The Juno Mission

S. J. Bolton[1] and the Juno Team, [1]Southwest Research Institute

Introduction: The Juno mission is the second mission in NASA's New Frontiers program. Launched in August 2011, Juno arrives at Jupiter in 2016 for a one year prime mission. Juno science goals include the study of Jupiter's origin, interior structure, deep atmosphere, aurora and magnetosphere. Juno's orbit around Jupiter is a polar elliptical orbit with perijove approximately 5000 km above the visible cloud tops. The payload consists of a set of microwave antennas for deep sounding, magnetometers, gravity radio science, plasma and high energy charged particle detectors, electric and magnetic field radio and plasma wave instruments, ultraviolet imaging spectrograph, infrared imager and a visible camera. This paper discusses the mission and the associated challenges with developing the science instrumentation.

Mission Overview: Juno uses a solar-powered, spinning spacecraft placed into an elliptical polar orbit around Jupiter. Nominally, Juno will be in a orbit around Jupiter for about one Earth-year. The prime mission has 32 orbits which allows the entire mission to be completed between solar conjunctions. Primary science data is collected during the six hours around each Perijove (PJ) pass although additional data is collected throughout the orbit. The close perijove [1.06 R_J] and polar inclination avoids the bulk of the Jovian radiation field. Even with this orbit, radiation is a major challenge and the spacecraft design mitigates this by centrally located most sensitive electronics into a single radiation vault thereby minimizing the mass required to shield. Each instrument as well as the stellar reference units all required careful design and testing to deal with the radiation environment. Further challenges included solar power at Jupiter, especially challenging given the environment.

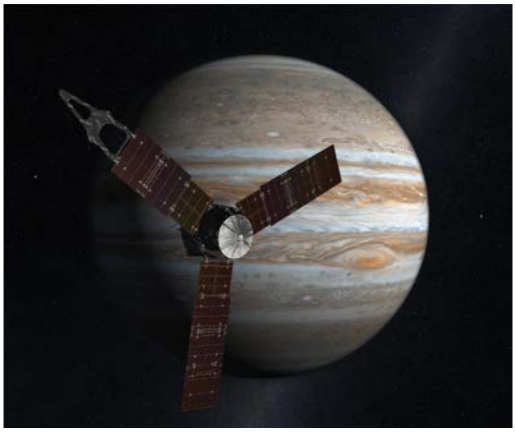

Fig. 1. The Juno spacecraft at Jupiter.

Juno Payload: A dedicated Payload System Office was established to help manage and oversee the instrument developments and their interfaces to the Spacecraft. The Juno Payload is the collection of science instruments on Juno.

Magnetometer. The MAG experiment is a set of fluxgate magnetometers developed by GSFC and a set of magnetically clean star cameras developed by Danish Technical University (DTU). All sensors are mounted on a stable magnetometer boom located at the end of one of the solar array wings. The MAG electronics are contained in the radiation vault. Driving requirements for the MAG include the range of magnetic field magnitude sampled, electromagnetic cleanliness requirements (EMC), star camera pointing precision, and optical bench stiffness.

Microwave Radiometer (MWR). MWR is a set of six antennas and receivers to obtain measurements at frequencies: 600 MHz, 1.2 GHz, 2.4 GHz, 4.8 GHz, 9.6 GHz and 22 GHz. All components, except the antennas and associated feed lines, are located in the radiation vault. The MWR electronics box and radiometer box are housed in the radiation vault. Driving requirements for the MWR include measurement precision (relative as opposed to absolute), antenna beam patterns, frequency range, EMC, and radiation tolerance.

Gravity Science. The Gravity Science investigation uses both flight and ground elements. The basic measurement is the Doppler shift in the tracking frequency measured by the ground station during the Jupiter perijove periods. The flight elements consist of both X-band and Ka-band translators and power amplifiers. The ground element consists of a Ka-band transmitter and receiver supplementing the X-band system. The ground elements also include an advanced water vapor radiometer to determine the water vapor in the Earth's troposphere. Driving requirements for the gravity science include frequency bandwidth, dual band up/down capability and system noise levels.

