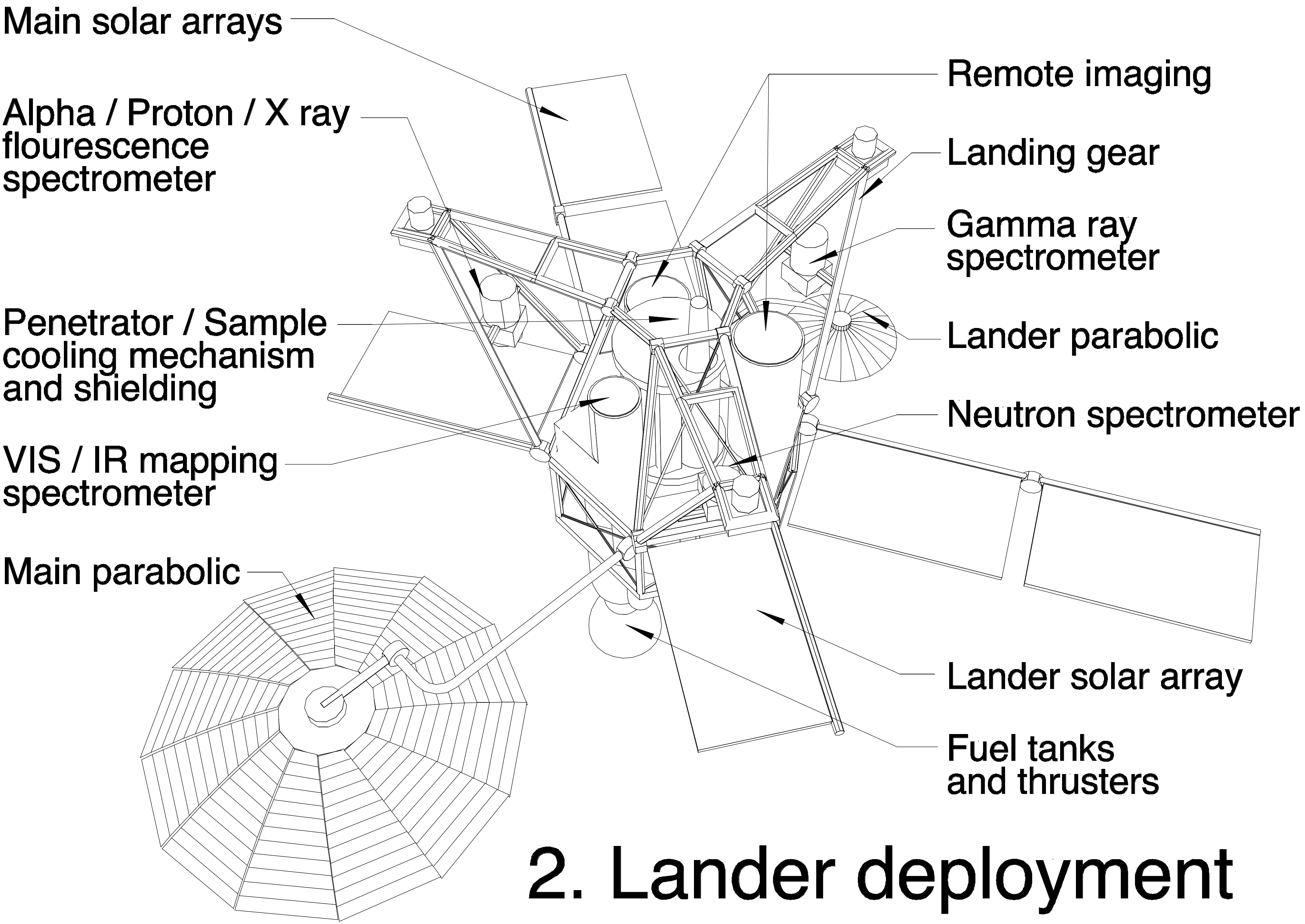
Lander parabola in storage position

Spacecraft in storage position

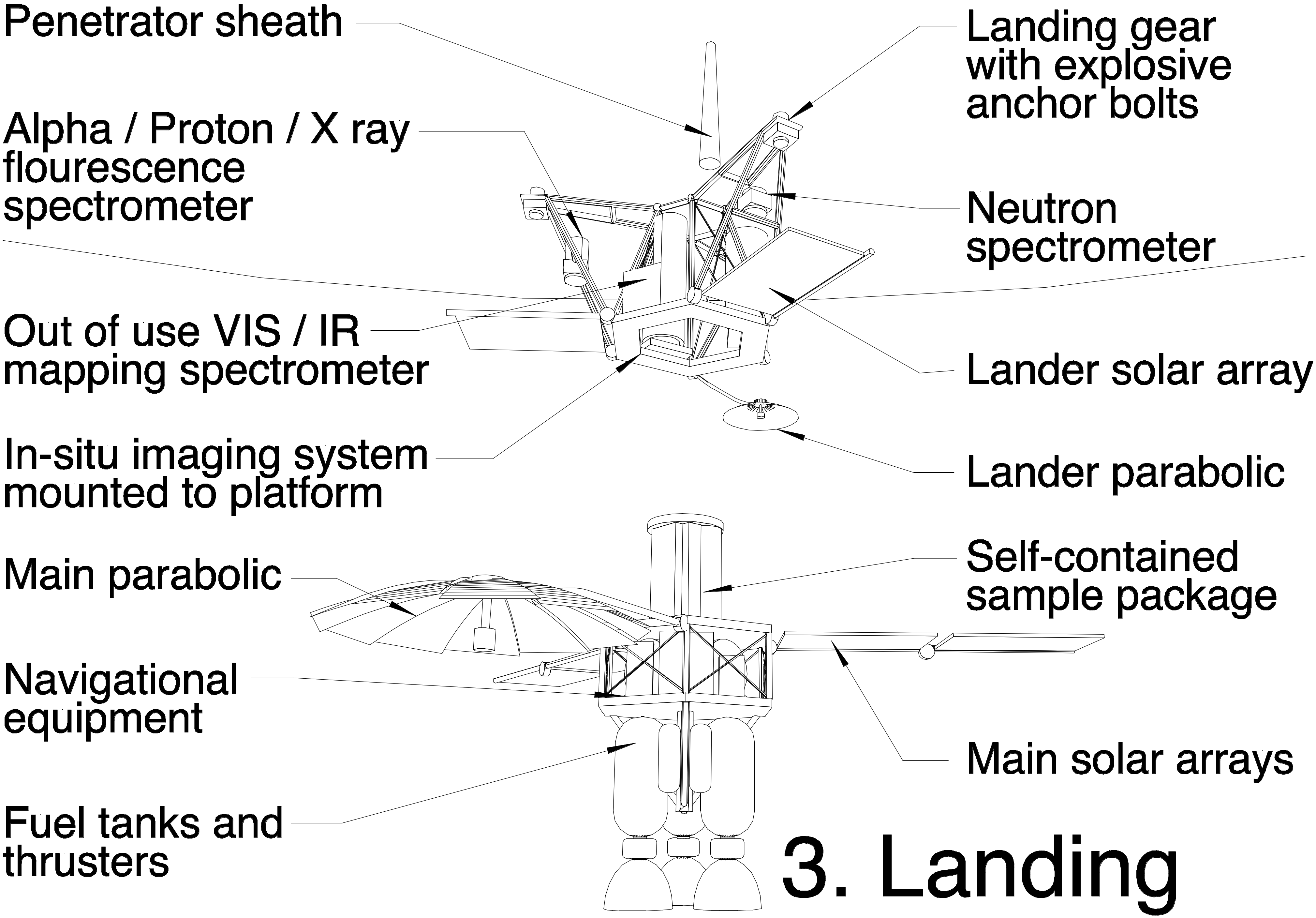

Main parabolic in storage position
Landing gear in storage position
Sample cooling mechanism and shielding
Penetrator
Lander parabolic in storage position
Solar arrays in storage position
Navigation equipment
Main fuel tanks
Thrusters



1. Spacecraft deployment



2. Lander deployment


Penetrator sheath
Alpha / Proton / X ray flourescence spectrometer
Out of use VIS / IR mapping spectrometer
In-situ imaging system mounted to platform
Landing gear with explosive anchor bolts
Neutron spectrometer
Lander solar array
Lander parabolic
Main parabolic
Navigational equipment
Fuel tanks and thrusters
Self-contained sample package
Main solar arrays

3. Landing

4. Sample recovery