NASA-CR-197174

Excellent - Heat exchanger ... control altitude well done but incomplete. This entire section of the report is quite ... Gondola design and cooling incomplete. ... conceptual with but limited design - should have been more. Design of entry vehicle pretty good - a lot of stuff considered and looks OK but many jumps made with little justification.

Venus Cloud Bobber Mission: A Long Term Survey of the Venusian Surface

NASw-4435

James Wai
Cheryl Derengowski
Russ Lautzenhiser
Matt Emerson
Yongho Choi

Engineering Mechanics 569
University of Wisconsin-Madison

May 9, 1994

IN-91-CR
26158

(NASA-CR-197174) VENUS CLOUD BOBBER MISSION: A LONG TERM SURVEY OF THE VENUSIAN SURFACE (Wisconsin Univ.) 121 p
N95-12533
Unclas
G3/91 0026158

ABSTRACT

What is this?

~~As requested~~, we have examined the Venus Balloon concept in order to further develop the ideas and concepts behind it, and to creatively apply them to the design of the major Venus Balloon components. This report presents our models of the vertical path taken by the Venus Balloon and the entry into Venusian atmosphere. It also details our designs of the balloon, gondola, heat exchanger, power generator, and entry module. A vehicle is designed for a ballistic entry into the Venusian atmosphere, and an atmospheric model is created. The model is then used to set conditions. The shape and material of the vehicle are optimized, and the dimensions of the vehicle are then determined. Equipment is chosen and detailed that will be needed to collect and transmit information and control the mission. A gondola is designed that will enable this sensitive electronic equipment to survive in an atmosphere of very high temperature and pressure. This shape and the material of the shell are optimized, and the size is minimized. Insulation and supporting structures are designed to protect the payload equipment and to minimize mass. A method of cooling the gondola at upper altitudes was established. Power needs of the gondola equipment are determined. Power generation options are discussed and two seperate thermo-electric generation models are outlined.

TABLE OF CONTENTS

DIAGRAMS

TABLES

VENUS CLOUD BOBBER MISSION PROPOSAL

SYSTEM DESCRIPTION

An entry vehicle and survey package are proposed for a scientific expedition to Venus. The total mass of the vehicle and package is 157 kilograms (345 pounds) and has a total volume of 0.179 cubic meters (11040 cubic inches). The entry vehicle will be attached to a spacecraft bus that could possibly carry multiple probes of this same configuration. The entry vehicle is a trimmed blunted cone of half-angle 45 degrees with a base radius of 19 inches and a bluntness ratio of 1/2. An AVCOAT 5026 heat shield of thickness 2.81 inches protects a titanium aeroshell of 0.164 inch thickness. Inside the entry vehicle is a survey package with a total mass of 89 kilograms (196 pounds) which consists of a dual balloon system, a science gondola, and a heat exchanger. The cigar shaped polyethylene balloons carry hydrogen as the primary gas and R30 as the phase change material for a cylindrical aluminum heat exchanger. The balloons have a mean radius of 2 meters (79 inches), thickness 4 mils, and combined height of 22 meters (866 inches). The heat exchanger is 0.3117 meters (12.27 inches) long and the diameter is 0.2286 meters (9 inches). It serves as altitude control for this survey package, as an unmodified dual balloon system would reach an equilibrium height. The maximum range of the balloon system with the heat exchanger is 64 kilometers and is attained three hours after deployment from the entry vehicle. The gondola is a single titanium sphere of radius 8 inches and thickness 90 mils. It has fibrous aluminum-silica insulation on the inside of thickness 1.41 inches. Power is generated by a smaller scale heat exchanger, and is used to run the camera, sensors, and communications equipment onboard the gondola.

WHAT HEIGHT?