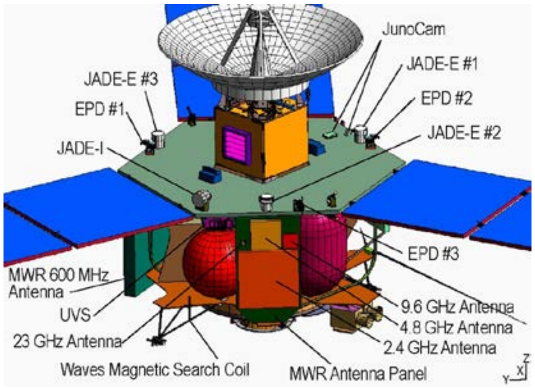

Fig. 2. Layout of instruments on Juno.

Jupiter Energetic Particle Detector Instrument (JEDI). JEDI measures energetic electrons and ions to investigate the polar magnetosphere and the Jovian aurorae. Ions are measured, and discriminated by elemental composition, using a Time-of-Flight (TOF) versus energy (E) technique. Two JEDI sensor units are configured to view into a ~360 degree fan normal to the spacecraft spin axis. A third JEDI sensor unit views in a direction aligned with the spacecraft spin axis, and obtains all-sky views over one complete spin period (~30 seconds). Each JEDI sensor is self-contained, so there is no JEDI hardware included in the radiation vault. Driving requirements for the JEDI experiment include energy, mass and angular resolution, launch environment, and radiation tolerance.

Jovian Auroral Distributions Experiment (JADE). JADE measures low energy electrons and ions to investigate the polar magnetosphere and the Jovian aurora. JADE measurements include the pitch angle distribution of electrons, ion composition and the three-dimensional velocity-space distribution of ions. JADE comprises a single head ion mass spectrometer, three identical electron energy per charge (E/q) analyzers to measure the full auroral ion and electron particle distributions. The JADE electronics (LVPS, DPU, and HVPSs), other than pre-amplifiers, are provided in a dedicated box that is located inside the radiation vault. Driving requirements for the JADE experiment include energy, mass and angular resolution, pointing knowledge, low energy cutoff, EMC, launch environment, and radiation tolerance.

Ultraviolet Spectrograph (UVS). The UVS instrument images and measures the spectrum of the Jovian aurora in the UV nm range of the electromagnetic spectrum. The images and spectra are used to characterize the morphology and investigate the source of Jupiter's auroral emissions. Juno UVS consists of two separate components: a dedicated optical assembly and an electronics box. The UVS electronics box is located in the Juno radiation vault. Driving requirements for the UVS experiment include wavelength range, single-photon sensitivity, launch environment, and radiation tolerance.

Waves. Waves measures both the electric and magnetic fields components of in-situ plasma waves and freely propagating radio waves associated with phenomena in Jupiter's polar magnetosphere. The instrument includes two sensors: a dipole antenna for electric fields and a magnetic search coil for the magnetic component. The instrument has two modes to scan over relevant frequencies and a burst mode to capture waveforms. Waves' electronics (including low- and high-frequency receivers) are located in the radiation vault. Driving requirements for the Waves experiment include frequency coverage, launch environment, and radiation tolerance.

JunoCam. The JunoCam camera provides full color images of the Jovian atmosphere to support Education and Public Outreach (E/PO). JunoCam consists of two parts (both mounted outside of the radiation vault), the camera head, which includes the optics, detector, and front-end detector electronics, and the electronics box, which includes the FPGA, the image data buffer and DC-DC converter. It acquires images by utilizing the spin of the spacecraft in "push-broom" style. The JunoCam hardware is based on the Mars Descent Imager (MARDI) developed for the Mars Science Laboratory. JunoCam is designed to obtain high resolution full disk images of both pole regions of Jupiter.

