ASPIRE 1

Design report of the first UKSEDS rocket project

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1 Introduction

In order to celebrate the International Space Year 1992 the World Wide Launching Campaign (WWLC) of student rockets was organised under the aegis of the International Astronautical Federation (refs 1&2). It comprised two events, one in the USA and the other in Mourmelon, near Reims in France. A group of university students in Britain decided to participate in this, perceiving it as an ideal opportunity to make a name for Britain and get back into the international rocketry arena. In May 1991 the initiative was taken to involve the students and branches of the United Kingdom Students for the Exploration and Development of Space (UKSEDS), forming project teams from these branches and supplying initial funding. Thus this rocket project was born, with teams created at Bath, Bristol, Cambridge and Kent universities. This report details the development of the rocket, called ASPIRE, that was entered into the launching campaign: its final specification was as follows.

Length:	1.864m
Mass:	22.3Kg
Motor:	CNES Caribou solid rocket motor
Propellant mass:	4.8Kg
Average thrust:	2900N
Burn time:	3.5 seconds
Max. acceleration:	15g
Max. speed:	370m/s (835mph)
Max. altitude:	3500m (11000ft)

See figure 1.

1.1 Aims

The intention of the ASPIRE project was not to expand the realms of science but to, in effect, redefine the limits of expectation and achievement against the tide of otherwise insurmountable odds and restrictions, and thus gain a truly remarkable result. What we have achieved in this project has all been done before but that was obviously not our intention. For our task was to realise a supersonic rocket whose lifespan was just fourteen months from conception to launch. To this effect, the standard of size and complexity of this vehicle was intended to be on a par if not better than those entered from other countries. A supersonic rocket carrying an experiment was evidently a good basis for this - one of the requirements of the competition was that the payload should perform some experiment or measure some condition that could not more easily be achieved terrestrially. Naturally we wanted to keep the project exclusively British and in this respect our intent was to acquire a British rocket motor.

1.2 Objectives

Initially the project was poorly defined, but by December 1991 the scope of the project had been decided:

The rocket was to be approximately 2m long, and was to reach an intended altitude of 2-4Km in 30 seconds (just touching the sound barrier), then deploying first a small drogue parachute and then a larger one, under which it would descend back to earth in about 3 minutes.

The payload would measure the dynamic pressure and temperature during ascent and ambient pressure and temperature during descent under the parahute. The results would be stored onboard in computer memory and also transmitted in real-time down a radio link (telemetry system). A tracking system utilising this radio signal would also be developed. These measurements would allow testing of a spiked nosecone, proposed by Alan Bond for the HOTOL single stage to orbit vehicle.

Photographs (showing sky, land and possibly the parachute) would also be taken every few seconds (except for a few seconds during launch in which high g-loads may be too high for the film transport mechanism to function). A cloud backscatter sensor (nephelometer) was also to be included in this payload.

2 Project Progress

The following is amalgamated from the combined accounts of Ralph Lorenz, James Murray and James Macfarlane and are their own personal thoughts on the progress of the project; the conclusions are theirs also.

2.1 Summer 1991

In May of 1991 letters were sent to all of the branch representatives of UKSEDS at Universities throughout the UK. This was not the ideal time to initiate a project as, already, most universities were in full preparation for end of year examinations. However the response was heartening for very enthusiastic replies were received from the Universities of Bath and Cambridge and communication was made with the UKSEDS committee. The enthusiasm was overwhelming with Mike Howell from the University of Kent demonstrating a keen interest in the organisation of the project. It was agreed that Kent's substantial experience in the building of interplanetary probes and payloads would be a great asset in developing a considerably impressive payload for the rocket. From here the project was left over the summer holidays, though letters were sent out to persons and organisations who possessed experience in the field.

With the start of the academic year (October 1991) began the saga of the project. Subgroups were formed at Bristol and Bath, Cambridge and Kent and the process of organising their respective teams began. It was here in the early stages that ambitions were allowed to run wild and ideas were given the scope to evolve. We still had no information on the event and in our eyes, with no restrictions, anything was possible. What was brought to our attention was that two years prior the Technion Institute in Haifa, Israel had built a rocket which achieved an apogee of 21Km. We were expecting them to be there and in fact were intending to build something of comparable performance. For this, research was done into all manners of propulsion. We considered solid fuel and liquid fuel rockets and even pursued newer developments such as hybrid rocket motors.

The project was first introduced to the public at the 1991 UKSEDS National Conference held at Leicester University. At this time, the first general ASPIRE meeting was held.

At the conference was the entire Cambridge coalition, a sizeable representation from Bath, Kent being represented by Mike Howell. The general theme for this meeting was " Nothing's Fixed, Nothing's Defined ". Up to this point we were still waiting for the rules and regulations from France, though we were now registered as an entrant in the French event along with approximately 20 other teams from around the world. All the faxes had been sent off and we were just awaiting the details. But then again there was much to talk about. With the use of a good deal of emotive language, we discussed who we were up against and what we had to prove... the project was at this point being powered on a few scanty details on the event and lots of emotive language and keen interest.

2.2 Modularity

With the distribution of the universities, lessons in project management had to be utilised as well as learned. The best approach foreseen was that of achieving a high level of modularity in the design of all of the different systems and their subsystems with simple interfacing. In using a design principle of 'black box' engineering the problems associated with the distances between groups would be minimised. Thus the design work was split into various areas and these assigned to specific project teams.

Bath

As they were all primarily electronic engineering students Bath became involved in the electronics, being asked to research into the electronics of rocketry: its sequencing, control, timing circuits and all of the available methods of solution, under the guidance of James Macfarlane. Included in this was the data storage and the telemetry and tracking systems.

Cambridge

Situated very close to Irvin Emergency & Recovery Parachutes, the Cambridge team were asked to look into parachute recovery and were essentially designated as the group in charge of this. Looking back, they were faced with a very difficult situation as they were to approach a company with very little information on the actual scope of the project: something they did quite well.

Kent

Having a traditionally excellent foundation with the development of payloads, Kent were asked to define and develop a practical experiment for the payload - something with a lot of elegance and which would sufficiently impress ourselves as well as the rest of the world. We did not want to show up with the standard arrangement of experiments but with something that would stand out. Also, from what preliminary details that we did have, as a basis of the competition rules, the experiment had to perform or measure something at altitude that could not be done more easily from the ground.

Bristol

The project management was co-ordinated from Bristol, under the influence of Project Manager James Murray, and became the clearing house or hub of the project. Specifically Bristol were also responsible for the structural design and logistics.

2.3 Autumn 1991

Research started on all forms of structures and aerodynamic principles on rocketry and the forms of electronic control normally used were investigated. It was the intent that while the project was in limbo (generally reflecting the fact that we still knew next to nothing about the event) that it would be wise to learn as much as possible about the science of rocketry. This knowledge could then be used effectively to proceed through the design as efficiently as possible when the time came, and thus Bath began experimenting with model rocketry.

Bristol were sent out in all directions researching and working out logistics. This was where we had encountered a bottle neck for we basically couldn't outline a design until a motor had been secured. We had knowledge of available French motors which were quite expensive. We were hoping to get sponsorship and were not interested in paying for a motor. The sponsorship of a motor would have been far better, thus we liased with Royal Ordnance for something suitable for the rocket: what we were interested in was to build a supersonic vehicle and this required something around the 10000Ns. (2300lbs.s.) impulse region. The idea was to obtain a motor of roughly that size and Royal Ordnance reacted favourably to these intentions.

The problem during this wait was that we could not confirm the rocket dimensions or specifications for the rest of the team: Cambridge, Bath and Kent. Thus, what we opted for was to chose one particular motor and then design for that. When we confirmed the particular motor that we would use, our design could be scaled accordingly to meet the specifications of this new motor. This was fine in theory but when it came down to practice, there were so many fine points in the details of the rocket design (examples of standard material sizes and construction practices) which depended on the performances of the motor and resulting rocket structure, that what was elegant for one motor was not suitable for the use of another. The fact was that every factor depended on another and the good deal of six weeks was spent switching from one motor specification to another with subsequent changes in design approach. This was very frustrating for the entire team as new figures continued to flow outwards and uncertainty kept flowing back. With nothing concrete, Cambridge still did not have sufficient information to confidently approach Irvin and other companies with realistic plans. Kent found this even more deterring as they needed space allocations quite urgently in order that they could proceed with the specification of the payload - without which they could not be sure that the experiments would be volumetrically practical. But nevertheless, research which could be done carried on.

The above was the prevailing state of affairs when the first informal meeting between all factions was held. Sadly, due to the short notice of this meeting, the Cambridge team were unable to attend. A motor had not been secured nor had a design been confirmed with any fixed allowances and parameters. The project seemed to be in jeopardy at this point and we made the decision that if we did not procure a motor from Royal Ordnance by January, then the project would be cancelled as important time had been irretrievably lost. We saw that we were going nowhere in terms of tangible progress and were fast approaching being 2 months behind schedule in a 14 month lifespan. This was the reflected opinion of many in the group and in retrospect seemed quite drastic.

For when rational thought was applied concerning the extent of the progress, the knowledge gained, and also the number of fall-back options which had been explored, the contrary would have been dictated. However, the commencement of one of the sagas which was to haunt the project had begun, to which no degree of persuasion would thwart. For overnight, the support of almost half of the Bristol team was lost - this trend was to be reflected in the other universities throughout the duration of the programme as general apathy flourished and other priorities took over.

2.4 Spring 1992

1992 had arrived, but the spectre of acquiring a motor still loomed. There was no confirmation of a motor from Royal Ordnance and the decision was therefore taken to use a French motor. This destroyed the idea of keeping the project expressly British but by now that had become an impractical luxury. We needed to get the programme moving as time was quickly encroaching upon us. This decision was promptly conveyed to the French authorities and a motor was reserved.

But this was no ordinary amateur motor. Those who lie in French amateur rocketry circles would pay the utmost homage to the grandest of the solid fuel rocket motors in the series. The reply before their confirmation of our request was a simple question of: " The Biggest? ". Our intention was questioned with much respect and reservation, but the wishes of young Britain were granted. Caribou, as detailed in section 3.1, is a pretty formidable motor. At least that was the general conception, but in essence this motor would suit our requirements ideally.

Having made this decision, the project progressed by leaps and bounds. We had produced more tangible results in one week of intensive labour than in three months of research and negotiation. By the end of the week, fundamental performance, weights and space allocations had been determined. All groups could now begin concrete progress on system development. At this point there appeared on the scene the collective aid of angels, namely the University of Bristol, British Airways Materials & Maintenance Division and Serco Space Ltd. They assisted the project, gave financial backing and rescued it from many a difficult situation.

Now that it was in tangible development, the situation was simpler but no easier. We had defined a few but very important objectives in order to confirm that our goal would be achieved. Fundamentally, we wanted elegance and professionalism throughout the project. Everything needed to be as modular as possible to allow each team the freedom to exclusively concentrate on developing their system to perfection. A functionally efficient design with low structural redundancy was required, allowing us to get the maximum performance possible out of the vehicle. Above all, there was a need to guaranty its ease of manufacture and considerable consideration and foresight was given to the ease of assembly on the day and the reusability of the entire vehicle.

This was where we traded one challenge for another. In the design, the ease of manufacture was of paramount importance, a direct result of the project existing on borrowed time. Literally, this meant that we were in a race as well as primarily having to negotiate for the use of the Universities' facilities and resources. It was thus of great benefit to our cause that we reduced the inconvenience to our already stretched resources to as little as possible. This had a direct influence on our choice of materials and ultimately on the choice of design for it was not adequate enough to produce just a functional solution but one that was also feasible. This, while aiming for a saving in time, also resulted in a saving in money. For in some cases, these do go hand in hand...especially for express projects.

Aluminium alloy was the chosen material. While having incredible strength and stiffness, it also had the versatility and machinability to allow considerable design options. It was also ideal due to the Bristol University aerospace laboratory's extensive experience in working with aluminium thus avoiding the need to waste time in familiarisation. But even when one can chose one's material, there is still the problem of obtaining it in the required form.

Aluminium, while being of quite low density, can still amount to significant weights if used in conventional engineering sizes. But in a project where weight is measured in grams and dimensions in millimetres, tares can rapidly add up. To solve some of these imposed problems, we had to call on the manufacturing expertise of other companies, namely the facilities and personnel at British Airways in Heathrow. Here they were able to competently fabricate the fins and the nosecone. The fins, whilst being of aluminium, were designed to be an incredibly simple and stiff shell with the planform of a supersonic double-wedge which was very light. For our purposes, the fins were over-designed as the time of supersonic flight and the level of supersonic flow was low. For stability reasons, the fins needed to be as light and as strong as possible. We thus traded the ease of manufacture of a much heavier variety for these qualities and British Airways admirably rescued us from this predicament and also offered a substantial weight saving in the construction of the nose. The nose was an important contribution to the aerodynamics of the vehicle as it in itself was an experiment. Designed by Alan Bond (the man behind Britain's now defunct HOTOL single stage to orbit vehicle), it was intended to simulate the conditions of the HOTOL's engine intakes across the transonic range. As expected, it was not of conventional design and initial intentions were to machine it out of aluminium. This would have been a fairly delicate and difficult operation if its weight was to be within a stated parameter. Needless to say, we leapt at the opportunity when British Airways suggested making it out of carbon fibre reinforced plastic (CFRP).