THE BALLOON'S PERFORMANCE IS NOT DESCRIBED SATISFACTORILY

MISSION OBJECTIVES

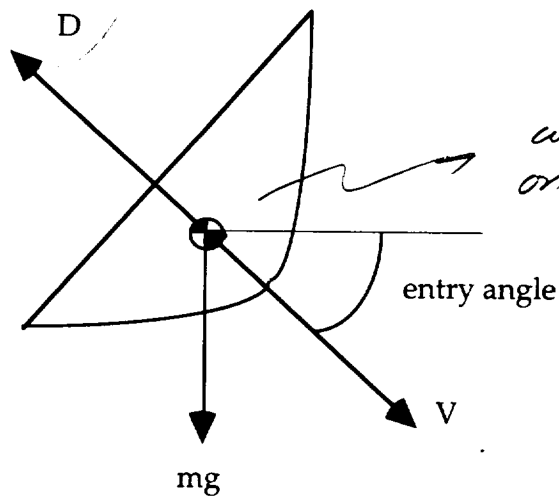
The primary goal of the mission is long term observation and measurement of the low altitude properties of the Venusian atmosphere and terrain. Other possible science returns include the study of wind variation by time of day and season, evaluation of gondola decay due to acidic exposure during ascent and descent through the cloud layer, and a precedent setting design that could be used for surveys of all planetary atmospheres. Adaptations of the basic gondola design would allow surface sampling missions and passive horizontal flight control. The mission is desirable because of its lightweight design, which reduces payload costs. The mission also offers the prospect of a repeatable design, where several of these survey packages could be produced, reducing the high cost of producing a unique one shot package.

Entry Methods

The simplest method of entry was chosen for study. The ballistic entry is a trim, minimal heat trajectory characterized by a constant angle of entry, four basic equations of motion, and good closed form solvability (Weisel). It is required that the vehicle have negligible or zero lift, or skipping may occur. A skip entry is characterized by an entry vehicle that pulls out of its descent and exits the atmosphere at the same angle it entered (Regan). The craft eventually descends again, with reduced speed. The skip entry would be a considerable alternative if peak heating rates for ballistic entry were found to be too great a burden for a lightweight vehicle to handle (Ely). Moderate lift to drag ratios produce partial skipping, in which the craft momentarily ascends without leaving the atmosphere before falling to the planet (Regan).

Deployment Sequence

In all likelihood, the deceleration module will have an initial spin rate. There are some advantages to keeping the spin rate unchecked. A slow, steady spin will cancel out unexpected lift forces and help distribute thermal energy more evenly (Duncan). Currently, no provisions exist for inertial navigation or propulsion systems. However, a simple yo-yo despin mechanism could be used to set the spin rate before entry (Weisel). Such a mechanism was used with the Pioneer probes and proved to be a cheap means of spin axis control (Fimmel). Even though the vehicle is supposed to be trimmed, any uncompensated lift could increase entry time, resulting in increased heating and less accurate tracking of the vehicle as it descends. To prevent tumbling of the craft during entry, the center of pressure should be located extremely close to the center of mass (Griffin). The desired orientation of the entry vehicle is shown in Figure 1; note that the only major requirements for attitude control are maintaining colinearity between the craft's axis of symmetry and keeping the craft in the nose-first position instead of the base-first position. A balance will have to be made between the desire to push the mass center towards the nose of the vehicle, and the need to keep thermally sensitive components away from the hottest portions of the craft.



WHERE IS CENTER OF PRESSURE ON THIS FIGURE.

(FIGURE IS NOT CLEAR)

Figure 1: Forces on a ballistic entry vehicle (Weisel, p.220)

Equations of Motion

$$\frac{dX}{dt} = V \cos(\text{angle}) \qquad mV\frac{dV}{dt} = -mg\cos(\text{angle})$$

$$\frac{dH}{dt} = V \sin(\text{angle}) \qquad m\frac{dV}{dt} = -D - mg\sin(\text{angle})$$

AWKWARD SET-UP (NO TRANSITION PRIOR TO EQNS.)

These equations of motion can be manipulated to solve for the velocity (V), and the aerodynamic deceleration (a). For each height listed in the spreadsheet, there are five unknowns:

K_d, an inverse density parameter
H_o, a fictitious reference height
B_o, an energy parameter
a, the aerodynamic deceleration, and
V, the craft's current velocity.

