MODULAR EXPERIMENTAL PLATFORM FOR SCIENCE AND APPLICATIONS

by

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ABSTRACT

Boeing has been involved in the production of small, low-cost space vehicles since the mid-60's including 20 booster upper stages, 7 USAF satellites, 2 NASA satellites and the first Swedish satellite to be launched in 1985 on Ariane. Based on this heritage, Boeing has developed a modularized, standardized spacecraft bus, known as MESA, suitable for a variety of science and applications missions.

The basic bus consists of a simple structural arrangement housing attitude control, telemetry/command, electrical power, propulsion and thermal control subsystems. The general arrangement allows extensive subsystem adaptation to mission needs. Kits provide for the addition of tape recorders, increased power levels and propulsion growth. Both 3-axis and spin stabilized flight proven attitude control subsystems are available.

The MESA bus can be launched on Ariane, as a secondary payload for low cost, or on the STS with a PAM-D or other suitable upper stage. Multi-spacecraft launches are possible with either booster. Launch vehicle integration is simple and cost-effective.

Depending on specific mission requirements (which determine equipment selection and delivery), the MESA bus can be generally integrated and delivered in approximately two years after contract award.

The low cost of the MESA bus is achieved by the extensive utilization of existing subsystem design concepts and equipment, efficient program management and test integration techniques, the assignment of a proven, experienced Boeing design team and use of program-dedicated manufacturing, materiel, contracts and finance support experienced in small, low-cost space vehicle programs.

TEXT

Introduction. In 1964, almost two decades ago, Boeing was awarded the USAF Burner II Thor upper stage contract which eventually led to 12 Burner II launches, 8 Burner IIA launches and the series of spacecraft shown in Figure 1. The early spacecraft designs used the Burner II/IIA as a 3-axis space platform by integrating payloads directly onto the booster upper stage. In the mid-70's, separate satellites were designed and successfully flown. The STP P72-1 spacecraft was the first vehicle that was not a direct derivative of the Burner II/IIA upper stage. Since that time, all of the Boeing small, low cost spacecraft have been independent satellites; the Burner II/IIA stage is no longer in production.

The chart (Figure 1) shows the program costs and the delivery schedules for these Boeing spacecraft. The costs are "then year" dollars so have to be inflated from the 60's to current dollars to make direct comparisons. However, a number of observations are possible:

- Vehicle costs are very low compared to conventional spacecraft. The methodologies used to achieve these low costs are discussed later in this paper.

- Delivery schedules are short but with a trend toward lengthening. The primary reason for the schedule stretches were supplier delivery problems due to the great demand for space quality components (IC's especially) and connectors in the 70's time frame.

- Low cost doesn't mean low reliability. A launch success of 96.4% has been experienced to date. Since the SESP 68-1 failure was due to a booster shroud malfunction, we can claim 100% success for vehicles that achieved orbit.

The Swedish Viking Bus is to be launched on the Ariane booster in 1985 and we are discussing future small low-cost spacecraft programs with a number of domestic and foreign potential customers. We expect to continue this business for a long time including new commercial ventures currently under investigation.

Based on this extensive heritage, Boeing has developed a modularized, standard spacecraft bus, known as MESA, which is suitable for a variety of missions and adaptable to either Ariane or Shuttle launch systems. The remainder of this paper presents this bus concept in some detail and summarizes its applicability to typical science and applications missions.

MESA Bus Design. The general arrangement of the MESA platform is depicted in Figure 2. The central core section is the primary structural body and contains the majority of the housekeeping equipment and spacecraft subsystems. The octagonal outer structure can be mission unique and provide solar array area (spinning configuration), boom mounting locations, payload equipment installation and payload sensor mounting. This arrangement allows considerable design flexibility and adaptability. Specific mission studies, described below, have verified the modularity features of the basic design.

