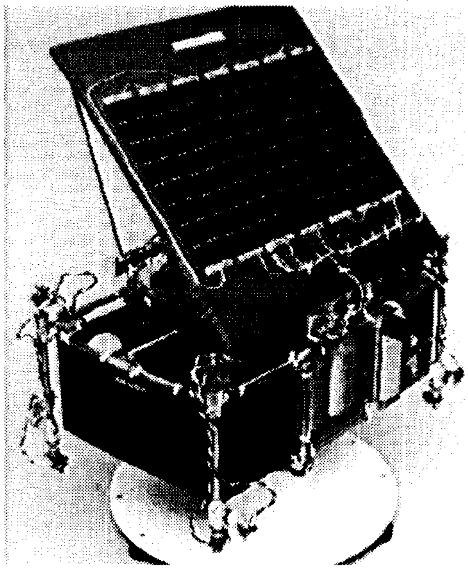
JPL MICROSPACECRAFT TECHNOLOGY DEVELOPMENT [MTD] PROGRAM

2/1/97

The Vision of the MTD program is to be the most innovative spacecraft technology developers in the world. The program **Objective** is to perform ground based hardware demonstrations and software simulations, at the spacecraft system level using very advanced technology, aimed at enabling future microspacecraft. Our **Approach** is to demonstrate new technology in a system context at the "bench top" every 6 months [4/96, 10/96, 4/97 . ..]. The MTD Mission **Focus** is on planetary and deep space microspacecraft. The **Technology Focus is on** using Micro-Electro-Mechanical-Systems [MEMS]. We are using the Second Generation Microspacecraft [1] **System Architecture**. The second generation microspacecraft concept has been developed at JPL since 1993. Additional information about microspacecraft at JPL is contained in references 2-5.

The MTD program has Small Business Innovative Research partnerships with SSG, inc. of Waltham MA. for silicon carbide structures and with Marotta Scientific Controls, inc. of Montville, NJ for microthruster research. Students at MIT and Stanford universities are also contributing to the work.

10/96 **Hardware Delivery**



The 10/96 hardware is the second of a series of spacecraft system level demonstration articles. Subsequent deliveries will come every 6 months. The 10/96 delivery was designed/built in 6 months, primarily with commercially available parts. It has most of the functionality of the Second Generation Microspacecraft for a Near Earth Object Flyby mission. The most significant deviations are in the science instrument where there is no infrared spectrometer functionality and the propulsion subsystem where there is no delta V functionality. While it has most of the functionality, the performance of those functions is still much less than that required of the technology for the Second Generation Microspacecraft. The required performance and the science instrument functionality and propulsion subsystem will be implemented through technology development in subsequent deliveries.

This hardware has a relativity immature readiness level compared to that needed for a flight mission. This microspacecraft is one of the smallest in the world known to include an attitude control propulsion subsystem. The microspacecraft has the following dimensions, 25x35x40 cm and a mass of about 8.9 kg. To the best of our knowledge, this microspacecraft demonstrates the following "firsts": 1) use of MEMS components in a propulsion subsystem, 2) low data LAN on a spacecraft, 3) lithium ion batteries plus a GaAs solar array power subsystem, 4) use of the structure for propellant distribution, 5) MEMs micro-gyro integrated onto a spacecraft and 6) Composite Silicon Carbide structure on a spacecraft. A brief description of the subsystems of the microspacecraft follows.

Propulsion

A regulated, nitrogen cold gas propulsion system provides the attitude control function. The system consists of a single string of 12 cold gas thrusters oriented to provide attitude control in all three spacecraft axes. A MEMS microvalve, made by TiNi has been adapted to function as both a microthruster and a "hang-hang" pressure regulator. Another MEMS microvalve, made by Redwood Microsystems, has been adapted to function as a microthruster. These valves both use material deformation in their actuation, but differ in other features and specifications. The regulator is capable of regulating downstream pressure between O and 100 psi with a response time 0.2 seconds. Miniature pressure transducers are used, both upstream and downstream of the pressure regulator, to monitor system pressure and provide feedback to the regulator.