WHAT SPREADSHEET? IT WAS NOT PREVIOUSLY MENTIONED

A complete list of terms used in this report is available in appendix A. Five equations are available to solve for these five unknowns, and a more detailed treatment of determining the height profile is given in Appendix B.

WHICH PAGE? YOU HAVE 7 PAGES IN APPENDIX B, WHICH ONE(S) SHOULD I FOCUS ON.

The deployment sequence begins when the craft speed has decreased to 35 meters per second. An accelerometer and pressure altimeter will be used to determine when this speed has been reached. At that time the onboard computer will send a command to release the chute attached to the aft cover. This will further decrease the craft speed. When the craft speed has been reduced to 10 meters per second, the computer will activate the explosive bolts and inflate the primary balloon. Sensors in the canister valves will monitor the flow of gas into the primary balloon. When the computer receives readings of negligible gas flow, the computer will send its final command to sever the survey package from the aeroshell. The sequence is shown in Figures 2a-2d. The entry vehicle has served its purpose and the operational phase of the survey package can now begin. The final speed at which the survey package begins the operational phase is about 9 meters per second.

Your decisions are not justified at all.

A Model Atmosphere

Data on the physical composition of the Venusian atmosphere was obtained for heights up to 120 km by Pioneer probes (Fimmel, Vargaftik). Above 120 km, a mathematical model was used (Hunten). This model interfaces smoothly with Pioneer data and serves as a reasonable approximation. The variations of temperature, density, and gravity with height for this model are shown in Figures 3a-3c. Instead of taking a conventional simplified treatment of the atmosphere for entry calculations, the data was used to create an accurate model of vehicle descent. The traditional entry model uses an isothermal exponential atmosphere of invariant composition (Weisel). While this makes the determination of the trajectory and heating profile easier, it sacrifices a significant amount of accuracy.

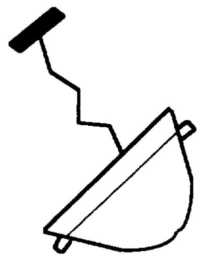


Figure 2a: Initial deployment of parachute

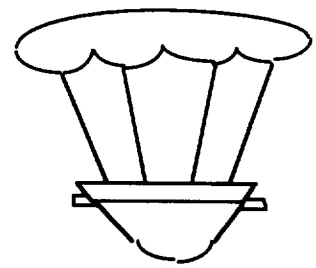


Figure 2b: Velocity reduced from 35 m/s to 10 m/s

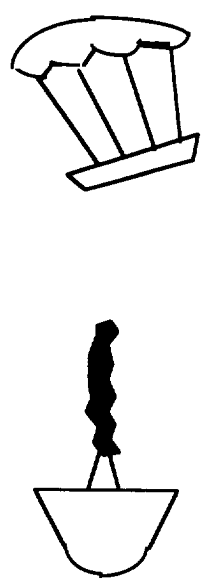


Figure 2c: Explosive bolts activated and aft cover released

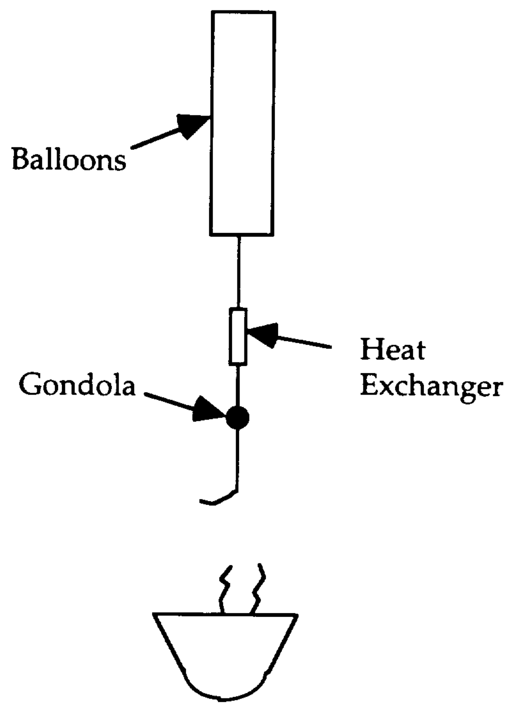


Figure 2d: Balloon inflated, connections severed

(GOOD USE OF FIGURES)