The Bath team, by this time, had outlined the entire control and telemetry system. After an exchange of ideas and advice from the French Authorities, and an ingression of funds from UKSEDS, construction began of a fully automated control system utilising an array of information storage techniques. The Cambridge and Kent teams, under the direction of new and very dynamic leaders (Jan Grothusen and Ralph Lorenz), had made dramatic progress.

Cambridge, after a set of acquisition difficulties of their own, conveyed their interfacing requirements to Bristol and proceeded to secure a purpose-built parachute from Irvin, and all of the necessary pyrotechnics from ICI and Dynamite Nobel. Members had been fully trained in the art of parachute handling. At this point, Cambridge already had the situation well under control.

Kent had defined the payload: namely consisting of a nephelometer, a 35mm camera, magnetic tape data recorder with velocity and temperature sensing capabilities. Direct communication with Bath on the control interfaces had begun and construction was well underway.

Meanwhile, back in Bristol, the material acquisition problem continued. The intent was to use a monocoque shell to which everything would be fastened and through which all inertial loads would be distributed. These would then be taken by a rigidly fastened thrust plate to which the motor housing was affixed. From our calculations, a 1mm (0.044 inch) thick tube was more than adequate. However, for the diameter that we required, standard tube sizes had a minimum thickness of 3mm. This raised the total weight by more than 5Kg and this was less than satisfactory. All attempts to locate or to fabricate a tube to the required specifications were to no avail. There was the possibility of using composites which would have met our requirements. However, this would not have allowed us the flexibility of any last minute alterations to which metal is more tolerable.

We therefore reservedly made the decision to procure the oversized and overweight tube. However, with all things considered, this did allow considerable redundancy and flexibility of the structural design to absorb any inherent errors or any unforeseen factors in the calculations or the fabrication (not that any were encountered). This was to prove invaluable when we were notified almost towards the last minute of some very adverse burn characteristics of the Caribou motor which occur in the first few milliseconds. These required our reserve factor to increase by almost a factor of 2.5.

Nevertheless, the additional 5Kg was too great a price to pay - a way of reducing the shell's weight was needed. Now, to reduce the weight of a 2m long section of aluminium alloy is physically no simple task. It is however easier to turn down shorter sections on a lathe. Luckily enough, the design catered directly to this solution. With the skill of the laboratories in Bristol, we were able to selectively turn down the sections leaving sufficient thicknesses in areas where we wanted to tap or countersink for the load bearing screws. In order to keep the assembly as simple as possible, components were kept to a bare minimum. It was decided that all of the systems, save for the parachute, would integrate onto a set of rails which would fasten to the monocoque shell. At this point, the design demonstrated a significant amount of elegance. With the high degree of close packing and due to the high degree of cross bracing within the tube as a result of the internal structure of the systems, the vehicle demonstrated an amazing amount of rigidity. Any measurable amount of deflection was negligible. This was to be proven admirably when the pre-launch tests were carried out.

After Easter time began to run out, with the Kent university team spending long late hours putting the electronics and metalwork together on the payload. As well as the usual cutting, drilling and soldering various tests were performed, including whirling the tape recorder round at 60rpm on a 2m piece of string to ascertain its operation under 2g loading as well as checking the camera would function with its autofocus disabled. There were fun moments (eg the worryingly large bang and blue flash when attempting to remove the flashgun capacitor from the camera), joyous moments (when things worked), and a few frustrated moments (when things didn't). All efforts were directed towards preparing components for the integration test in order to reduce work at the launch site.

3 Technical Description of ASPIRE

The following section is a full technical description of the ASPIRE rocket and all its sub-systems as finalised in Spring 1992. See figure 2.

3.1 Rocket Vehicle Structure and Performance (Bristol University Team)

ASPIRE consists of two sections. Each is based around a length of aluminium alloy tube of 114mm external diameter and 108mm internal diameter.

The bottom section is 788mm long and contains ASPIRE's propulsion unit, a solid fuel rocket motor called Caribou. This is to be supplied and fitted to the rocket at the launch site.

Supplier :	CNES, France.
Total mass :	11.4 Kg
Empty mass :	6.6 Kg
Propellant Mass :	4.8 Kg
Diameter :	102.8 Kg
Total Impulse :	9161 Ns
Average Impulse :	3014 Ns
Burn time :	3.5 s (approximately)

The bottom section also has the rocket's fins, for aerodynamic stabilisation. Four supersonic double-wedge type fins are employed. A faring at the motor exhaust improves aerodynamic performance with the under-expanded nozzle characteristic of the motor. The bottom section is coupled to the top section with a cylindrical coupler, which also acts as the motor thrust-block.

The 806mm long top section houses the payload, the flight controller and the parachutes and has a small window for the camera in the payload. The nosecone was designed by Alan Bond based on the HOTOL engine intakes. One aim of ASPIRE is to collect some data for this interesting design of nosecone as very little unclassified information is available. The central aerospike creates a shock-wave at supersonic speeds and this acts as a 'virtual nosecone'. The nosecone was produced first in aluminium, a mould made from plaster and the final carbon fibre reinforced plastic (CFRP) nosecone produced.

The fins and nosecone were kindly fabricated for ASPIRE by British Airways, who also supplied the body tube. All other work was carried out by the technicians at the Aerospace Department laboratory at Bristol University.

Rocket Performance :

The predicted performance of the rocket is outlined below :

Attained altitude :	3500m
Max. speed	370 m/s
Max. Acceleration :	15g

Aspire weighs 22.3 Kg and stands 1.864m tall. See figures 3 to 11 for engineering drawings.

3.2 Payload
(Kent University Team)

The payload comprises two instruments (temperature and pressure sensors) with their signal conditioning electronics, a telemetry recorder plus a camera.

A third instrument, the nephelometer (see later), had to be deleted owing to shortage of development time.

Due to uncertainties in the reliability of operation of the payload mechanisms (camera and tape recorder) these are disabled by timer during the 2 seconds or so of high acceleration at launch. (Note that in addition to the motor acceleration at launch, there will be substantial aerodynamic forces on the vehicle during flight. However, we have tested the tape recorder system at 2g, by swinging the recorder on a 2m piece of string at 60rpm) so we anticipate no problems).

The initial signal conditioning electronics of the sensors produces a voltage in the range 0-2.5V, so that it can be monitored and recorded digitally by the on-board computer. A second stage of amplifiers shifts this range to 9-12V for input to the next stage.

Voltages in the specified range (9-12V) are passed from each instrument to a voltage-controlled oscillator (VCO) which varies in frequency in direct proportion to the signal. Signals from two such VCOs (running at nominal frequencies of 730 and 1700Hz - corresponding to IRIG standard channels 3 and 6) are mixed (ref.3) and then passed to the tape recorder. The 566 VCO microchip has been selected on cost / simplicity grounds, and because considerable experience exists in the rocket community with this device (ref.4).

A clock pulse (every 8 seconds or so) from the on-board computer triggers a relay to take photographs during the flight. The pulse is gated by a delay triggered by the launch flag to suppress camera operation during launch. Similarly, the tape drive is deactivated during the acceleration phase.

Payload subsystem details

Camera - side looking based on standard compact 35mm unit (Chinon). Auto exposure and wind-on. Flash disabled (for safety as well as power reasons). Autofocus mechanism disabled due to limited window access. 400 ASA 36 exposure colour film to be used. Photos at regular intervals, except during launch phase.

Nephelometer - pulsed IR LED mounted coaxially with photodiode to measure backscattered light from clouds (possibly also from Mach cone if vehicle is transonic in moist air). Light sources driven by 3KHz oscillator. Sensor signal is filtered (to remove ambient light signal, and hence extract backscatter signal). Instruments of this sort have been flown on the Pioneer Venus probes (ref.5), Vega balloons and the Galileo probe. Unfortunately, lack of development time meant that this sensor had to be de-scoped from the payload.

Temperature - a thermistor, mounted near the stagnation point on the rocket skin (a lapse rate of 4.2K/km suggests temperature at apogee will be about 20 degrees Celsius lower than at the launch site, although at Mach 1 the stagnation temperature during flight may be as high as 360K). Whether the thermal inertia of the transducer will permit it to attain such a temperature during the short high-speed phase remains to be seen.

Pressure sensor - measuring total (pitot) pressure. Will thus monitor flight speed through dynamic pressure during ascent, returns near-static pressure profile during descent under parachute. At 4.5Km, the ambient pressure is just under 0.6 bar: at M=1 the stagnation pressure (computed using the isentropic flow equation with 100% pressure recovery) is about 1.9 bar. A Sensym SX30AN piezoresistive pressure sensor (0-2 bar) is being used. The sensor is mounted on the top payload deckplate, with a rubber tube connecting it to a pitot tube near the front of the rocket (it was originally intended to mount the tube in the payload section, but difficulties in aligning such a tube with a mounting hole in the rocket structure, and the potential boundary layer losses prompted the movement of the sensing port to the nose of the rocket).

For mass and volume reasons, a xenon flash beacon - originally proposed to assist ground tracking and recovery - will not be carried.

Structure

The payload is mounted on a structure comprising three 0.25 inch (6.5mm) thick aluminium 'deckplates', circular (104mm dia) except for small cut-outs to mate to the launch vehicle structure. Attachment is achieved using small aluminium brackets (6 in all) mounted on M3 or M4 screws. The deckplates are held rigidly in position by three M6 threaded rods. Units and boards are attached to the plates or rods by a variety of fastening methods (selected on an ad hoc basis).

Payload Connections

The electrical connections to the payload comprise of a single male 15 pin D connector in the top of the payload. This mates with a connector on a fly-lead from the Bath University flight controller. Pin connections are as follows :

1. +12v (in)	9. +12v (in)
2. CS1 (in)	10. SL2 (out)
3. CS2 (in)	11. SL1 (out)
4. SL3 (out)	12. Audio (out)
5. AN1 (out)	13. CS3 (in)
6. AN2 (out)	14. CS4 (in)
7. AN3 (out)	15. 0v
8. 0v	

0v is the analogue audio and power ground connection.

3.3 Flight Controller
(Bath University Team)

The following is a full final specification for the operation of the ASPIRE flight controller arrived at after consultation with all other parties. The flight controller must :

1. Fire pyrotechnic actuators with a recommended current of 1 Amp to release the two parachutes in the rocket at the correct point in its flight.
   a. Drogue `chute deployment actuator to be fired at apogee.
   b. Main `chute deployment actuator to be fired at a set altitude or a set time after apogee.
2. Generate timing signals to control the function of the payload.

Control Signal 1 (CS1) :	Enable +3v supply (this feeds the camera and the tape-drive).
Control Signal 2 (CS2) :	Trigger camera shutter.
Control Signal 3 (CS3) :	Sensor auto-calibration 1.
Control Signal 4 (CS4) :	Sensor auto-calibration 2.

Which are to be operated at the following times :

After pre-flight checks :	CS1 on. Pulse CS2. Pulse CS3 then CS4 (take a photo on the pad, calibrate sensors).
T-10 seconds :	CS1 off (disable camera and tape-drive prior to take-off).
T+3 seconds :	CS1 on. Start pulsing CS2 at 8 second intervals (enable tape-drive and camera after motor burn-out. Take photo every 8s).
20s after apogee :	Pulse CS3, CS4 (calibrate again).
180s after apogee :	CS2 off (disable tape-drive and camera prior to touch-down).

3. Monitor the operational status of the payload :

Status line 1 (SL1) :	Payload +3v supply ok.
Status line 2 (SL2) :	Payload -12v supply ok.
Status line 3 (SL3) :	Camera lens cap off.

4. Provide power for all electrical systems including the payload. Payload current consumption 500mA absolute max.

5. Measure altitude via a static pressure sensor and provide a second measurement of pitot pressure (in addition to that provided by the payload) from a vent at the stagnation point at the base of the nosecone spike.

6. Convert into digital form the analogue signals from :

   a. The 3 sensors on the payload (outputs 0-2.5v, AN1-AN3).

   b. The 2 sensors on the flight controller itself.

   c. 2 Supply voltage sensor in the flight controller (for self-checking purposes).

7. Relay the resulting digital data over a radio telemetry down-link to the ANSTJ telemetry reception van at 136.5 MHz.

8. Store the digital data onboard in battery-backed static RAM for retrieval after the flight, as a back-up to the telemetry system.

9. Provide an umbilical link to an external computer for pre-flight checks and post-flight data download.

The flight controller is being developed at Bath University by James Macfarlane and Harvey West. The following decisions were made regarding the implementation of the flight controller and how to meet the specifications :

It was decided that the many of the specifications above could be met by basing the flight controller around a small computer. Though this might at first appear an additional complication, it would actually be able to perform practically all the functions listed above if provided with sufficient basic interface circuitry. The Z80 microprocessor was chosen as this was a device the team had a lot of experience with. The following basic details were also decided upon :

The critical parachute and payload timing signals would be provided by the computer to allow flexibility but an additional discrete-component-based timer circuit would be employed to provide redundancy and ensure mission safety in the unlikely event of the onboard computer failing.

The telemetry signal would be transmitted on 136.5 MHz, the standard frequency used at the Launch Campaigns. The amplitude of the carrier would be modulated with the binary data using a Pulse Code Modulation system, and would be received using the telemetry reception facilities provided at the Launch Campaign.