Jovian Infrared Auroral Mapper (JIRAM). JIRAM is an infra-red imager and spectrometer. JIRAM obtains high spatial resolution images of the Jupiter atmosphere and investigates the atmospheric spectrum in the 2.0-5.0 µm range. The measurements contribute to the investigation of both the polar aurora and atmospheric dynamics through complementary observations with MWR and the magnetospheric suite of experiments (JADE, JEDI, UVS and MAG). The JIRAM optical head and electronics are accommodated outside of the radiation vault.

JIRAM was added to the Juno payload after mission selection, and thus is not required to satisfy the highest-level (NASA level 1) requirements. JIRAM does have to meet requirements associated with specific radiation tolerance (reduced, like JunoCam), field of view, and spectral capability.

Payload Challenges: There were many challenges to the development of the payload, including the usual: cost, schedule, mass, power, data rates, etc. Because of Juno's harsh target (Jupiter), the radiation is the largest single challenge. The management of the radiation issues were mission wide, and involved both the spacecraft team, instrument teams, mission design team and mission assurance teams. Management of reserves by the PI and PM was important for successful implementation. Identifying and understanding the key requirements of the Juno Payload was equally important. These were developed cooperatively by the Juno science and engineering teams starting in Pre-Phase A studies. The process was iterative. Several critical Payload technical interface meetings were conducted over more than a year's time in Phase B to finalize the requirements, and clearly determine which are key and driving.

The Juno Payload System requirements were managed using the DOORS requirements database. Requirements at levels both above and below the Payload System were also planned in the same database providing an method of linking requirements from one level to another. Attributes are defined for each requirement including the requirement text, rationale, owner, and verification method. This allows end-to-end management of the requirements definition, verification and validation process.

Key requirements were allocated by an upper-level element for items that are considered critical. Critical items can pertain to public safety, planetary protection and they are usually related to science goals or mission-critical parameters. Understanding the key requirements is essential to implement a design efficiently.

Driving requirements were identified by a lower level element as impacting the design or implementation of that element in a major way. Driving requirements are usually associated with performance, cost, mass, and schedule. In addition, driving requirements effectively define the architecture of the System or element(s). They involve the type of technology, type of equipment required, number of units, or software functionality

Random Vibration: The random vibration environment (as defined by the spacecraft based on the launch vehicle acoustic input) was hgher than some instruments' heritage environments. The radiation vault in the core of the spacecraft held most electronics and was massive, concentrating mass in a small area resulting in edges of the Flight System's forward and aft decks being lightly loaded. The random vibration environment for these areas then became fairly high. Three paths were pursued to address this issue. The S/C team investigated methods to reduce levels by modifying the S/C design. This included evaluation of options to reduce the random vibration environment through redesign of the structure and options to lower the environment seen by the instruments by reducing the response of structure. Instrument teams assessed design modifications to improve robustness (tasks like better support for MCP mountings, or additional mounting points at the S/C interface). In addition, relief from the launch vehicle's acoustic specifications was also pursued and provided.

Thermal challenges. The Juno thermal range requirements are typically higher than the instrument heritage qualification. The instrument teams delivered updated thermal models in advance of instrument PDR. A process and schedule for maturing the thermal design was developed with each project milestong and finalized by Project CDR.

Radiation enviroment challenges. The radiation environment at Jupiter was a driver for the Juno mission. Components located outside of the radiation vault experience a high radiation environment. High radiation levels drive parts selection and shielding design complexity. JPL provided parts evaluation and testing support for instruments, as part of an overall parts program plan. Instrument shielding designs were developed, and were aided by a specially developed radiation control program and the formation of the Radiation Working Group within the science team. Additionally, a Cable Working Group was also formed within the science team to monitor, investigate and make recommendation on the cabling between the electronics inside of the radiation vault and the instrument sensors located on the main deck.

Managing ten (10) instruments. The differing cultures of the many organizations presented challenges to the Juno Payload Office. Even differences exist between JPL and GSFC. Although both appear on the NASA organizational chart, they have developed distinctly different cultures and associated procedures for instrument development.