Figure 3a: Variation of Temperature with Height

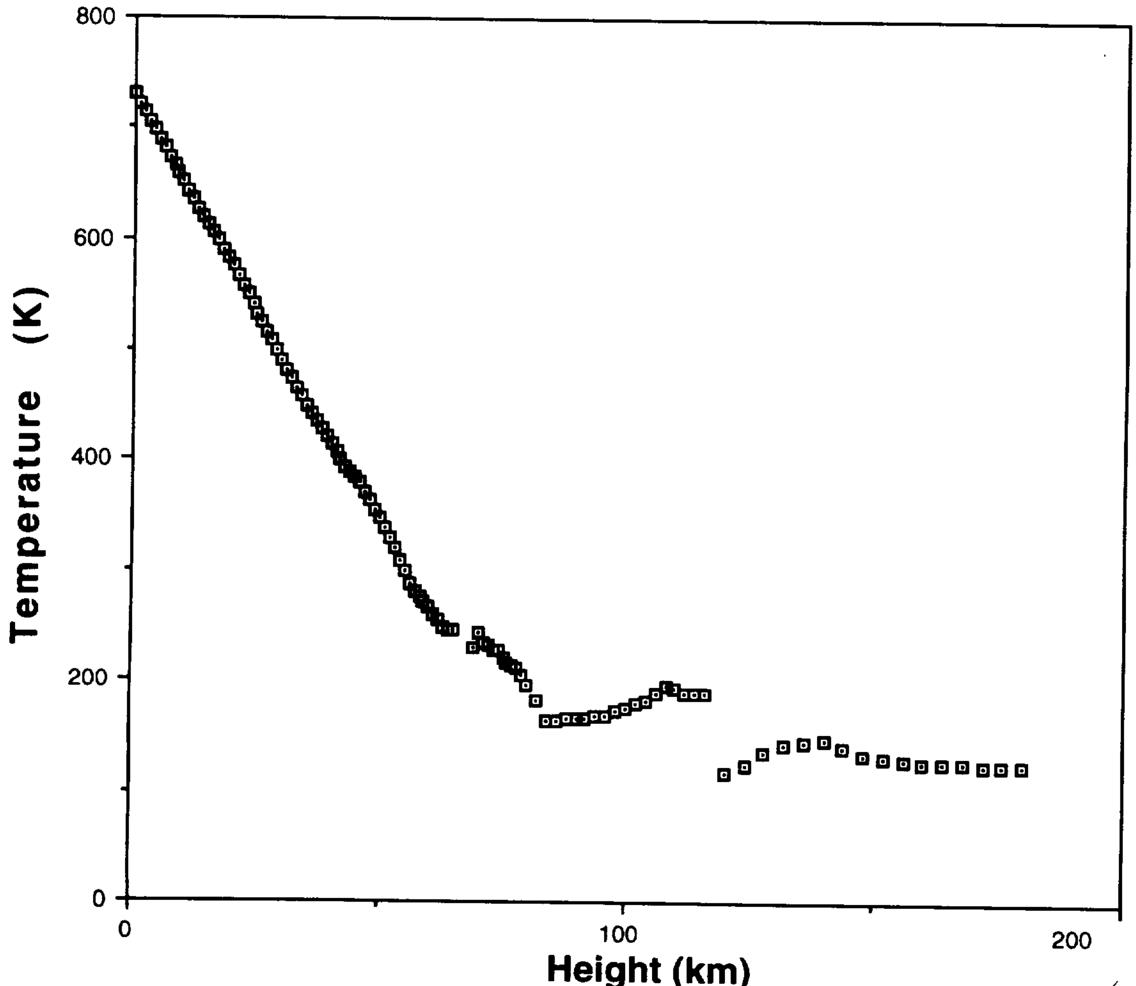