The ground umbilical would consist of a synchronous serial data link into the onboard computer. In conjunction with an external computer, this would allow pre-flight checks to be made and would provide a means of downloading the data stored onboard during the flight.

Power would be provided by nickel-cadmium (NiCad) cells. This type of battery was chosen because they allow us to draw a high current from relatively small capacity cells for the short duration of the flight. This gives a weight saving over conventional cells - with these we would require large cells, of a capacity much larger than needed for the short flight, just to allow us to draw enough current. The capability of NiCads to be re-charged was an additional bonus.

We decided to include additional connections in the umbilical link to provide ground-power for the rocket, i.e. to power its electrical systems on the ground, while waiting for lift-of. This would be essential for conserving the onboard batteries in the event of any hold-ups in the launch procedure.

After making these decisions, the flight controller was designed. The following is a full final description of the flight controller :

Power Supply - power is provided by 10 AA sized NiCad cells wired in series giving 12v. This is fed to the payload and to systems in the flight controller including a 5v monolithic regulator for microprocessor unit and a separate 5v regulator for the back-up timers.

Back-up Timers - back-up timers are included for all critical payload and parachute timing functions :

Drogue release timer.
Main chute release timer.
Payload CS1 timer.
Payload CS2 pulse generator.

All are based on 555 timer ICs. The back-up timers have calibration / checking outlets feeding the onboard computer to allow easy pre-launch set-up.

Parachute release pyrotechnic actuator drive circuits - for each parachute a TIP41 power transistors with current limiting emitter resistors is employed, fed from a 20ms monostable (555 based). The monostable can be triggered either from the onboard computer or from the appropriate back-up timer.

Onboard sensors - static pressure is measured using a Radio Spares 341-913 0-5psi piezoresistive bridge-type pressure transducer op-amp based amplifier circuitry. Dynamic stagnation-point pressure is measured using a similar arrangement but with a slightly different pressure sensor - the MPX100.

Onboard computer - the heart of the onboard computer is an 8-bit microprocessor, the Z80A which is run at a clock speed of 2MHz. 2K bytes of static RAM are included for dynamic data storage, stack, etc. 32K bytes of battery backed static RAM with write-protect circuitry is provided for onboard data storage. An 8K byte EPROM holds the program that the computer runs during the flight. A `watchdog' or `crash-proofing' circuit is included to monitor the processor and reset it if it is not operating correctly, i.e. if it `crashes'. This is simply achieved by monitoring interface activity.

Interfacing - 2 Z80A-PIO parallel interface chips are used for various digital input/output signals including the umbilical communication lines and monitoring and control of the payload, the parachute circuits, timers, processor watchdog circuit and other internal functions. A 10 bit Analogue to digital converter type ZN502 is fed from an 8 way analogue multiplexer chip which feeds it the analogue voltage from the various sensors etc. A 50 Hz timebase chip is used to sequence flight controller operations.

Telemetry - the transmitter is to be provided at the launch site and is an ANSTJ IBIS transmitter. Its carrier frequency is 136.5 MHz at 500mW max. output power into 50 ohms. AM modulation is achieved by variation of transmitter PA stage supply voltage. The modulation maximum bandwidth is 15KHz. The transmitter feed two 1/4 wave wire aerials, one on either side of the vehicle, suspended from flight controller section of the rocket to the tips of the fins. The digital data from the computer is encoded into a suitable serial format for transmission by a synchronous pulse code modulation (PCM) technique.

Each data byte from the computer gives rise to a transmitted data frame of the following format: 8 data pulses per frame, one per bit. A short pulse for a high bit, a long pulse for a low bit. The frame ends with a long synchronisation pulse before the next one starts. The data rate is about 200 frames per second, i.e. 200 bytes per second.
Electrical Interface to payload - the payload is connected to the flight controller by a 15 way female D connector on flying lead. For pin connection details, see payload description. The signals are as follows. Further description of these can be found above in the Specifications section.

4 TTL compatible digital outputs to payload : CS1-CS4
3 TTL compatible digital inputs from payload : SL1-SL3
3 Analogue 0-2.5v signals : AN1-AN3
Ground and 12v lines.
Audio input from payload tape-drive for diagnostics.

Umbilical Link - the data link is achieved by a 5-wire synchronous serial interface. Connections : Clock, Synchronisation, Data out, Data in, Ground. The Ground Power Supply is fed into the vehicle from an external 12v sealed lead-acid battery on pad.

Mechanical Construction of flight controller - 3 deck-plates (same design as payload's) of 4mm gauge aluminium are bolted at various positions on 3 lengths of plated steel M6 studding.

Length : 300mm
Diameter : 10.5mm
Mass allocation : 1.5 Kg

3.4 Tracking System
(Bath University Team)

The rocket tacking system was an ambitious and original project proposed in the early stages of the ASPIRE program. It was decided that there was insufficient time to develop it for the launch of ASPIRE. The tracking system is a `cosine' phase comparison (interferometer) position determining system. The following is an brief outline description of the system based on preliminary research conducted by James Macfarlane, who is planning to continue development of the system in the near future for the benefit of further rocket projects.

The rocket tracking system is based on two ground stations (A and B), each having three aerials connected to receivers. The system tracks the rocket by receiving the 136.5MHz telemetry signal the rocket transmits. A digital system will measure the phase difference between the signals received by each of the three aerials in each station. The digital phase measurements will be sent back to the main computer which will calculate the 3D spatial co-ordinates of the rocket relative to the baseline (imaginary line between the stations) and at the end of the mission produce, among other things, graphs of ground track, altitude, velocity and acceleration. Station A will be situated near the computer and will be connected to it by a cable. Station B will be situated about 1Km from station A and will send its phase measurements back to the computer by a radio link.

Each station consists of the three aerials spaced exactly half a wavelength apart in an equilateral triangle. Half a wavelength at 136.5MHz is just over 2 meters. A frame will be employed to space the aerials precisely. The aerials will be connected by coaxial cables to a box housing the three receiver circuit cards, a local oscillator card and a digital card connected by a backplane. In the case of the remote station, the unit will also contain a sealed lead-acid battery providing 12 volts power supply.

3.5 Recovery System
(Cambridge University Team)

The recovery system consists of two parachutes, which will be deployed serially. A drogue parachute will be deployed at apogee to stabilise the rocket initially on descent. The rocket will descend with a velocity of 22m/s for a period of 180s before the main parachute will be deployed at an altitude of 500m. This will reduce the rocket's terminal velocity to within the specified 5m/s minimum, hence a total descent time of 280s will be realised. Assuming a constant wind of 20m/s, this will yield a down-range distance of 5600m, well within the required 8Km maximum. The weight of the recovery system is 1.8Kg

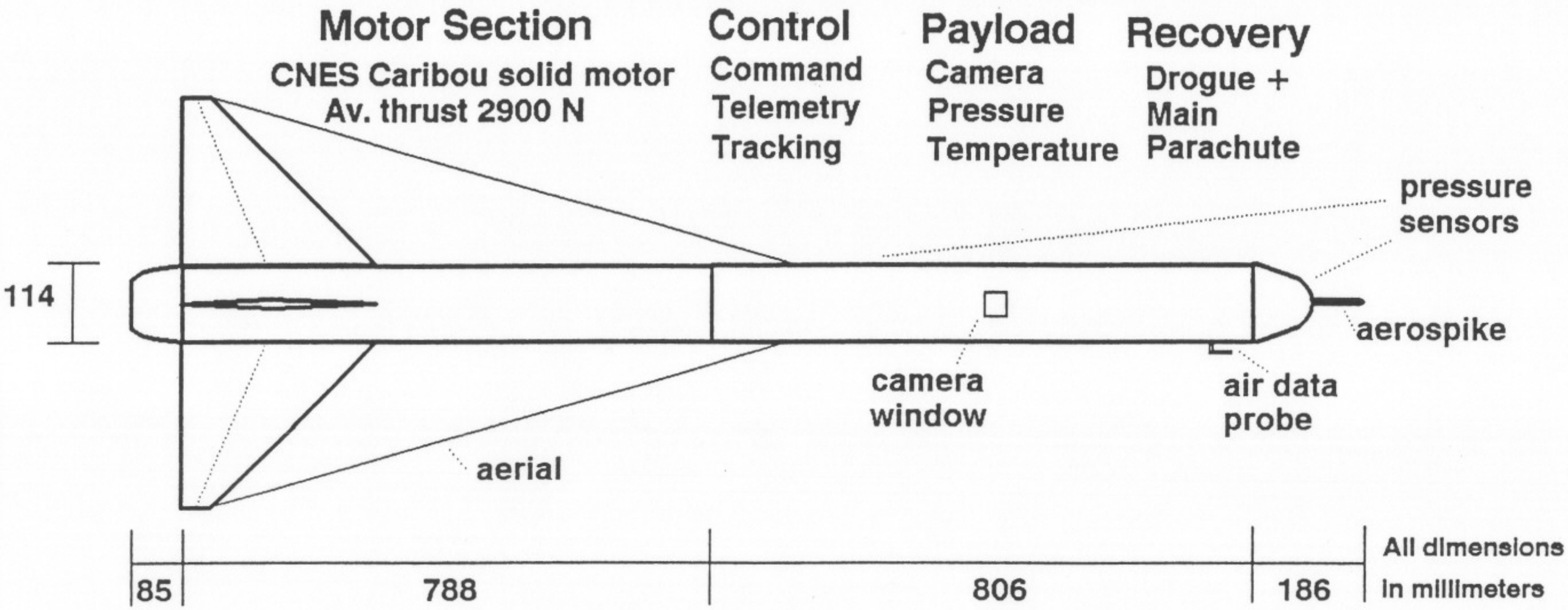
The first stage of the serial deployment is the drogue parachute, a standard spring auxiliary. The advantage of this system is that it includes its own deployment method, a conical helix spring within the drogue itself. The drogue is divided into an upper and a lower part, the drag area being made of nylon and a net (instead of lines) with an attachment loop at the lowest end. In its packed form the drogue parachute will be about 20mm thick. The drag area is approximately 0.683 sq m with a line of 1.5m attached to the attachment loop.

The drogue is situated just below the nosecone of the rocket and will be deployed when the pyrotechnic retractor that secures the nosecone is fired. The drogue's line is anchored to the rocket body by a length of kevlar which runs though a pyrotechnic guillotine. The drogue line is also connected to the main parachute pack so that when the guillotine is fired, the main parachute will deploy.

The main parachute is of a cruciform type to ensure a stable descent. The parachute has a drag area of approximately 11.74 sq m and is made from nylon. It will be stored in a cotton pack with its rigging lines at the bottom. When an altitude of 500m is reached on descent, the guillotine will fire and the drogue parachute will be released from the rocket and will pull the main pack from the rocket body and release the main parachute within, allowing it to deploy. The main parachute line will have a length of 0.5m and will be attached to a ring in the bulkhead at the bottom of the parachute compartment.

All lines and connections are realised with kevlar strops and rapide links, chosen to take a shock load of 0.5KN each.

UK-SEDS - ASPIRE RESEARCH ROCKET



STATISTICS

Length: 1.864 m.
Mass: 22.3 Kg
Propellant Mass: 4.8 kg
Burn Time: 3.5 sec
Max Acceleration: 15 g
Max Speed: 370 m/s (835 mph)
Max Altitude 3500 m. (11000 ft)

TEAM

Bristol - System, Structure, Aerodynamics
Kent - Payload
Cambridge - Recovery
Bath - Control, Telemetry, Tracking

MAIN SPONSORS

British Airways, Dynamite Nobel, ICI, Irvin Parachutes
REL, SERCO Space, University of Bristol