FIGURE 1

BOEING SMALL VEHICLE HISTORY

YEAR	PROGRAM	NUMBER OF VEHICLES	COST	FIRST DELIV.	FLIGHT HISTORY
1964	BURNER II	12	$1.1M EACH	12 MO	12 FOR 12
1967	BURNER IIA	8	1.2M EACH	12 MO	8 FOR 8
1967	SESP 67-1	1	.25M	4 MO	SUCCESS
1968	SESP 68-1	1	4.0M	11 MO	FAIRING FAILED
1969	STP 70-1	1	1.7M	13 MO	SUCCESS
1971	STP 72-1	1	6.4M	18 MO	SUCCESS
1972	STP S3	3	3.7M EACH	24 MO	3 FOR 3
1975	AEM BASE MOD.	2	3.8M EACH	21 MO	2 FOR 2
1980	VIKING BUS	1	8.1 M	28 MO	(1985)

FIGURE 2

Platform General Arrangement

MESA

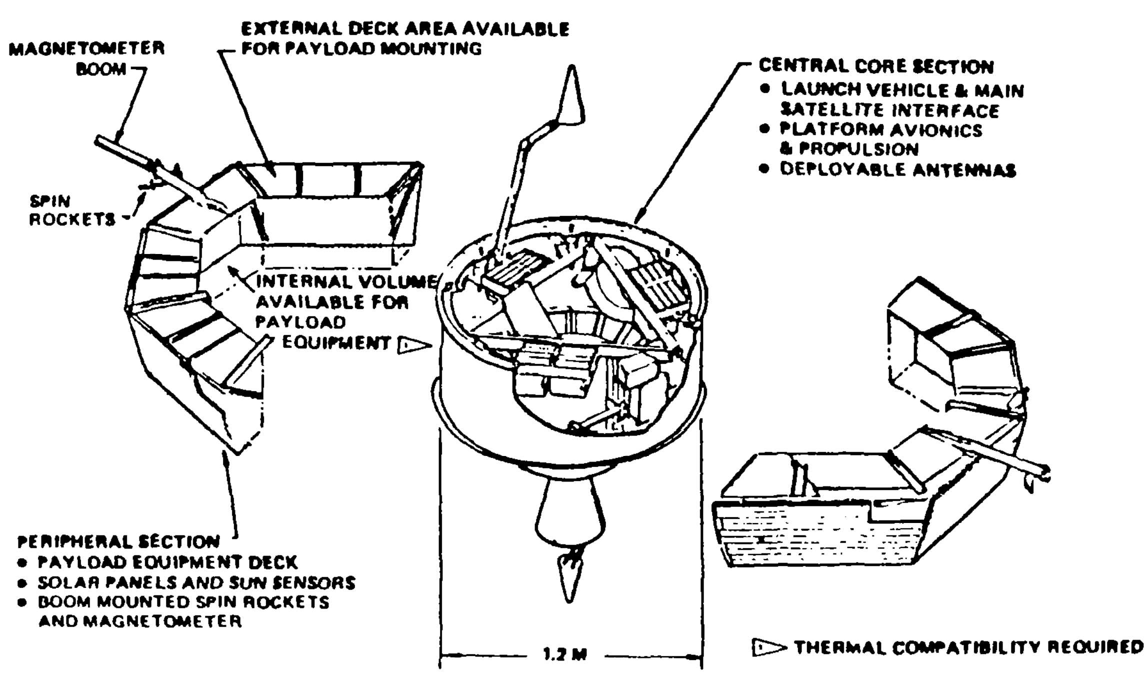


Figure 3 summarizes the subsystem features for the spin stabilized version. While these are the basic performance capabilities, other requirements can easily be met with variations of flight proven equipment or subsystems. For example, a 3-axis attitude control subsystem can be provided by adding the standard Ithaco momentum bias hardware. Control to $\pm 0.5^{\circ}$ in pitch and roll and $\pm 1^{\circ}$ in yaw can thus be provided. Also, telemetry equipment and antennas can be easily changed to suit specific mission needs. Solar array area and batteries can be added and the solar array can be paddle mounted and articulated if necessary.

To keep costs low, existing equipment and subsystems have been proposed for studied mission applications. A typical equipment complement is summarized in Figure 4. The supplier and space vehicle heritage is shown for the items being flown on the Swedish Viking version of MESA.

Mission Applicability. By providing considerable modularity and emphasizing a simple, flexible design, we have been able to show considerable adaptability to a variety of low cost science and applications missions. Figure 5 lists some typical programs studied and Figures 6 and 7 summarize specific missions as examples.

The Viking program, being funded by the Swedish Space Corporation, continues the long term work on auroral phenomenon conducted by various Scandinavian scientific investigators using sounding rockets. The orbit has a high apogee, placed over Sweden initially, that carries the spacecraft through the auroral zones. The mission life specified is very short (six months), so the spacecraft is essentially a single thread design. Science and housekeeping data is transmitted by S-Band to the Swedish ESRANGE ground station at 55 Kbps and 833 bps respectively.