Structure

The primary structure, while not designed for flight, gives multi-functionality to our demonstration model by providing structural support and gas deli very to the microvalves. It is constructed of tubing (S S303) and machined fittings (al alloy 6061). The structure is assembled using a bonding agent (Hysol EA9309, 7500 psi shear). Subsystems provide structural stiffness to this framework. The modular system is simple to fabricate, assemble and modify. The gas system was tested to 250 psig with no leaks. The operating pressure is i(K) psig. Threaded AN type gas fitting provide easy changout of new thrusters. Screen filters (2 micron) are contained within the structural tubing at each thruster location.

The optical instruments are supported by a ceramic fiber reinforced composite [CFRC] Silicon Carbide [SiC] chassis of a monolithic design. This material has excellent mechanical material properties and a nearly exact CTE match to SiC optical elements. This creates a passively athermal bus which can be expanded to become the entire spacecraft bus. Very complicated geometric shapes may be created in the preform phase of fabrication. This reduces machining and fasteners and the parasitic losses associated with them.

Avionics

The microspacecraft avionics are all integrated into a centralized rectangular solid or "brick". All of the conventional spacecraft avionics subsystems; attitude control, command & data, telecommu nications, and power are integrated into this brick. The electronics connects to the rest of the spacecraft by means of a single network. This network provides the means that the smart sensors and actuators communicate with the central avionics.

Each electronic subsystem is implemented in a module or "slice". The design was implemented in the following slices:

1) CPU and Solid State Disk
2) Power Converters
3) Telecom
4) AI'S Camera Interface
5) Smart Battery Charger

Electronic Packaging

The microspacecraft avionics are being transitioned from the "brick" packaging scheme to the "space-cube" packaging scheme. Those items still in the brick format include the CPU with solid state disk slice and the wireless LAN Telecom slice. Items packaged in the si~ace-cube include the power subsystem slice, the AI'S camera interface slice and the Smart Battery slice.

The "brick" packaging scheme is based on the commercial standards PC104 and PCMCIA. PC104 boards are 4" x 4" and are bused together with a 104 circuit connector along one edge. Thus a backplane is not necessary, since one slice plugs into it\ neighbor. Each PC104 board is packaged in a chassis (.8" x 4" h 8") which facilitates stacking and heat transfer. The use of commercial PCMCI A modules enabled us to take advantage of the high level of integration found in the portable computer market.

The "space cube" packaging scheme is comprised of stacking circuit slices (3.5" x 3.5") which have a 160 circuit connector on each edge. The slices are interconnected with an elastomeric connector and are not limited in thickness or material type. They could, in fact, be multi-chip modules (MCMs). At this time one of the 4 connectors is defined as a PC104 bus, another is partitioned into the camera interface bus, the MicroLAN and solar array input power. The two remaining 160 conductor buses can be used in ?????

CPU and Solid State Disk

The CPU for the microspacecraft is based on the CARDIO™ - 486 from S-MOS Systems. The CARDIO™ - 486 is essentially an entire IBM PC AT' condensed to the size Of a credit card. The card contains the Intel486™ SL super set (with 8KB Cache and FPU), together with VGA, FDC, HDC, 256KB ROM, up to i 6MB of RAM. The card runs at up to 33MHz and can be powered by either a 5 or 3.3 volt supply.

The flash disk is from SanDisk anti contains 20MB of flash nonvolatile memory and a controller. The controller allows the flash memory to be viewed by the CPU as an ordinary disk drive. This feature greatly reduced the amount of required software The flash disk can be upgraded up to 185MB.

The CARDIO™ - 486 is constructed with a mixture of Chip on Board (COB) and conventional packaging techniques. The volume is for the flash disk is less then i .5" x i .5" x 0.4" and is made possible by the stacking of thin packaged components.