17 June 1992

FIGURE 1

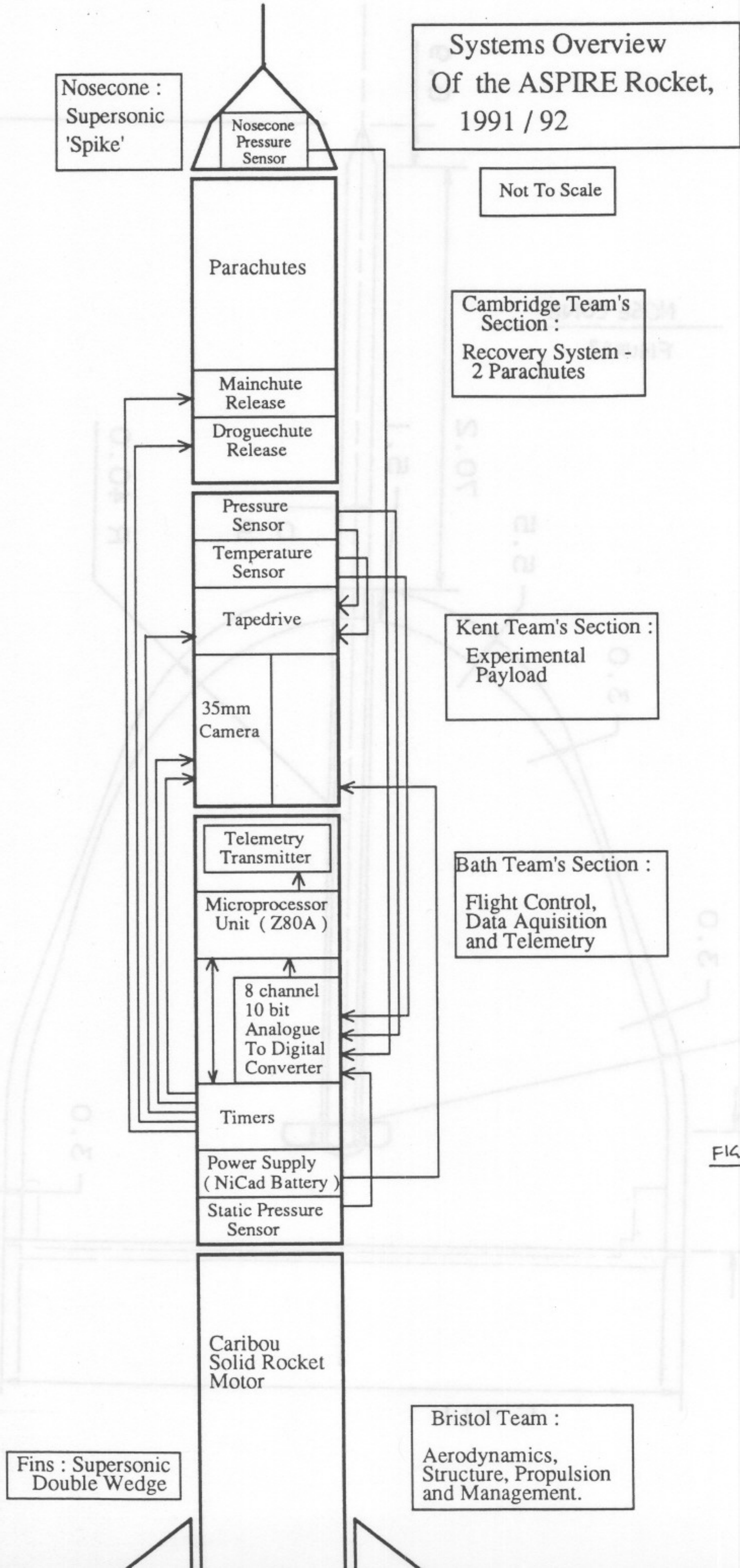
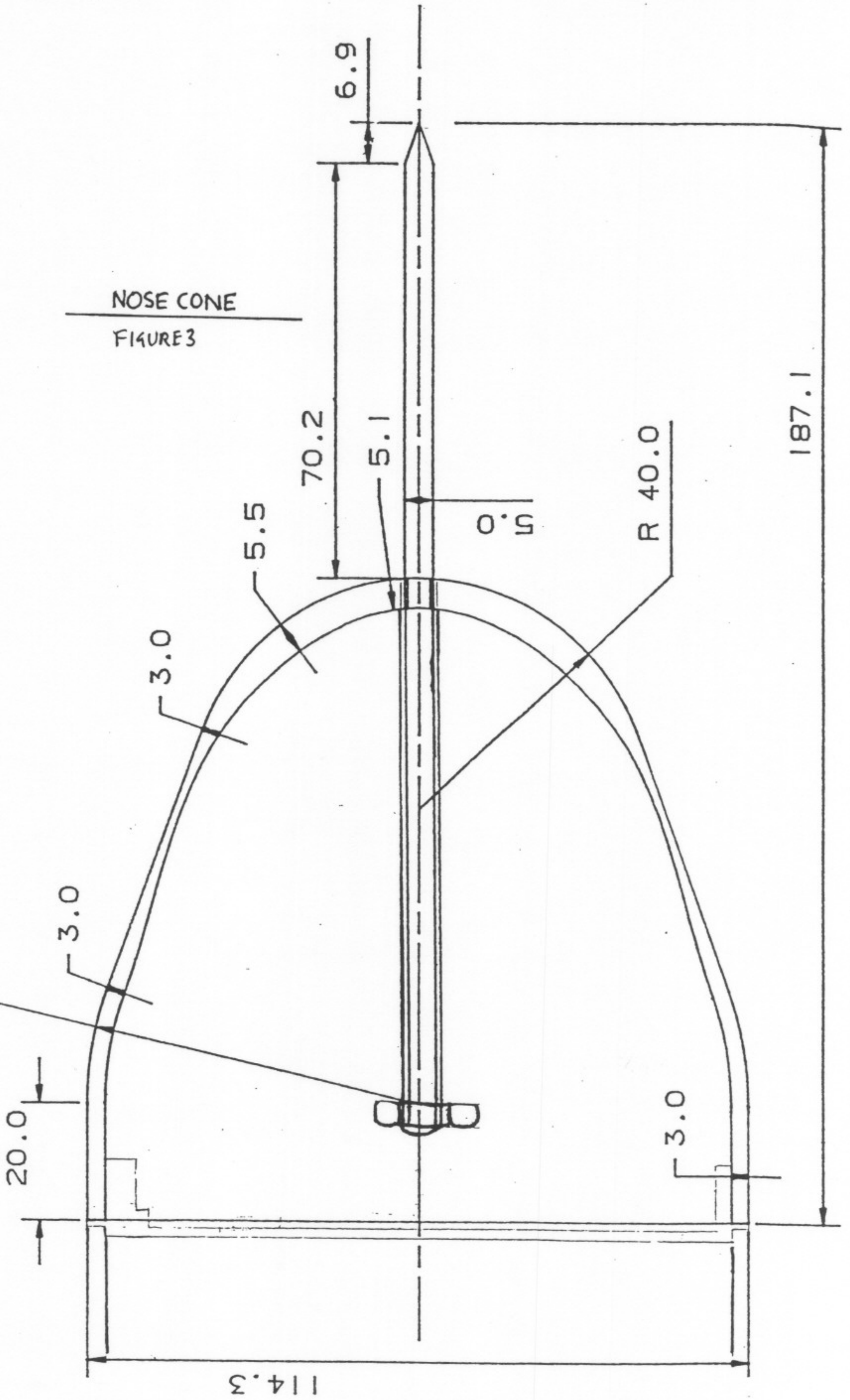

Systems Overview
Of the ASPIRE Rocket,
1991 / 92
Not To Scale
Nosecone :
Supersonic
'Spike'
Nosecone
Pressure
Sensor
Parachutes
Mainchute
Release
Droguechute
Release
Cambridge Team's
Section :
Recovery System -
2 Parachutes
Pressure
Sensor
Temperature
Sensor
Tapedrive
35mm
Camera
Kent Team's Section :
Experimental
Payload
Telemetry
Transmitter
Microprocessor
Unit (Z80A)
8 channel
10 bit
Analogue
To Digital
Converter
Bath Team's Section :
Flight Control,
Data Aquisition
and Telemetry
Timers
Power Supply
(NiCad Battery)
Static Pressure
Sensor
Caribou
Solid Rocket
Motor
Fins : Supersonic
Double Wedge
Bristol Team :
Aerodynamics,
Structure, Propulsion
and Management.