Boeing has studied the application of the MESA bus to the SARSAT (Search and Rescue Satellite) program in detail including a $50,000 funded study with CNES. The French are interested in a joint search and rescue/data collection system summarized in Figure 7. Since procurement of an American satellite would be difficult for a French program, Boeing has signed an agreement with MATRA that provides for joint MESA marketing activities for ESA missions and for MATRA to be prime contractor in the event of any hardware contract.

The specific MESA version developed for the French SARSAT/POST-ARGOS mission is shown in Figure 8. The spacecraft is 3-axis stabilized and the drawing shows the installation of the Ithaco subsystem mentioned earlier. The design life is extended to 5-years through selected redundancy in critical areas.

Launch Options. The basic MESA platform was designed for the Ariane booster, since the Swedes are part of ESA. Figure 9 shows on the left, MESA as a secondary payload mounted under the primary Ariane spacecraft. The central core of MESA is qualified to carry the full Ariane primary payload weight during boost. As shown on the right, MESA spacecraft can also be stacked one on the other to launch a cluster of vehicles, for a SARSAT program as an example, with a single Ariane launch.

FIGURE 3

Platform Design Summary

ATTITUDE CONTROL

- SPIN STABILIZED USING EARTH/SUN SENSORS AND MAGNETIC TORQUEING
- 3 RPM SPIN RATE
- < $\pm$ 1 DEGREE CONTROL ACCURACY
- MAGNETIC TORQUEING BELOW 4000 KM

TELEMETRY, TRACKING AND COMMAND

- S-BAND/ESA COMPATIBLE
- CONVOLUTIONAL CODING (UNCODED OPTIONAL)
- ESA/GSTDN TONE RANGING
- 85 KBPS HIGH RATE DATA
- 853 BPS LOW RATE ENGINEERING DATA
- 128 HIGH/LOW LEVEL COMMANDS
- SPHERICAL ANTENNA COVERAGE

POWER

- 28 $\pm$ 4 VDC SOLAR ARRAY/BATTERY
- 122 W ORBIT PEAK
- 80 W ORBIT AVERAGE
- 2.2 M^2 FIXED SOLAR ARRAY
- 12 AMP-HR BATTERY

PROPULSION

- TE-M-442-2 SOLID PROPELLANT ORBIT ADJUST MOTOR
  - 35,600 N THRUST
  - 621,800 N-S TOTAL IMPULSE
- MARC 3681 SOLID PROPELLANT SPIN/DESPIN MOTORS
  - 302 N THRUST
  - 300 N-S TOTAL IMPULSE

THERMAL CONTROL

- PASSIVE/MULTILAYER INSULATION, RADIATORS AND LOUVERS

FIGURE 4

Hardware Derivation /Design Base Summary

Structure	(Boeing) New
Cable Harness	(Boeing) New
Pinpullers	(SOS) Various Flight Programs
S-Band Antenna	(Boeing) S3, HCMM, SAGE, IUS
TLM Encoder	SAAB FE
CMD Decoder	SAAB FE
Transponder	SAAB FE
Coaxial Switch	(TRANSCO) Classified
Timer/Sequencer	(CYCLOMATIC) S3, HCMM, SAGE
Rocket Motor	(Thiokol) DOT
Spin/Despin Motors	(Atlantic Research) S3
Louvers	(Northrop) Mariner 10, S3, HCMM, SAGE
Thermal Blankets	(Boeing) Mariner 10, S3, HCMM, SAGE
Amphere-hour Meter	(Gulton) S3
Voltage Limiter	(Gulton) S3
Battery	(Philco-Ford) INSAT
Solar Panels	(Spectro Lab) New
Relay Box	(Boeing) New
DC-DC Converter	(ATC) Various
Sun Sensor	(ADCOLE) HCMM, SAGE
Earth Sensor	(ITHACO) SEASAT, 78-2
Nutation Damper	(Boeing) S3
Electromagnets	(ITHACO) HCMM
Interface Control Elec	(Boeing) New

FIGURE 5

Typical MESA Missions

- **Viewing of the Earth from Space**
- **Viewing of the upper atmosphere of the Earth**
- **Relaying communications between Earth stations**
- **Viewing of natural phenomenon from above the Earth's atmosphere including that related to other celestial objects**
- **Collecting and relaying data from Earth-based transmitters**
- **Carrying small objects into Space for purpose of testing**