Power Subsystem

The avionics of the microspacecraft are powered from either batteries contained within the power system or from the solar panel. Any energy not used by the electronics is used to recharge the batteries. The power system consists of the fol lowing components:

1) GaAs solar panel
2) 4 LiIon batteries
3) Battery charging circuitry
4) power converters

The solar panel is constructed of N strings of M cells each. The solar panel is capable of producing about - 10w at 2(I - 36 volts. Four Li - Ion batteries are contained within the electronics cube. The batteries are packaged as a single 0.6" slice at one end of the cube. The batteries are from the J]']. New Millennium Program and are pure'bawl from Sanyo Electronics. The batteries each have a 4.1 max. voltage and a 1.2 A-Hr rating. The batteries are booked in series to produce a max. voltage of I 6.4 volts. The batteries are charged at a constant current unti I a desired voltage is reached, at that time the batteries are charged at a constant voltage. The charging circuit is supervised by a PIC I 6C73 microcontroller. This microcontroller monitors the charging of the batteries, keeps track of battery voltage, current, temperature, ctc, along with battery charge supervision

One electronic slice provides all of the voltage necessary for the electronics. This slice makes use of commercial prepackaged power converter modules and MCMs. This card takes solar and battery voltages as inputs and produces the following voltages:

I) 5V	@1000ma
2) 3.3v	@1000ma
3) ±12v	@150ma
4) -5v	@200ma
5) +18v	@1000ma_
6) +15v	@1000ma_

Telecom

A functional place holder for a spacecraft telecommunication subsystem is made possible by means of a wireless network card. Wireless networks are used in the commercial environ ments to allow for portable com puter communication. The card chosen is the XIRCOM CreditCard Adapter. The card is PCMCIA based and has the following features: 1) 1Mbs operation, 2) 2.4 GHz frequency hopping, 3) Internal Antenna and 4) 750 ft range.

MicroLAN

Interface between a spacecraft's electronics and the outside is usually done in three tiers of communication as follows: 1) high speed backplane (ISB, PCI, VME), 2) medium speed serial bus (1553, 1773) and 3) discrete wiring.

The MicroLAN concept represents a way of compressing the complex, massive, and time cons uming discrete wiring down to a single serial bus. Any external device that is too simple to justify with its own 1553 interface can benefit from this concept, Three examples of this were illustrated in the demonstration, temperature sensors, simple actuator>, distribu ted microcontrollers

The MicroLAN is made possible by 2 devices from Dallas Semiconductor; the D S1820 temperature sensor and the 1) S2407 addressable switch. The devices appear to be a simple 3-wire transistor package, but are actua lly a complex serial addressable controlled. Communication is clone with I wire and a return, to the controlling processor. The device is powered from tbc data line. Each device contains a unique silicon serial number, allowing multiple devices to share the same bus.

The 1)s1820 temperature sensor measures temperature from -55°C to +125°C in 0.5 °C increments. Temperature is read as a 9-bit value. The 1) S1820 contains an internal A-D converter which does the temperature conversion in 20 0ms. The unit has practically no stand by power <10nw, and <40mw while operating. There are 20 temperat u re sensors scat tered throughout the microspacecraft.

The 1) 2407 is an addressable switch. The switch also contains an input capability which can be used to verify proper operation. The 1) S2407 also contains 1Kbits of One Time Programmable memory. The unit has an operati ng power of less the 10μw. These devices were used to control the thruster and pressure regulator in the microspacecraft.

The MicroLAN was augmented by the installation of smart sensors and act uators. These additions were facilitated by the use of the Microchip PIC16C73 single chip microcontrollers. These devices were used to connected the pressure sensors and the reaction wheel onto the network.