FIGURE 2



NOSE CONE

FIGURE 3

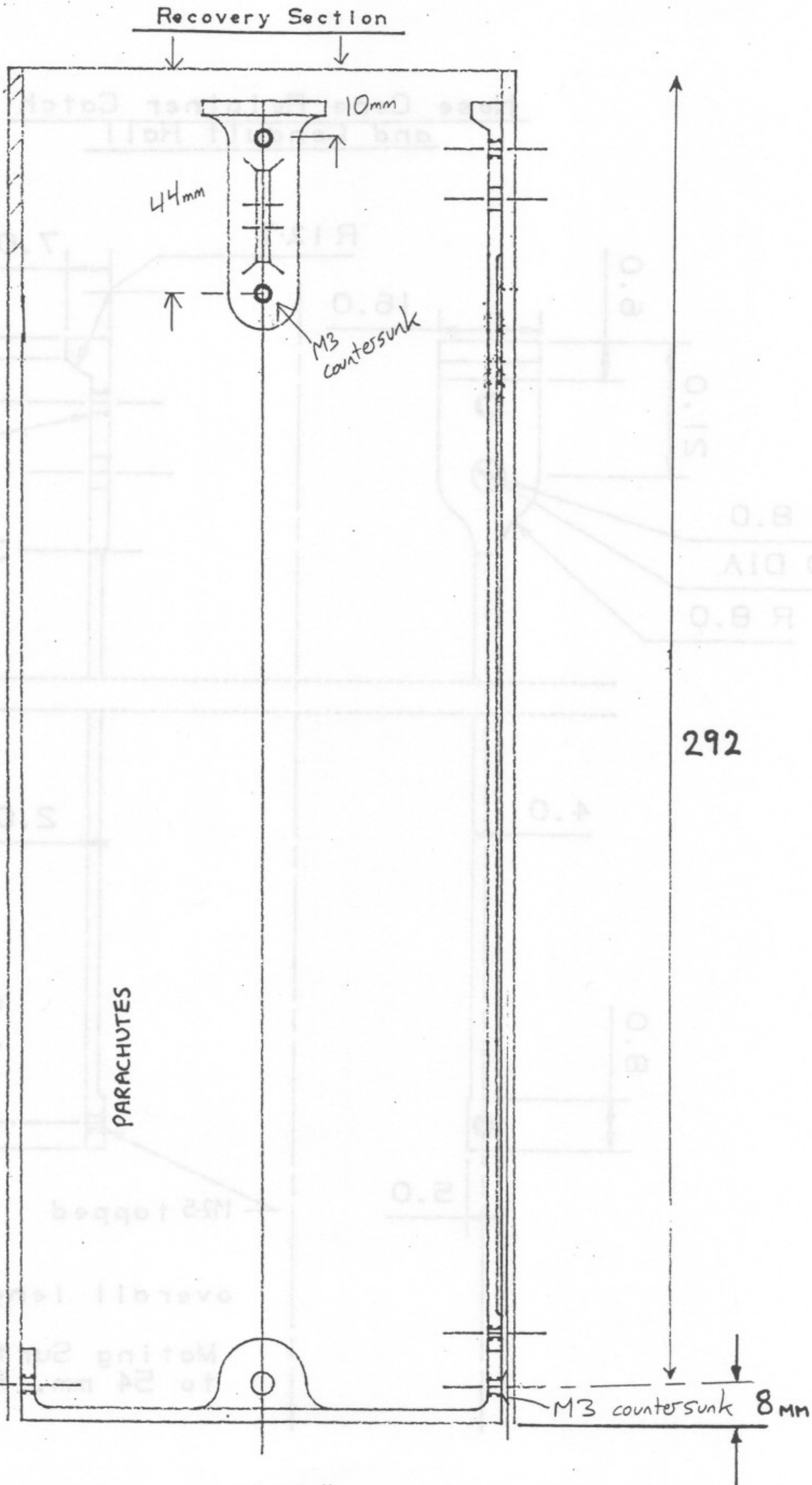

Recovery Section
10mm
44mm
M3 countersunk
292
PARACHUTES
M3 countersunk
8 MM

FIGURE 4

Nose Cone Retainer Catch and Conduit Rail

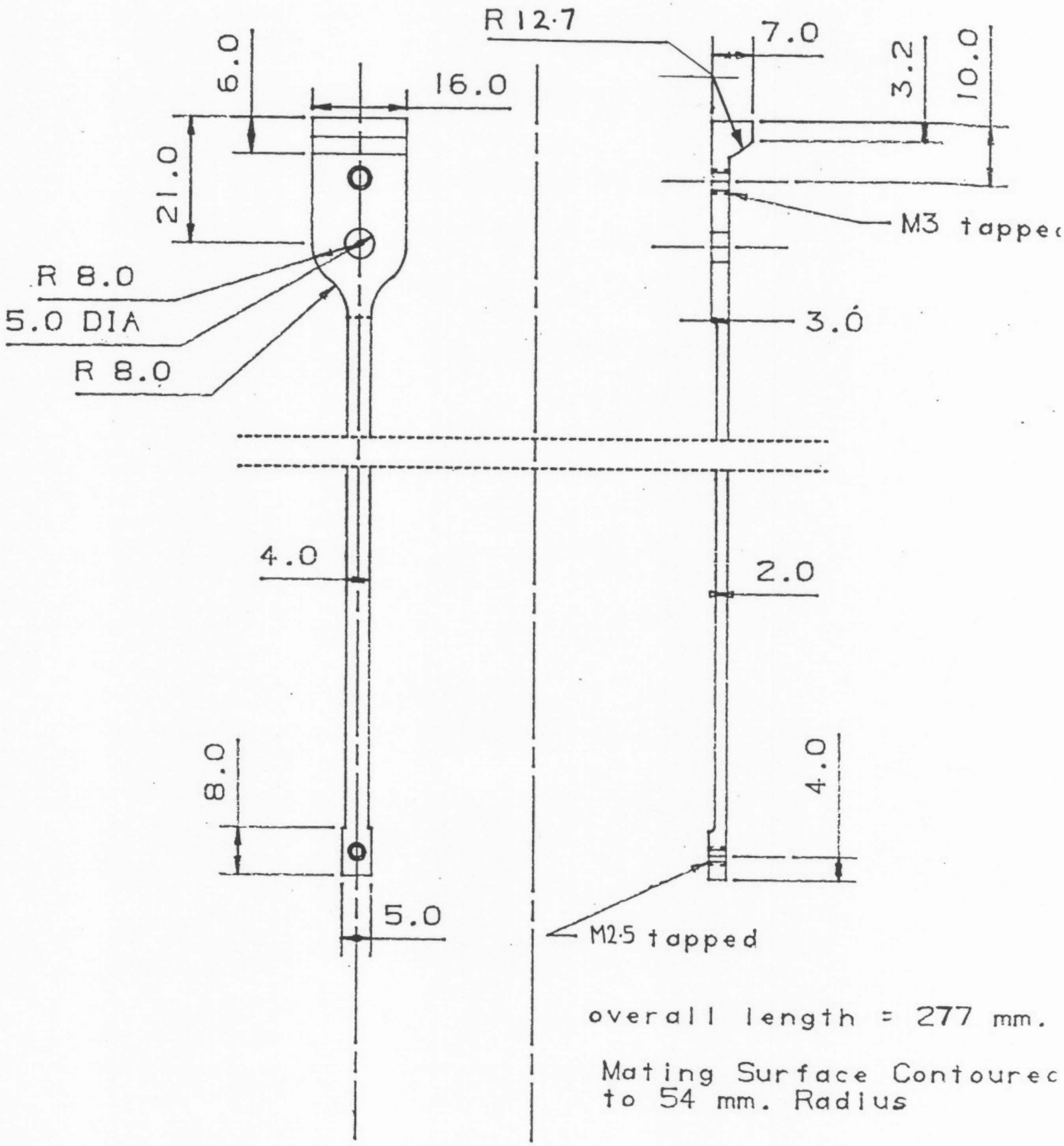


FIGURE 5

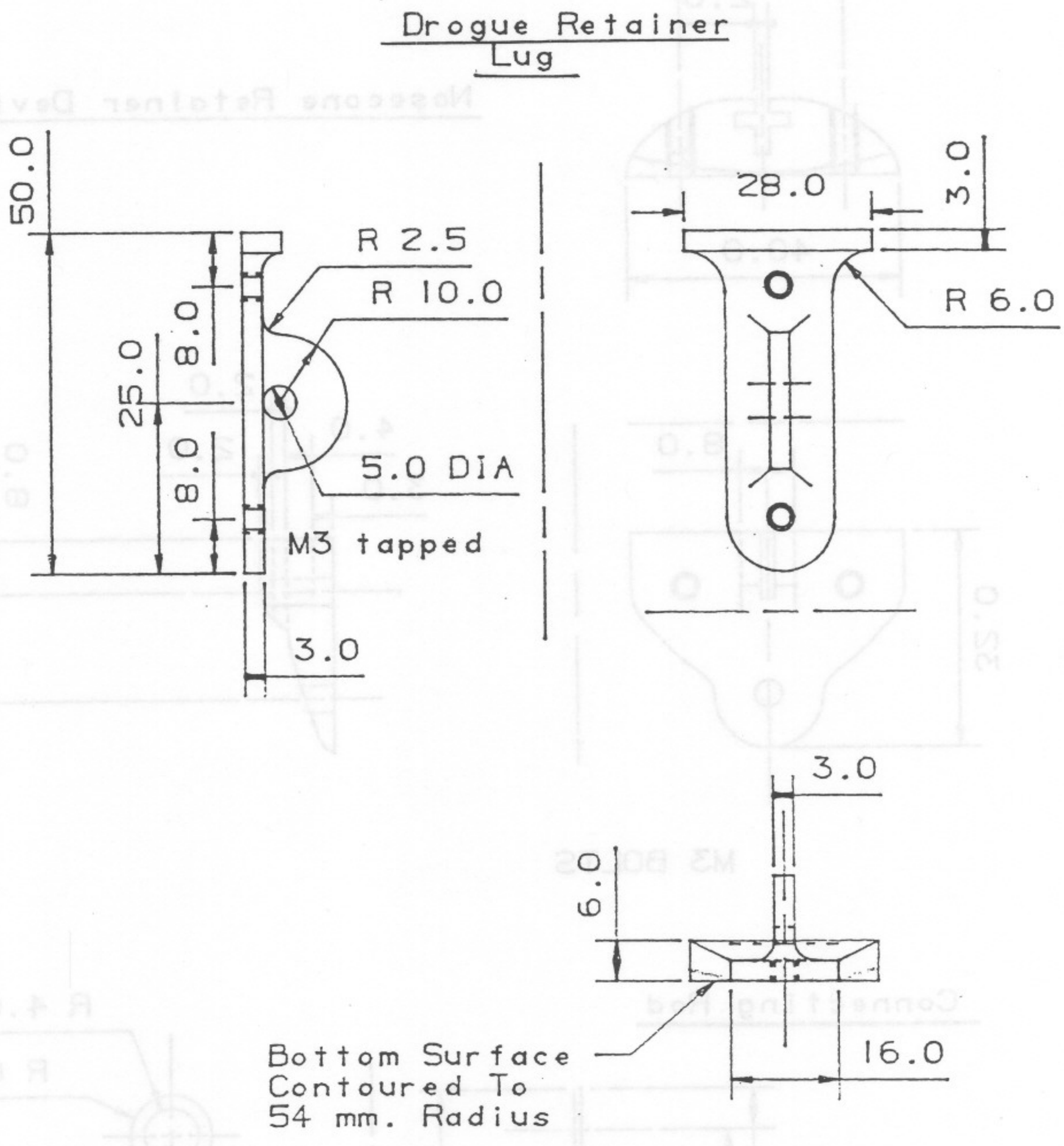
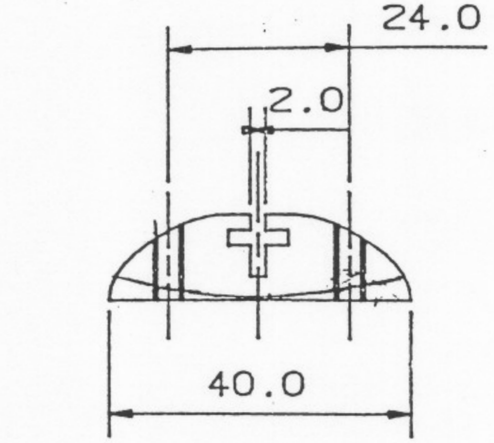
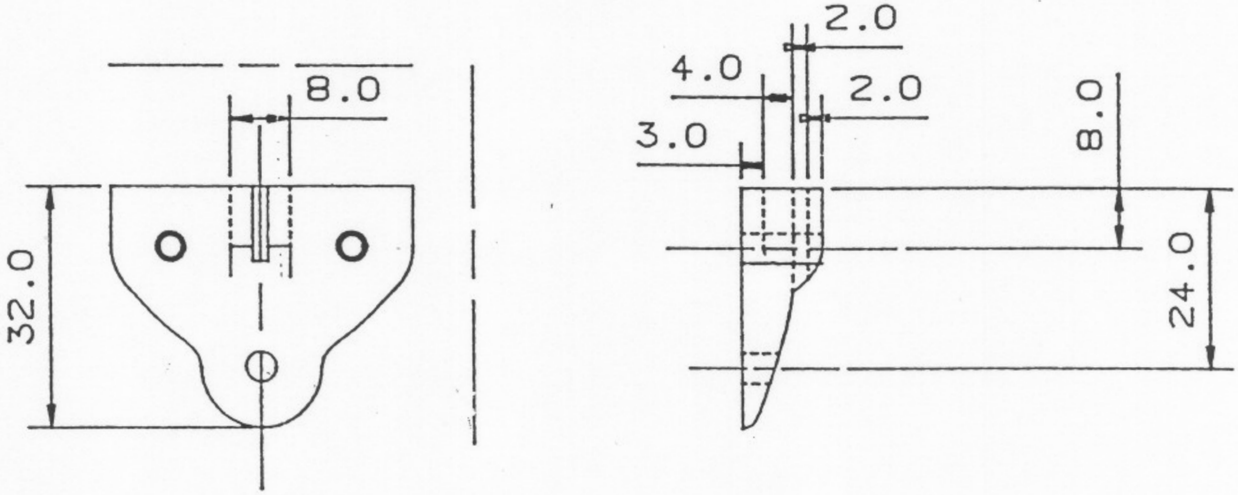

Drogue Retainer
Lug
50.0
25.0
8.0
8.0
R 2.5
R 10.0
5.0 DIA
M3 tapped
3.0
28.0
3.0
R 6.0
3.0
6.0
16.0
Bottom Surface
Contoured To
54 mm. Radius

FIGURE 6

Nosecone Retainer Device





M3 BOLTS

Connecting Rod

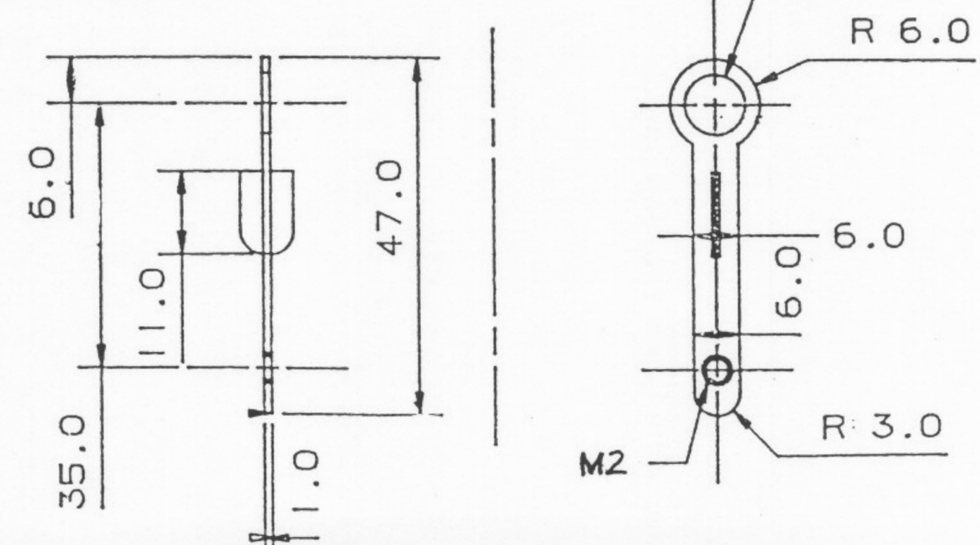


FIGURE 7

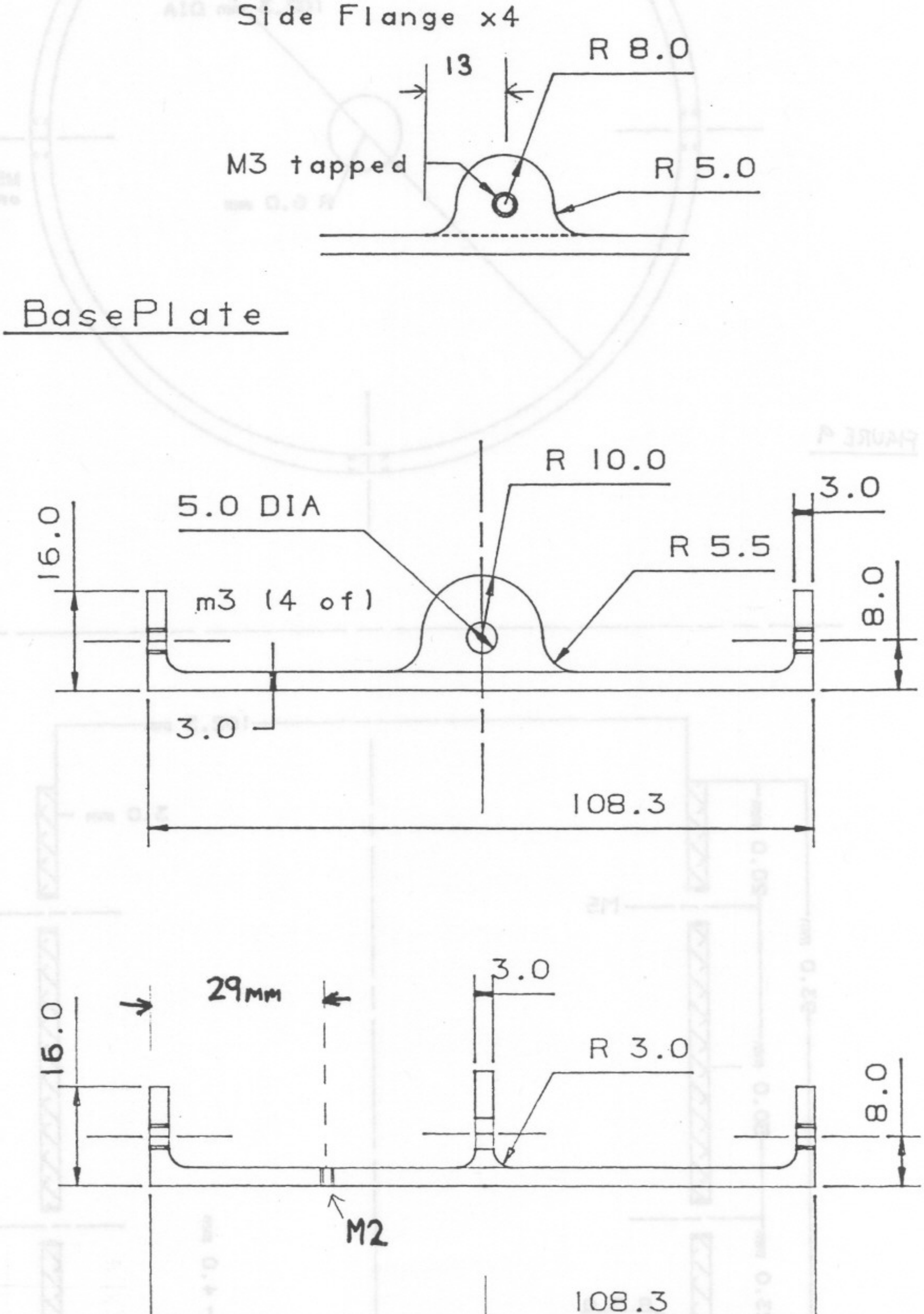

Side Flange x4
13
R 8.0
M3 tapped
R 5.0
BasePlate
R 10.0
5.0 DIA
3.0
16.0
R 5.5
m3 (4 of)
8.0
3.0
108.3
29MM
3.0
16.0
R 3.0
8.0
M2
108.3