FIGURE 6

Viking Scientific Mission

MESA

OBJECTIVE

- **Investigate interaction between hot and cold plasmas along auroral field lines**

SCIENTIFIC EXPERIMENTS

- **Electric Field – Sweden, Royal Institute of Technology**
- **Magnetic Field – US, John Hopkins University/ONR**
- **Particle Experiment – Sweden, Kiruna Geophysics Institute**
- **Plasma Wave Experiment – Sweden, Uppsala Observatory; Denmark, Space Research Institute; France, Centre de Recherches en Physique**
- **UV Images – Canada, York University**

FIGURE 7

SARSAT/POST-ARGOS Mission

- Prompt detection and localization of distressed units
- $50K study with CNES to evaluate feasibility of MESA platform as satellite component
- Memorandum of Understanding with MATRA:
  - Joint investigation of potential European missions applicable to MESA
  - MATRA will serve as prime contractor
- SARSAT/POST-ARGOS: combines search and rescue with a data collection system:
  - Basic MESA bus: Boeing
  - Instrument module and integration: MATRA
  - Telemetry subsystem: Thomson, Crouzet, SAAB
  - Other potential European suppliers

FIGURE 8

SARSAT/Post-ARGOS Platform Summary

MISSION:	COMBINES SEARCH AND RESCUE FUNCTION WITH A DATA COLLECTION SYSTEM
MASS:	480 KG
POWER:	130 WATT AVERAGE
LIFETIME:	5 YEARS
LAUNCH:	SHARED ARIANE
STABILIZATION:	3-AXIS, REACTION WHELL WITH MAGNETICS
SIZE:	OCTAGONAL DECK, 2 METERS ACROSS FLATS
FREQUENCIES:	121.5/243/406 AND 401.8 MHZ UPLINKS
ORBIT:	1000 – 1200 KM CIRCULAR QUASI-POLAR CONSTELLATION (4 OR 5 SPACECRAFT)