MicroGyroscope

A JPL/UCLA developed silicon micromachined vi brat ory microgyroscope was used for attitude determination. This microgyro depends on the Corolis force to induce energy transfer between oscillating modes to detect rotation. The gyro mechanism is packaged in a 2cm evacuated cube, which together with its associated electronics is attached to one corner of the spacecraft structure. The gyro has its own PIC16C73 which it uses to communicate to the central avionics over the MicroLAN

APS Sensor and Electronics

A 256 x 256 active pixel sensor (AI'S) is used to implement the spacecraft camera functionality. The APS is fabricated with conventional CMOS techn iques and represent a 10 fold decrease i n power over conventional CCD arrays. The APS used ha\ on-chip digital control and produces an analog output. This output is sampled by an A/D converter placed at the camera, and shifted in a parallel fashion to a dual-ported frame grabber contained with the central avionics core. All camera operation is done under the supervision of microcontroller capable of MicroLAN communication.

SOFTWARE

Just as the hardware was facilitated through the use of commercial of the shelf [COTS] components, so was the soft ware. The software is based on the following commercial components: 1) DOS, 2) Windows For Workgroups, 3) Microsoft Visual Basic, 4) Microsoft Visual C++, 5) Xircom Credit C a r d Driver for Windows and 6) Labview.

The software for the 4/96 demo consists of two components; a spacecraft control program and a simulated ground station.

The spacecraft control program is written as an application running under Windows. 1'0 facilitate the development, visual development tools were used. The application program is written in a combination of C++ and Visual Basic. A very primitive real time system was generated using Visual Basic. Tasks were written to process the various microspacecraft functions, such as upl i nk, downlink, control processing, heading gathering, etc.

Programming of the individual microcontrollers was clone using a C compiler from Custom Compu ter Services. Assembly language was seldom i t ever used in the microcontroller programming.

The Ground Station program for the microspacecraft was designed using the visual programming language called labVIEW by National Instruments, Inc. The purpose for creating the ground station was to acquire data and send commands to the microspacecraft via wireless ethernet. The wireless ether-net was accomplished by using the XI RCOM wireless 1 .an Card.

Data from the microspacecraft is processed into files and placed into a directory called Ethor. Once the files are in the 1 ;thor directory, the ground station looks for particular files to open. The ground station continuously looks for a file called Telemetr.lck. When the station locates this file, it knows that a lilt by the name of Telemtr.cmd is in the directory. The ground station opens l'elcnltr.end, reads and displays the file's contents on the ground station display. Telemtr.cmd is then closed and Telemetr.lck is deleted from the directory followed by Telemetr.cn id. This allows the microspacecraft to create new files of data.

The ground station sends commands to the microspacecraft using a similar procedure. It creates a fi le in the Ethor directory called Command.lck. The ground station is designed to check and sec that there is no other file by this name in the directory. If not, the ground station creates Command.lck and then also creates a file named Command.cmd. Command.cmd is where the actual commands wil I be placed, The microspacecraft wi l l then follow a similar procedure for reading the commands as the ground station did with the telemetry data files.

The ground station can send up to 9 commands to the microspacecraft. But only 5 of the com mands were implemented for the I 0/96 demo. One of the commands that could bc sent was the thruster command. This would allow the ground station to operator to fir e any of the I 2 thursters independently by pressing a control switch. The station w ould be placed i n a mode to only fire the thrusters in corresponding pairs. A video downl ink control command was also integrated into the ground station to enable and disable transmission of video data from the microspacecraft. This feature is not working on the microspacecraft as of this writing. A pressure control was also integrated into the microspacecraft to allow control of downstream pressure. A gyrocal command was used to cal ibrate the heading i n the attitude algorithm]. Another command was the DESH EAD command which commands the microspacecraft to desired orient at ion using the gyro data in the control loop. A gyro track command was also integrated but not used allowing the gyro-tracking algorithm to be turned off and on. A video tracking switch was also integrated into the ground station but has not been used.

The telemetry data received by the ground station were ti me elapsed since the reference date. Thruster state data is received and displayed. Battery voltage and current data is received and displayed along with the solar array voltage and currents. The received data is then used to calculate the power which is displayed graphically.

Voltage l .imit indicators were integrated into the ground station to show when battery voltage had dropped below a set point. Temperature data is also received and displayed. Using a pul l down menu control temperature of a certain device on the space craft can be read. Pressure of the tanks is received and displayed. A screen image of the ground station is shown below.