FIGURE 8

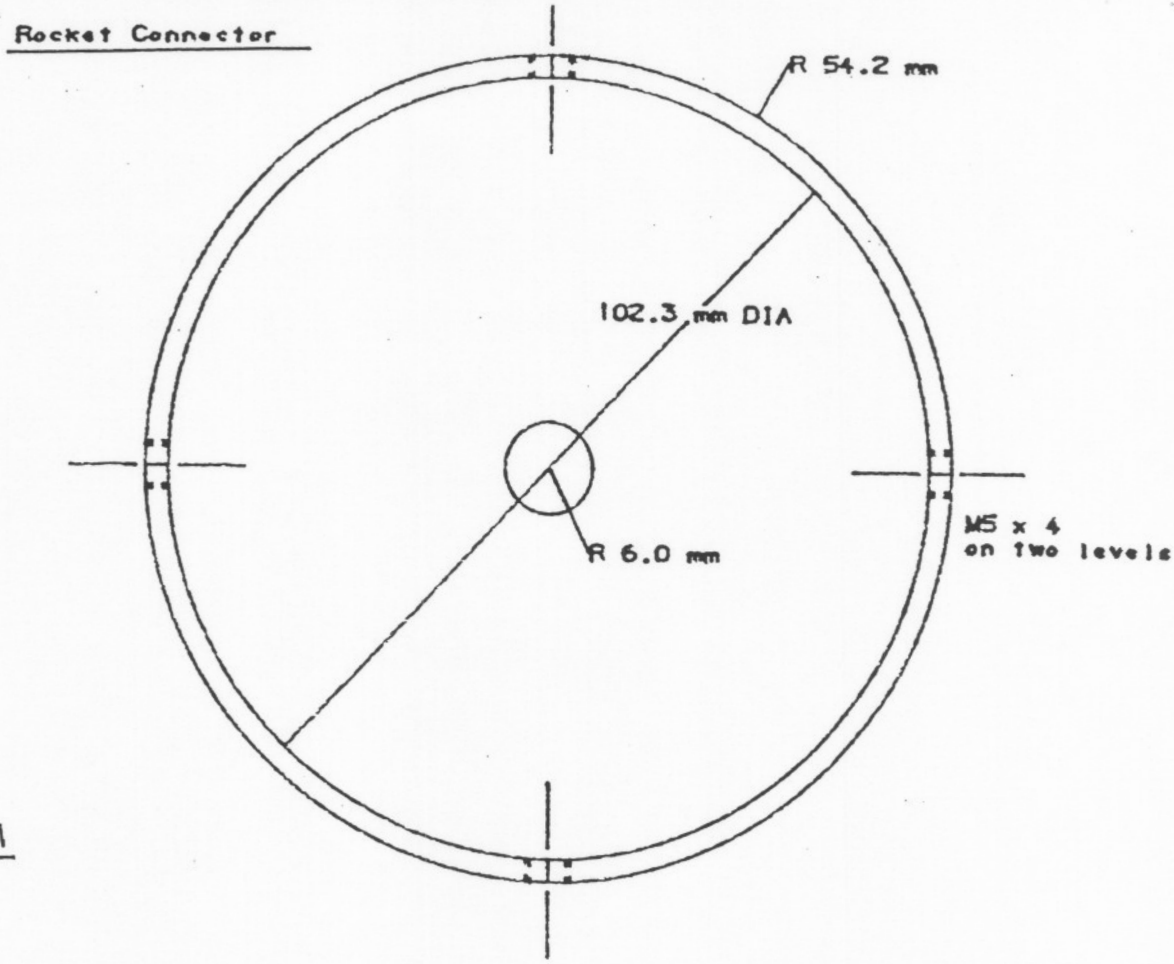
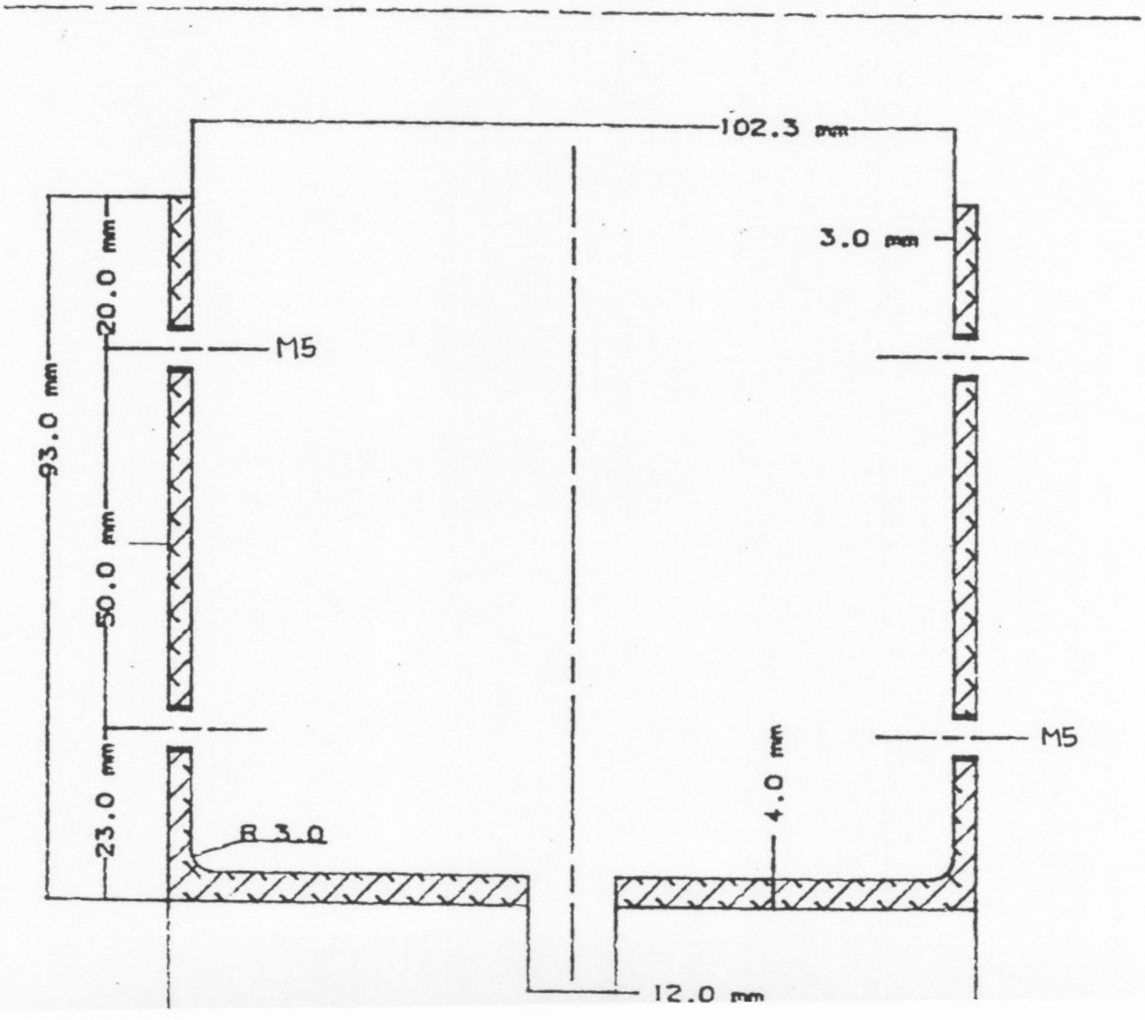

Rocket Connector
R 54.2 mm
102.3 mm DIA
R 6.0 mm
M5 x 4
on two levels

FIGURE 9


102.3 mm
3.0 mm
20.0 mm
M5
93.0 mm
50.0 mm
M5
4.0 mm
23.0 mm
R 3.0
12.0 mm

Rear Fairing

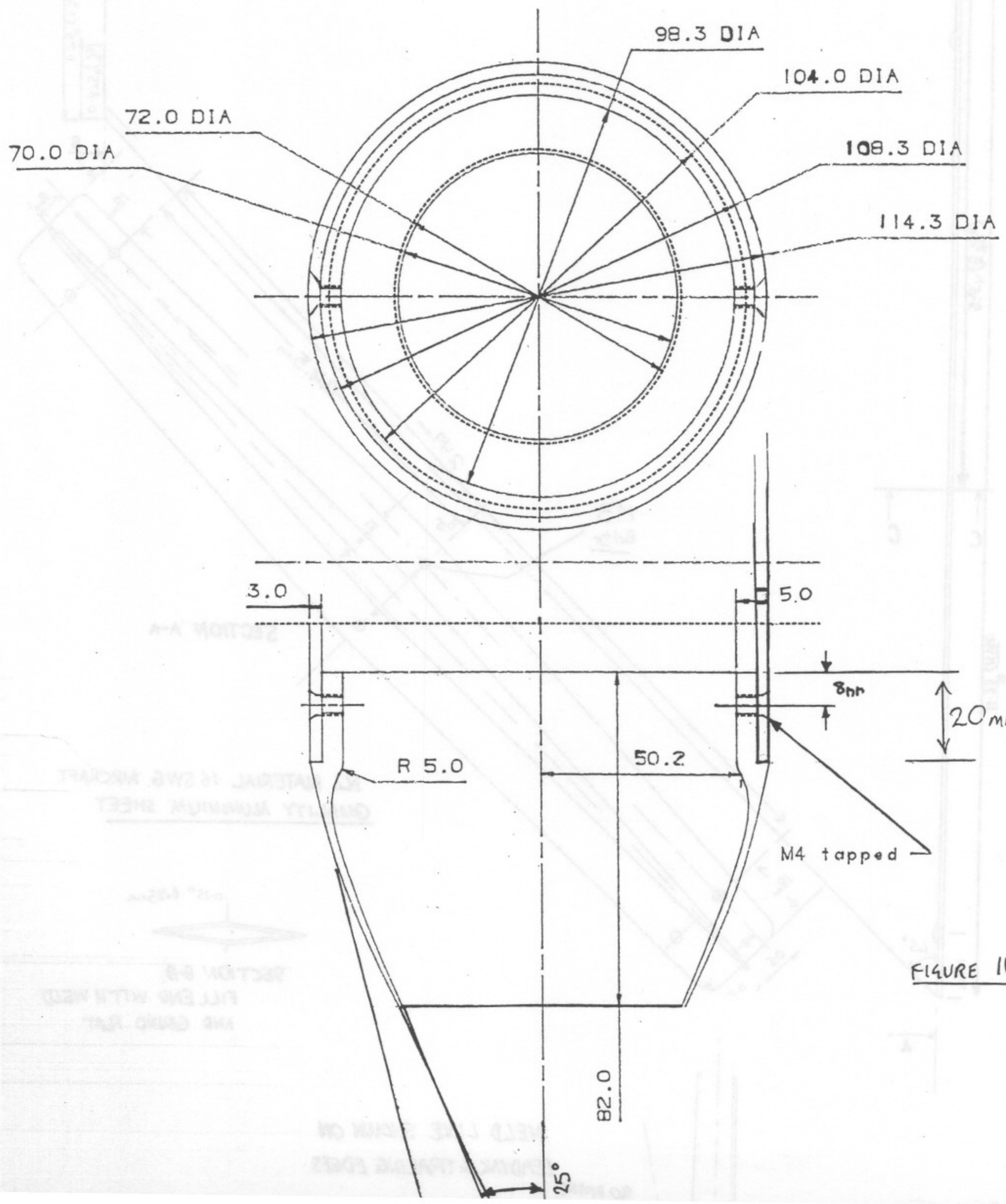
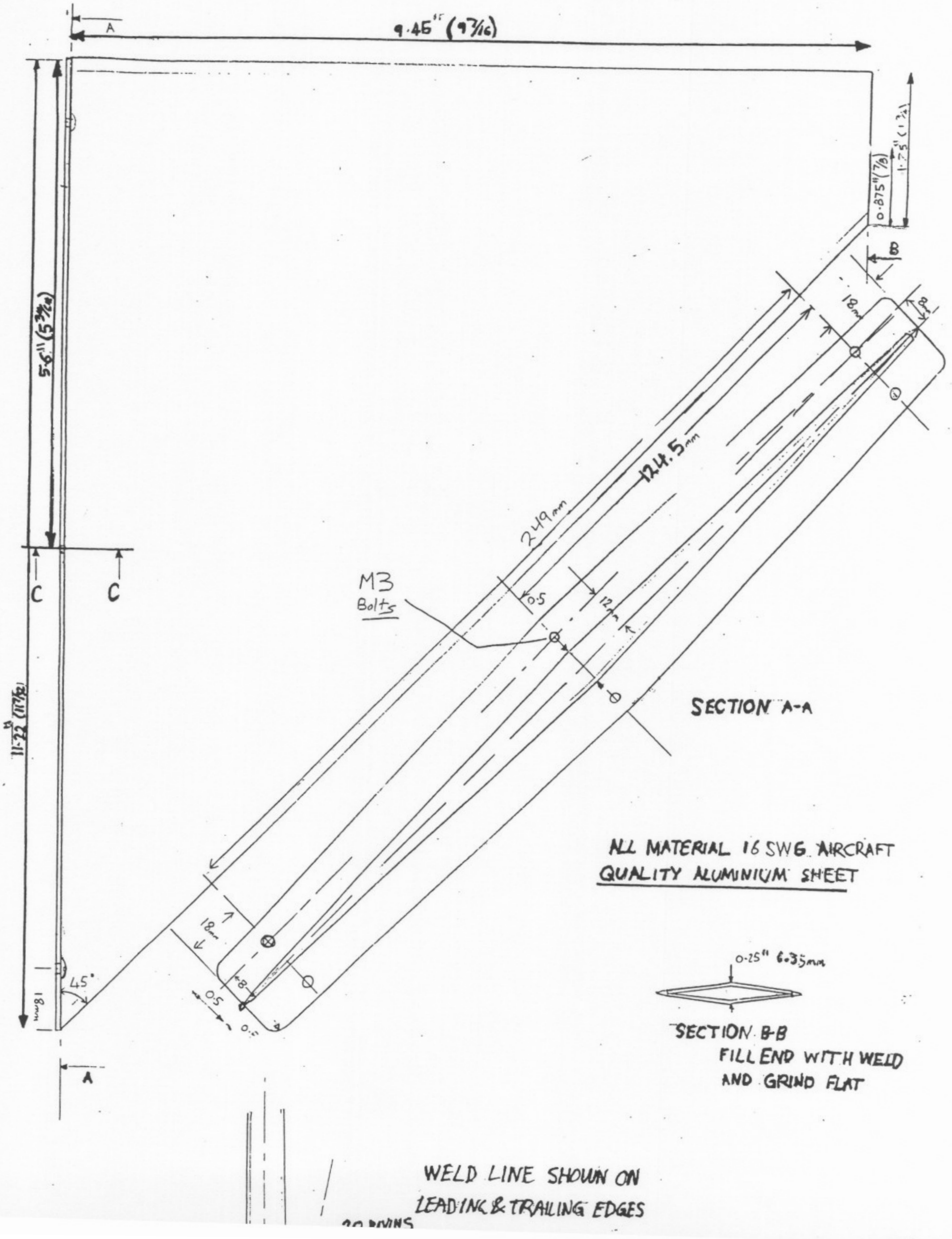