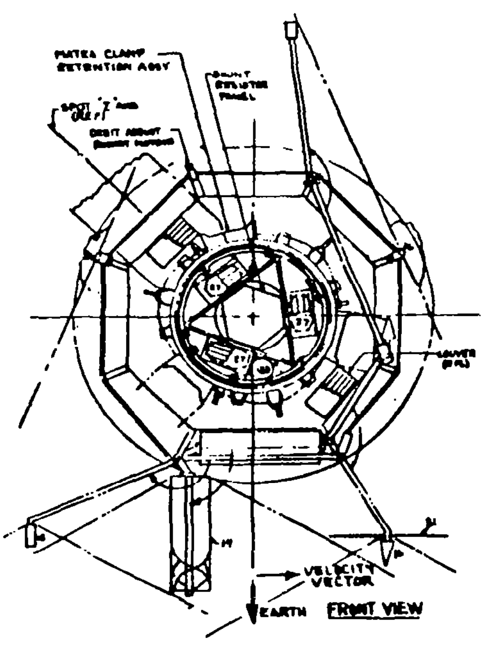


FIGURE 9

Various Launch Configurations Available

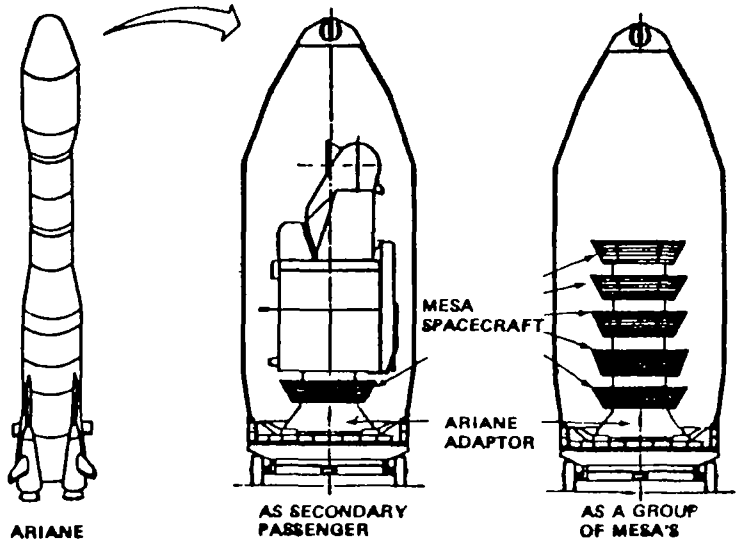
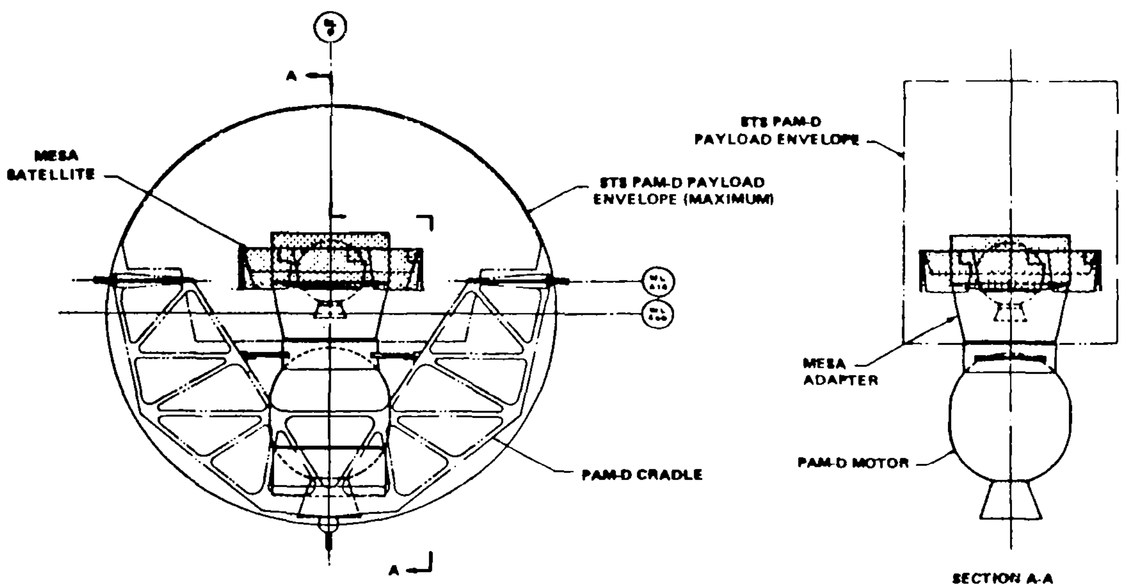


FIGURE 10

MESA Bus on PAM-D



Although originally designed for Ariane, MESA can be launched on the Shuttle by using a suitable upper stage. Figure 10 shows the adaptation to the PAM-D. Other upper stages have been investigated and there are no interface or functional problems with these concepts. All adaptations reviewed to date verify the feasibility of our modular, low cost design approach.

Because the envelope of the Ariane (and Shuttle, of course) payload volumes are quite large, the MESA can be modified to a number of configuration concepts without affecting the primary structure and the general housekeeping equipment installations. Some typical designs (related to specific missions under study) are shown in Figure 11. They all conform to the allotted Ariane envelope, shown on the left, and the Shuttle/PAM-D envelope depicted in the previous figure.

Low Cost Features. The very low cost of the Boeing small spacecraft systems is due partly to the simplicity of the missions flown, short mission design lives and state-of-the-art technology generally used. However, there are some specific management and design philosophies used that are directly responsible for our low cost performance. Figure 12 summarizes key management approaches.

First, it's important that the organizational structure suit the program philosophy. We do not use many management tiers and we insist on using only experienced, multi-skilled engineers and technicians. By keeping such a small, experienced team we have been able to develop a strong team spirit that we deliberately exploit and expand into the experimenter and customer organizations.

With a small team and a close working relationship with other agencies, we can reduce the normal degree of program formality, documentation and design reviews that are costly contributions to a spacecraft program. Our experience is that by developing a strong team spirit at the working level, experimenter and customer agencies have a high degree of confidence and enthusiastically support our management approach.

A key program cost driver are the subcontractors and suppliers. They must be indoctrinated and continually monitored for compliance with our low cost philosophies. We flow down the "team spirit" attitudes, lack of formality, small amount of documentation, design reviews, etc. into their involvement as well. This is somewhat unconventional and many suppliers are skeptical at first, but we have developed a set of subcontractors over the span of these programs that support us very well. A key problem to them is our small quantity procurements (often only one unit) so it's important we remain as little a burden to them as possible.