To resolve these differences, Payload System Management had to establish contracts, MOUs, and a clearly defined set of deliverables and receivables for each instrument. Routine schedule and technical reporting requirements were established. The Project traveled to each instrument provider and reviewed JPL's Design Principles and Flight Project Practices against their institutional practices to understand gaps and differences.

Weekly technical discussions were a standard project tool for ensuring that appropriate development issues were identified early and addressed. Instrument teams supported routine discussions on the payload, software, radiation, mission design & scenario, and other topics. In addition, the project established various working groups (EMC, Mag-boom, pointing and alignment, etc.) to ensure that the requirements were satisfied.

Coordinating the MAG boom. One of the challenges was the development and integration of the magnetometer boom and the instrumentation attached to it. The boom itself is one of the larger pieces of structure on the spacecraft, and it held the sensors for the FGM and ASC. The formulation agreement was that LM was responsible for the boom, while GSFC was the lead for MAG. In order to achieve successful development and integration among these parties, a Mag-boom working group was established, and which defined interfaces between instrument and spacecraft.

EMC/EMI/Magnetics The breadth of EMI requirements was extensive because of the Payload's inclusion of certain instruments (Waves & MAG, in particular). Other instruments bring certain requirements to the table (surface charging limitations for JADE) that were not present on previous missions (LM had no 'heritage' for such a requirement from MRO). The sensitivity of the MWR was also a challenge with respect to EMI. Even at launch, special efforts to ensure no cell phones went near the spacecraft and no radar or other strong radio frequencies were around Kennedy Space Center once the Juno spacraft had been mated to the launch vehicle.

Another key challenge was ensuring that quality measurements were produced in the high magnetic field of Jupiter. In order to mitigate this concern, the project established Mag/EMC/EMI cleanliness and test programs, under the auspices of a Magnetics Control Board (which also oversees the modeling and analysis of electromagnetic effects), and the co-investigator for MAG was a valuable advisor to the Flight System designers with respect to magnetics. Magnetics workshops were held throughout the formulation and implementation phases.

Contamination control for MCPs: Multiple instruments within the payload (JEDI, JADE, and UVS) include micro-channel plates (MCPs) and MCPs are known to be highly contamination-sensitive. The Flight System design (e.g. thruster locations) and ATLO flow needed to account for the needs of the MCPs vis-à-vis contamination control. Appropriate science requirements were documented, and analysis was needed to gain confidence that MCP performance would not be degraded. The resulting design trade-offs impact Flight System mass and the instrument FOVs. Thruster locations were adjusted, as required to ensure all instruments met science performance requirements. Analyses was provided to instrument teams for their review (to ensure requirements are met).

Burst Mode: Juno has an enhanced instrument data rate which is called "burst mode". It is a feature whereby high-rate data is collected for very short periods of time, with only higher quality data downlinked. The instruments that participate in burst data collection are JADE and Waves, with UVS using a data management scheme that is based on the same principles. It is a special feature because the information from one instrument (Waves) is used to on-board-process the data from another (JADE). What makes it especially intriguing is that the processing is done by the S/C, not by either of the two instruments. Design features like this typically get special attention on JPL missions because of the general principle that the failure of a single instrument should not propagate to another. In this case, burst mode can be enabled or disabled for each instrument, thereby creating isolation.

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Summary: The challenges on Juno were numerous, with many similar to other NASA missions. The special challenges for Juno included the radiation, solar power, power, mass, and the shear number of instruments. The management of our limited resources required careful and constant monitoring. Issues throughout development had to be dealt with efficiently in order to stay within the cost cap. Juno's novel approach to conceptual design (synergy between science, engineering, and mission design) was key to our successful implementation. The inherent efficiency gained by this conceptual approach provided the basis for a flagship style outer planet orbiter at a New Frontiers program cost level. Continuation of this synergistic approach during implementation forced constant and effective communication across the project's engineers and scientists. Discussion and decision meetings both routinely occurred withn this synergy framework, including our weekly meetings. Everyone was on ONE team.