FIGURE 10



SECTION A-A

ALL MATERIAL 16 SWG AIRCRAFT QUALITY ALUMINIUM SHEET

SECTION B-B
FILL END WITH WELD AND GRIND FLAT

WELD LINE SHOWN ON LEADING & TRAILING EDGES

4 Integration and Pre-launch

The remaining days were running out. Everything was on schedule, it had to be, for there was no room for error! Because of this, we had to sacrifice the prestige of developing a few subsystems - namely the 3-D tracking system, and the nephelometer. The information and the designs were there and waiting, but there was a lack of time and manpower to construct them as well as sort out all of the bugs in good time. In retrospect, it was the right thing to do for it is better to get the essential systems fully functioning than to attempt to get only adequately functioning (hence not guaranteed to work under all conditions) all of the systems that you would have liked to incorporate into the vehicle. And so everything was on schedule - not finished, but projected to be completed in time.

The final week had come: a group of 6 set off for Mourmelon in the county of Champagne, France, to be joined there by the others. Once again, the most essential rule: communication is the key to the avoidance of all headaches. The lack of adequate communication between ourselves and the French authorities set us off on an arduous journey. We did communicate, to a venerable extent! Something that the University of Bristol and British Telecom will vouch for. But when documents are exchanged, there is always something extremely important that is forgotten, that only experience can make up for. This was the single most important factor that raised our stress levels to heights previously unimaginable during that week.

On the mechanical side, it all began with motor performance. We were given the news that in the first few milliseconds of burn-time of the motor, the internal explosion - it really could not be called a burn - sets up thrust levels of more than twice the median: many rockets in the past have fallen prey to this shock. In addition we were to be visited by a French-German team who were also using a Caribou powered rocket called DIGIMACH II. They had tales to tell us about the fate of DIGIMACH I, and how the previous year they managed to *launch the motor*! The fate of the vehicle itself (or what was left of it) was a bit more unsightly. These scare stories had their required effect. ASPIRE was adequately strong enough to withstand these horrors but we were adamantly told that ASPIRE would not be passed through the pre-launch safety requirements unless we doubled up on just about all of the load bearing structures. Most of the work done at these events is wholly experimental and based upon experience. Generally, introducing the idea of having tight reserve factors was a totally new concept which was not well received. Nevertheless, we had to comply to interesting degrees. Basically, it was not believed that the fins would survive the launch, but when it is almost possible to suspend an elephant or two from the assembly it does seem a bit overdone.

Then came the problems of motor dimensions. We had been given Caribou diagrams with completely different dimensions in length: the actual motor was exactly 70mm shorter than designed for. In our eyes, this was equivalent to a trip to the moon and back. But then again, such a thing is not impossible to solve: man has gone to the moon. After much joint discussion and theatricals, the decision was made to make a 70mm extension to add to the Caribou so that to the rocket, we have a motor of the design length. Simple to say, and simple to plan, but when one considers a cylindrical block of metal 100mm in diameter and 70mm in length, it pertains to something rather large and quite heavy. Making it out of aluminium would have been tolerable but the plan was to have the French military manufacture it out of steel. Being at this point inseparable from a pocket calculator, the figure of 5Kg suddenly popped up. There is something about this figure that is disturbing for it has now been on two occasions that ASPIRE has requested to be 5Kg heavier than its ideal design weight. Nevertheless, as soon as the authorities grasped the gravity of this situation, things became a bit more reasonable.

In the end, the extension was made out of PTFE which weighed in around 700g. Considering the predicament, this was more than acceptable.

A problem was then encountered which was due to poor communication between the groups and lack of foresight on the part of the design team. Due to the separation between the Universities and the lack of time, a complete fit check had not been carried out. This is something that is essential as the fractions of a millimetre do add up along the length of the body. Allowances for error were designed in, in the motor section, which gave us the much needed freedom to strengthen up on the fins. However, this philosophy was not carried through to the systems section where tolerances were very tight. The resulting squeeze did much for the overall rigidity but not much for our sensibilities. In the end, it resulted in every bit of available space within the vehicle being used (as was designed for) but in essence leaving no room for error. In fact, that was the end of the mechanical adventures, luckily enough, as we were fast running out of mental tolerance if not design tolerance.

The other systems also held their own adventures. Kent had a battle with an infestation of bugs, some of which displayed their own form of intelligence in the counter-attacks, and grounding problems caused failures of the tape recorder and a microchip in the pressure sensor. But in the end the essentials were functioning. Many lessons were learnt. One comment from the group that basically challenges the entire theory behind electronics is that electronics run on smoke. This we have demonstrated: for if smoke evolves and escapes from the device, it suddenly ceases to function. Thus it may be inferred that electronics run on smoke. QED. This was one of the many jokes that kept us going throughout the week.

The Bath team had a different story to realise altogether. It can be attributed to the severe lack of manpower, the very unfortunate supply of faulty electronic components and the poor communication of essential principles which in retrospect, having the experience of encountering them, seem blatantly obvious. At the campaign, there are a significant number of safety requirements which must be met before any permission whatsoever to fly is given. One of the most important, since we are working with high explosives, is the pre-launch sequencing of all of the on-board systems. The system we had was adequate and functional, but we could not guarantee its safety and security under all conditions. Therefore, we had to implement these safety requirements mechanically into the electronics which was not an easy task, thus the all-important parachute inflation would be performed by hardwired electronic back-up timers, as was the camera triggering. An unfortunate side effect was that the completion of the telemetry suffered. In the end, it was sacrificed in order to be ready to launch on time, with the intent that all of the data would be recorded on board, despite late-night work by the team. This was something which eliminated the redundancy which we were later to regret heavily.

5 Flight Results

On a nice, warm, sunny French Sunday morning, the 26th of July, with absolutely no time to spare, everything was completely ready. The motor and sections were assembled for flight and the pre-launch began. With a little Saki from our new Japanese friends to steady the nerves, everything went smoothly. With all the indicator lights showing GO FOR LAUNCH, the final minutes disappeared. As the final seconds approached, there was the silence of death among the crowd. We were warned that the launch would be incredible but were not prepared for what occurred.

Essentially, at zero hour, with the push of a button, from the launch pad there came an explosion. ASPIRE leapt out of the tower and screamed towards the heavens before disappearing from view. The hush continued until at the predicted time of apogee, the call came from the visual tracking stations that the parachute had opened...cheers and applause from all directions, only to be augmented about 20 seconds later by the eerie sound of a missile accelerating towards terra firma. This could mean only one thing, but, what had happened ? The parachute had opened, but, we had had a ballistic flight.

5.1 Time Breakdown of Flight

T = time after launch.

At T = 0s:	Angle of inclination = 70 degrees (to horizontal). Conditions - light wind, hazy sunshine. Onboard control systems initiated. Launch initiated.
At T = 3.0s:	Altitude = 700m (approximately). Sound barrier broken.
At T = 3.2s:	Maximum velocity attained.
At T = 3.5s:	Motor burnout. Subsonic ballistic trajectory.
At T = 24.5s:	Apogee point achieved. Altitude = 4Km (approximately). Drogue parachute deployed. Horizontal velocity = 100m/s (230mph) (approximately).
At T > 24.5s:	Main parachute deployment at speed. Parachute mooring failure. ASPIRE follows ballistic descent.

At T = 50s: Distance downrange = 2.2Km.
Terminal velocity = 240m/s (approximately).
ASPIRE impacts on ground.
Penetration depth = 0.66-1m (approximately).
Systems section is obliterated.
Motor section is undamaged.

Note: performance figures and times are calculated from expected performance of the rocket and motor, thus they are not necessarily accurate.

5.2 Flight Analysis

After all the calculations and simulations, what could have caused this unfortunate result? The answer was to come the following day when the vehicle was recovered. The rear motor section and fins were all completely intact, but the front systems' section had been crushed into oblivion. All data and photographs had been lost. A significant proportion of the system electronics had melted indicating that the heat generated on impact had been immense. The surrounding clay had been heavily compacted and scorched from the heat. But, there was sufficient evidence there to allow us to competently speculate on what had happened. Inside the wreckage, there was a badly mangled length of Kevlar having one frayed end. The other was still attached to its rapide link and what was left of the rocket body. There was no sign of the parachute, the drogue, or its retaining assembly. This indicated that the parachute did deploy as reported. But why did the drogue assembly not perform its job ? We can attribute this to one single factor:

Our request was for a near vertical launch, necessarily at 85 degrees inclination. This would give an apogee speed of around 60mph. The inclination that we were given was conveyed to us as the launch tower, ASPIRE within, was being raised: the inclination was 70 degrees. Under the circumstances, we were in no position to competently assess the ramifications of this, to our demise. The difference in apogee speeds, owing to the way that sine curves behave at these near vertical angles was significant. Theoretically, the apogee speed was of the order of 230mph. The resulting shock forces due to the deployment of the nosecone and drogue tore out the retaining assembly (which was stressed to half a metric tonne) which prematurely deployed the main parachute at speed which consequently failed its mooring. The activity at altitude would have been spectacular. A now aerodynamically clean and very ballistically stable ASPIRE continued it journey minus parachute which was left behind at the 4Km deployment altitude. Terminal velocity was calculated at 240 m/s (500mph) and the impact deceleration over the metre of penetration into the very hard sunbaked French terrain, in excess of 2880g.

5.3 General Results

The lack of telemetry system meant that all data had been lost, unfortunate, because it would at least have been some tangible result of the flight and given evidence of the successful operation of the payload. However, upon dismantling the crushed payload the roll of film was found, though in very poor condition. When measured it was found to be just 118cm long - some 20cm shorter than a test film taken before launch: it was reasonable to assume that some 5 frames had been taken.

Considerable effort in developing the crinkled wreck of a film resulted in one recognisable frame. Though overexposed it was sufficient to make a black and white print in which the fields and roads of the Mourmelon launch site were visible and thus 14 months after starting the project proof had been found that the payload had operated correctly.

Costs of the project:

CNES Caribou rocket motor	£1378.00
General expenses	£63.10
Launching campaign expenses	£936.72
Total	£2377.82

The above cost was met by the combined donations of Serco Space Ltd., Bristol University and personal contributions from the teams. Other costs (i.e. manufacturing and materials) were met by the sponsors and universities carrying out the work.

6 Conclusions and Recommendations

We had lost all of our valuable data, and had practically physically destroyed a years labour, but we had and still have reason to celebrate. In a year, we managed to link the talents of inexperienced students from four British Universities. We encountered just about every problem imaginable: money, communication, organisation, inexperience, time schedules and limits, design, manufacture and integration. But above all, we persevered and accomplished the goal that we had defined: to build a state of the art supersonic research rocket and with it, enter Britain into the world arena.