Finally, an extremely important consideration is the discouragement (ideally the elimination) of changes after a program is underway. A conventional philosophy often perceived is that contractors like changes because it adds big ECP's to their acquisitions. On small, low cost, often fixed price, one-of-a-kind spacecraft programs, changes can be a cost and schedule disaster. For one thing, it is not possible to really comprehend the impact of a change when it is first conceived and unless the resulting ECP is deliberately overpriced, the contractor often loses money in the final analysis. Also, schedule delays and slides, vehicle rework, subcontractor changes, etc. add considerable program cost even for very minor changes. It is imperative

FIGURE 11

Configuration Options Compatible with Piggyback Envelope

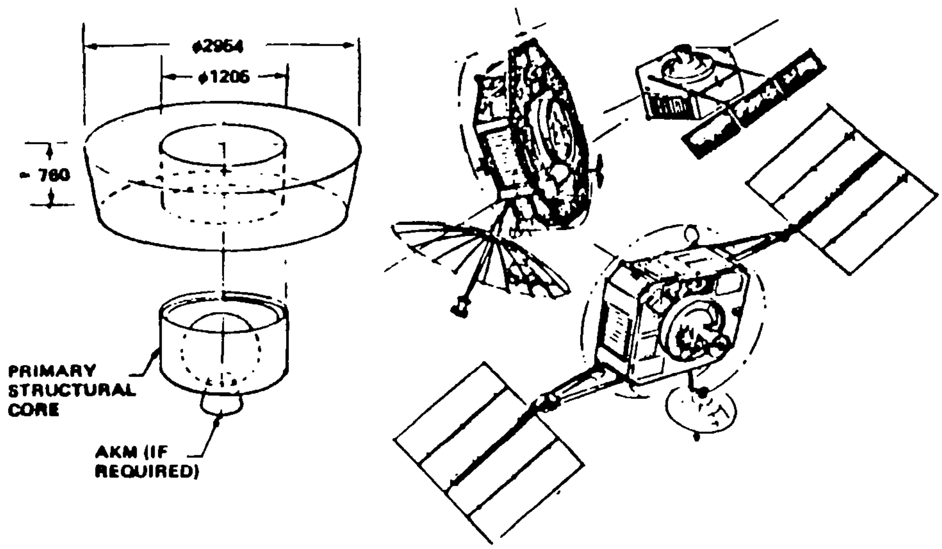


FIGURE 12

LOW COST MANAGEMENT APPROACH

- A SMALL, EXPERIENCED, MULTI-SKILLED ORGANIZATION:
  - "CONTRACTOR-GOVERNMENT-EXPERIMENTER TEAM" ATTITUDE
- A MINIMUM OF FORMALITIES, DOCUMENTATION, DESIGN REVIEW POINTS AND "ILITY" INVOLVEMENT
- PROPERLY INDOCTRINATED AND COOPERATIVE SUBCONTRACTORS
- DISCOURAGEMENT OF CHANGES:
  - FROM CUSTOMER AND EXPERIMETER
  - BY DESIGN TEAM

that the entire program team, the customer, experimenter, suppliers as well as the design engineers, recognize the severe potential cost impact of changes and keep them to an absolute minimum. We have a posted motto to help instill this philosophy: "Don't make it better, make it work."

Similar philosophies are carried over into the engineering activities associated with these low cost programs (Figure 13). The first step in ensuring we can achieve a low cost design is to identify the program requirements that are costly and then challenge them. Very often in our experience an experimenter doesn't understand the impact of what he wants until it is explained to him. He can often make trade-offs and reduce his requirements. One very typical problem is attitude (pointing) control. Most experimenters ask for very tight pointing. Our experience is that they can almost always accommodate looser pointing if they have accurate attitude determination suitably time-tagged and recorded or transmitted. In their data reduction process, the attitude determination data is used to update and "correct" the attitude control data to obtain what is the equivalent of precise experiment results. It is easier and much less costly to get attitude determination data through earth and sun sensors than to achieve accurate pointing control in space. There are other similar trade-offs to make when one is trying to optimize spacecraft subsystems for cost.

As mentioned earlier, we have developed a set of compatible and cooperative suppliers and we tend to go back to them continually to reuse the same equipment with which we are familiar and for which the supplier has existing designs, tooling, test procedures, etc. This "off-the-shelf" equipment set is proposed to our new potential users although it is often what everybody considers old technology. When necessary, we fly new designs, but don't get into new developments just to save a little weight or improve efficiency. This approach is another difficult attitude for some engineers and customers to adopt but it is possible to show documented significant cost savings to a program.