Although there is no substitute for the actual experience, the closing pages detail some of the lessons that we have learnt over the course of the project.

6.1 Parachute

Every study and every worst-case scenario must be done to ensure that the vehicle will survive the extremes of the flight envelope. This is what we neglected to do fully. The design we had was for a specific condition of flight and we did not consider the probability of this condition ever changing. Like all projectiles, there is a significant horizontal velocity at apogee and if any high speed deceleration is required, then we need to guarantee a full-proof system.

For example, when a parachute is used, if you perceive that its deployment will be at speed, then a system needs to be used so that there is a speed reduction before deployment: airbrakes for instance or a drogue stressed for high speed deployment. Also, a method of destroying the aerodynamic cleanliness of the vehicle by separation of sections might also be a solution. An experienced German rocketeer had told me that the most important system on a rocket is the main parachute. The second is the reserve. In America, there has been a significant amount of problems with man-made fibres used as moorings for parachutes. Groups from the U.S.A. have resorted to steel chains and cables which can take the shock loads imposed more securely. Nylon has also posed a problem. A Canadian team at the event had a fairly thick section of nylon line snap cleanly as a result of the shock loads on the parachute. If nylon is favoured, then one could possibly consider the undrawn variety as used by mountain climbers.

6.2 Sponsorship

Money along with hard labour, keeps a project alive: sponsorship is thus essential. Our difficulty was that while looking for donations of money, the country was in the midst of a recession with little sponsorship to give. Luckily, Serco Space and the University of Bristol, along with the myriad of others, came to continually rescue the project from certain demise.

The act of finding sponsorship is a long and trying process. It needs to always start at the beginning of a project.

6.3 Modularity

The modular approach to system design is a fantastic idea, especially when you are working with four different groups. The idea of integrating the talents of four different groups of students is a very formidable task indeed. The division of the problems into autonomous sections facilitated their ease of progression.

However, all groups should at least know of each others progress and problems. Thus if opinions and suggestions or aid is possible, then it can come to light. This we found out when we realised that Cambridge would have been very capable in assisting Bath.

6.4 Assembly And The Use Of Hatches

One design philosophy which in retrospect we should have considered more closely, was the use of hatches. But with our design philosophy, the use of hatches would far more complicate the design. They would also quickly introduce redundancies as allowances in the load bearing shell for holes would play havoc with the stress distributions. It was thus decided to find a way, almost at all costs, to design without the use of hatches. The use of the hatch deployment for a parachute does hold a few problems which our method of top ejection does eliminate and is thus a superior method. But for the other systems, the price paid for mechanical simplicity was in the facility of system access within the rocket.

The lesson learnt was that the integration or assembly and access to one system should have as little a bearing as possible on the position or access of another system. For ASPIRE, we had to assemble the systems together and then slide the internal skeleton into the load bearing shell. Once assembled, the effort required to access a certain part was considerable. When one considers the ease of assembly, one should also consider the ease of disassembly.

6.5 Motor

Always confirm all measurements. It is essential to guarantee that there are absolutely no problems at all with the most important component of one's rocket. A used casing or a full-scale model to perform adequate fit checks to determine any size or assembly anomalies weeks before the event should at least have been used.

6.6 Logistics

One of the most important considerations, especially when one is entering as part of an international event, is to familiarise oneself extensively with the safety requirements imposed at the event. In order to make the entire process proceed as cleanly as possible, one must find out what particular safety requirements are important in your case, making a comprehensive check-list, and ensure that they have all been allowed for.

We were understandably stretched for time and were unable to comply with the recommendation. As obvious as it sounds, the critical nature of the consequences do not become apparent until you have experienced the 'What if?' first hand. In truth, long before the week before launch, one must have had everything assembled and **fully** functioning. The word fully must be stressed as it does save a good deal of unnecessary stress during the final furlong of the race. Whilst some people can work miracles under stress, the situation is not at all good for the coronary system.

One must at all times be realistic and practical. Quite a few subsystems under development, never had their chance to perform. We had under design a Nephelometer (the concept was to measure atmospheric particle densities, using the same principle that numerous planetary probes had) and a three-dimensional radio tracking system. Both of these were feasible but unfortunately victims of time. One of the most elegant concepts of the programme was the design of the aerial. Having a metallic body had the effect of giving us the problem of where to put our transmitting aerial. One could run braced cables between supports along the outside of the rocket but this would have had an unfavourable effect on the aerodynamics of the rocket. The idea was that, owing to the fact that the rocket was a metallic body in two sections of almost exactly one wavelength in length, one could electrically insulate the top from the bottom half and therefore form a dipole. Ingenious in its concept, but in simplifying the aerodynamics, one complicates the design of the interface. In the end, the trade-off in the time scale we had available was just too great!

There is just no substitute for experience. If you are attending an event, it is very wise to get first hand advice from someone who has been there before. Speaking with John Pitfield of Spacecats, in Dorset and Nigel Parry-Jones of British Aerospace in Filton, Bristol had been invaluable in preparing us for the actual conditions at the site. Without this information, we would never have launched - better still, the ideal way to learn is to go there.

One of the lessons of this project that has most impressed upon us is that as a group, we lacked the arrogance of knowledge. This prompted us to be as direct and as plain as possible in the action of requiring the invaluable aid of those more experienced. What we were doing in Britain had never been done before at our level. We knew that in order to succeed, there was a good deal of work to be done, none of it ever simple. This is one of the reasons why we were able to achieve so much in so little time.

In this, try to communicate with as many people as possible who have done things before that you are trying to achieve. This will provide insight on how to best approach a problem rather than make the same mistakes as they did.

Even now, with all of the experience we have learned, we still know only a small portion of the entire field of rocketry. What we have learned is that there is still much to learn.

6.7 Recommendations for Rocket Electronics for future projects

Many lessons we learnt on the ASPIRE project by the flight controller (Bath) team some of these are outlined below and anyone considering undertaking the construction of electronics systems for future project should read this, share our experience and learn from our mistakes instead of repeating them.

Sequencing, parachute release and timing

1. For parachute release, though it would be preferable to abandon timers altogether, using electronics altimeters (pressure sensors) and accelerometers, timers are in fact the simplest and most reliable means of releasing a parachute at the right point in a rocket's flight. As long as a reasonably good prediction of apogee time is available, there is no reason why timers should not be as accurate as other means. ASPIRE's flight controller released its parachute right on time. It was just the velocity of the rocket which causes it to crash.
2. The parachute release timers and circuits should be TOTALLY AUTONOMOUS from the rest of the electronics and have their own power supply. They should be placed on a separate circuit board.
3. The timers should be based on accurate, reliable discrete digital or analogue circuitry.
4. The parachute timers should be able to be tested, calibrated and operated easily from a hatch or window in the rocket tube and should have easily visible status indicators (eg LED's).
5. The parachute timer circuits should reset themselves on power-up. A big problem we had with ASPIRE was that 555 monostables trigger themselves on power-up. This fact was unfortunately neglected. It was not until we came to the launch campaign that we discovered the dire consequences of this - actuators being fired as soon as we connected the power - which had to be remedied on site.
6. Switches should be included which totally isolate the parachute actuators from the timers while power-up or calibration is carried out. Ideally these switches should also short the actuator leads together as a precaution against static.
7. The parachute timers should have a simple and accurate means of programming and calibrating the release time as well as some accurate means of predicting the required time settings, eg a computer simulation of the flight.
8. The parachute actuators must not be powered from the same supply as the timers. The actuators (especially pyrotechnic ones) will cause spikes which could reset or disrupt the timer. If more than one parachute or actuator is used, each should have it's own firing supply battery. A small PCB mounting NiCad (memory back-up type) is suitable. If more than one timer is used these may share a common supply.
9. The parachute timer and actuator batteries must be in top condition before launch. This may be insured by the use of ground-power and the use of brand-new or freshly recharged batteries.
10. The timers obviously need to be triggered when the rocket launches. The simplest way of doing this is to either detect the absence of ground power, as was done with ASPIRE (as the umbilical rips-out on launch) or use a wire which breaks on launch. Don't use optical techniques or accelerometers. These devices are too complicated and unreliable.
11. KEEP IT SIMPLE
12. Build the circuitry ruggedly. Use a PCB rather than veroboard. Take care with soldering.
13. Use good quality components.
14. Test the design and the finished product thoroughly.

15. The parachute release circuits should be developed as early as possible in the project. The rocket can't fly without them !

Digital Telemetry

1. Though we invented our own PCM type encoding format, it would be sensible to use standard asynchronous serial format at a standard baud rate. This means that use can be made of standard microprocessor serial interface chips or a microcontroller with a built-in serial interface.
2. To encode data stream into a suitable form for transmission, frequency shift keying (FSK) was recommended by other groups at the Launch Campaign. It is easier to decode in the presence of the large changes in received signal strength that occur when a rocket takes-off. Standard modem chips could be used for this.
3. The IBIS transmitter uses AM. However, FM would give even better results with large signal-strength changes. It would be worth experimenting on a system which uses the serial data stream (see 1) to directly FSK the carrier. Reception and demodulation could be achieved by use of the Costas type receiver as used in radio pagers. This system would be much simpler than other types, eliminating the need for modem chips, encoders or high-power amplitude modulators. However, the ANSTJ reception facility could not be utilised as it receives only AM signals.
4. Aerials - aerials on a rocket, especially a metallic one, are a problem. This is aggravated further in the case of supersonic vehicles as every protrusion creates a shock-wave and increases drag. A simple helical or whip antenna inside or protruding from the nosecone would seem to offer the best solution for most situations. We could not make use of this, however, due to the fact that the nosecone had to detach from the rocket.

Power

1. The use of ground-power is recommended. It prevents drain on internal batteries until the moment of launch - a useful facility in the event of a delay in the count-down.
2. The performance of the nickel cadmium AA cells was entirely satisfactory and NiCads seem to provide a good power to weight ratio. Lithium batteries were considered, initially, because of their impressive power to weight ratio. However, legal restriction on their shipment and other safety factors prohibited their use.

7 ASPIRE II - An Introduction

ASPIRE II is a follow-up project to ASPIRE, building on the experience learned and involving some of the original team, mainly James Macfarlane. It was launched on May 8th, 1993 at Imperial College, London, by Project Manager Philip Dembo of UKSEDS, with a call for interested parties to come forward. It is not intended to be just a single rocket launch but a whole organisation to support a development program for rocket and space-flight technology. Our initial goals are outlined below, though they are constantly being up-graded as the project is still in its infantile stages.

Summer 1994 : Launch of a small rocket, of a similar or slightly greater size than ASPIRE, to test various technologies being developed for the next launch :-
Summer 1995 : Launch of a rocket of much greater size, speed and sophistication than ASPIRE I, using new propulsion techniques i.e. a hybrid motor, and carrying a scientific payload of some kind.

These rockets and their sub-systems will be developed in a modular fashion by the Launch Vehicle section of ASPIRE II.

Meanwhile, other sub-groups of the ASPIRE II team will :
1. Research and develop new propulsion systems for use with the rockets described above.
2. Plan scientific research programs and develop payloads to fly on the rockets.
3. Provide administrative, financial and management back-up for the ASPIRE II program.

7.1 Progress To Date

1. We are collaborating with a research project underway at Bristol University to develop a hybrid rocket motor (i.e. one that uses a solid fuel and a gaseous oxidiser). This is the only hybrid rocket research going on outside the USA (to our knowledge) and initial results are very promising. The ASPIRE II program will provide the first actual flight-test of this motor.
2. The design process is well underway for our first launch vehicle.
3. Interest is growing and some very prominent people and organisations have shown immense interest and enthusiasm for ASPIRE II.

7.2 Objectives

1. We are going to do some original scientific and technological research. The exact direction we take towards this end is not yet fully defined, but possible areas of exploration are :

a) Rocket motor technology, eg hybrid motors.

b) Waveriders - a fascinating type of hypersonic (Speed > Mach 4) vehicle that `rides' on a shock-wave.

c) Single-Stage-To-Orbit (SSTO) vehicles & Space-Planes.

Many more new areas for research will open-up as the program develops.
2. To put Britain back on the space-flight map ! (Though we are looking into collaboration with groups from other nations, too).

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There are many more, and those who have contributed have been remarkable...

9 References

1. P. Buddington, G. James, G. Kennedy, P. Miller and C. Piper ' The World-Wide ISY Student Payload Launching Campaigns; Part 2 - Curriculum Enhancement, Safety Assurance and Participation in North American Events' IAF-91- 516, Montreal, Canada 1991.

2. M. Zirnheld, P. Beaudou, G. Pignolet, H. Grundler and H. von Muldau 'The World-Wide ISY Student Payload Launching Campaign' IAF-91-515, Montreal, Canada, October 1991.

3. M. Combier ' Principle du codage par multiplexage en frequence' ANSTJ Note Technique 3.

4. M. Combier 'Multiplexage en Frequence: le V.C.O. a circuit integre LM566' ANSTJ Note Technique no.24.

5. B. Ragent, T. Wong, J. Blamont, A Eskovitz, L. Harnett and A. Pallai ' Pioneer Venus Sounder and Small Probes Nephelometer Instrument' IEEE Transactions on Geoscience and Remote Sensing , Vol. GE-18, No.1 January 1980, pp.111-117.