Low cost "designs" are a difficult concept to comprehend but is a key element of our approach. A low cost design is one with a high degree of producibility, testability, maintainability, accessibility and reliability (through simplicity). Some designers can achieve this, others cannot. To develop this trait we work very closely with the manufacturing and test personnel (team spirit again) who will be assigned to these spacecraft. This coordination starts at the very beginning of the program and our engineers are instructed to listen to and respond to the suggestions, criticisms and comments provided by these organizations. The point made about few machined parts should be mentioned; any complex machining operation, especially on small quantities, is expensive. We work hard to ensure structural joints are simple and can be made without machined parts where possible. Intuitively, it would seem that this would cause a structural weight penalty, and it probably does, but our experience is that it is very small and this approach has never gotten us into an adverse program weight problem.

Just as we want an experienced engineering team with program-to-program continuity, we strive for the same with support organizations such as Finance, Contracts, Materiel, etc. We use a "dedicated" fabrication and test facility, rather than meshing into the large Boeing production facilities, just to ensure we can monitor and control those activities. We in-

FIGURE 13

LOW COST DESIGN APPROACH

- CONTINUOUS CHALLENGING OF REQUIREMENTS
- EXTENSIVE USE OF FLIGHT PROVEN, OFF-THE-SHELF EQUIPMENT
- LOW COST DESIGNS REQUIRING:
  - SIMPLE TESTING
  - SIMPLE TOOLING
  - FEW MACHINES PARTS
- DEDICATED SHOP, MATERIEL AND FINANCE SUPPORT:
  - QUICK REACTION, LOW COST
- PROTOFLIGHT TEST CONCEPT EMPHASIZING:
  - EXPECTED MISSION CONDITIONS
  - INTERFACES
  - SYSTEM LEVEL

FIGURE 14

Summary

- Boeing has demonstrated that small, simple spacecraft can be produced at low cost.
- Low cost does not mean low reliability:

  27/28 = 96.4% success
- With the advent of space commercialization low cost approaches become even more important.

sist on experienced, multi-skilled personnel in these organizations also and have been successful in keeping the same cadre of manufacturing and test people on our programs for many years. Such an approach allows us to efficiently respond to customer requests, new program initiatives and other marketing activities. We can get a new program going very quickly.

The testing philosophy associated with these low cost programs emphasizes a "protoflight" concept. That is, we build one vehicle to test and fly. By environmental testing to qualification levels for acceptance durations we don't over-stress the vehicle structure or equipment. We do not introduce program risk by this approach but do save considerable cost. Associated with this approach, we carefully structure our test programs to emphasize expected mission conditions (rather than test to "discover" actual margins). We also emphasize interfaces with the payloads, booster and ground stations as these are often critical operational weak points. Finally, although many programs use multilevel testing such as that required in the new MIL-STD-1540A for example, we have kept our focus on system level testing to shorten schedules, reduce stress on our protoflight vehicles and drastically reduce test costs. There are considerable arguments to be raised for and against this testing philosophy but our experience shows us that for small, low-cost programs, we can expect a high degree of success with this approach. We continue to make trade-offs on all new programs and carefully consider the cost-effectiveness of protoflight testing.

Summary. There are three specific points to be made in summarizing the MESA concept (Figure 14):

First, we have demonstrated for almost two decades that small, low-cost space vehicles are a reality. Admittedly, it is a small and unique market and we do not presume to imply that all space programs are suitable for the approaches discussed herein. Nevertheless, for the class of vehicles of a few hundred pounds and for simple, scientific and/or applications missions, there is no question that small space vehicles can be produced for costs in the neighborhood of $10M at todays prices.

We have also demonstrated that low cost does not mean poor reliability. The cost savings are achieved by eliminating and/or controlling program characteristics that are not cost-effective, not by eliminating tasks that are necessary. In other words, we don't do anything that is not necessary, but what is necessary we do extremely well. People have been critical of low cost programs because of a mistaken belief that the product is "cheap" by definition. That is absolutely not the case. Reliability is achieved by simple designs by an experienced design team using flight proven concepts and equipment. Low cost approaches, as we define and use them, do not compromise these factors and therefore, do not compromise product reliability.

An important final point, in our judgment, is that if low cost was important to government programs, it is even more important in commercial programs where considerable financial investment from private sources is at risk. Factors such as return on investment, cash flow, revenue sources and competition are coming into play more and more. We believe we are well positioned to adapt to these characteristics with our decades of demonstrated low cost experience.