Fig 8c.3

Figure 3b: Variation of Density with Height

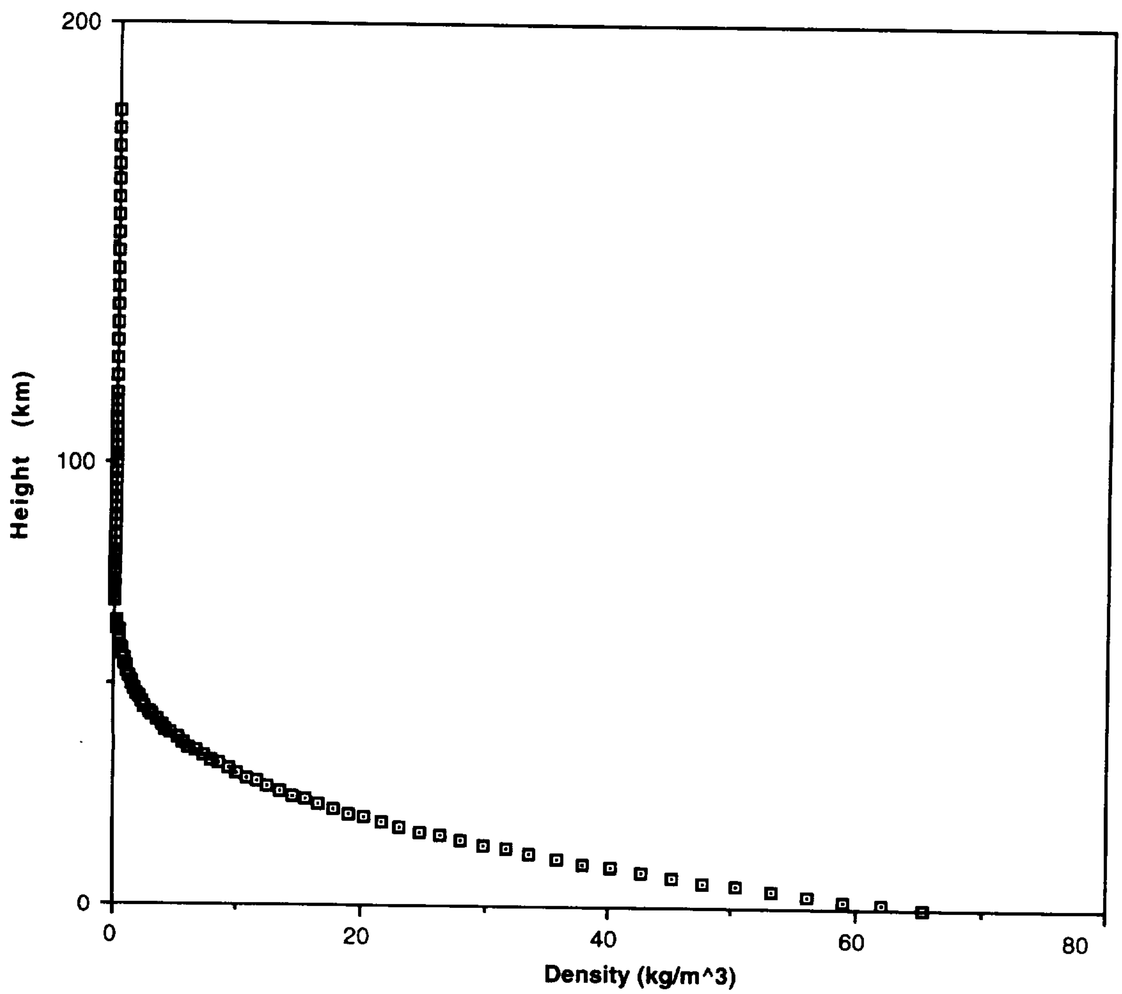
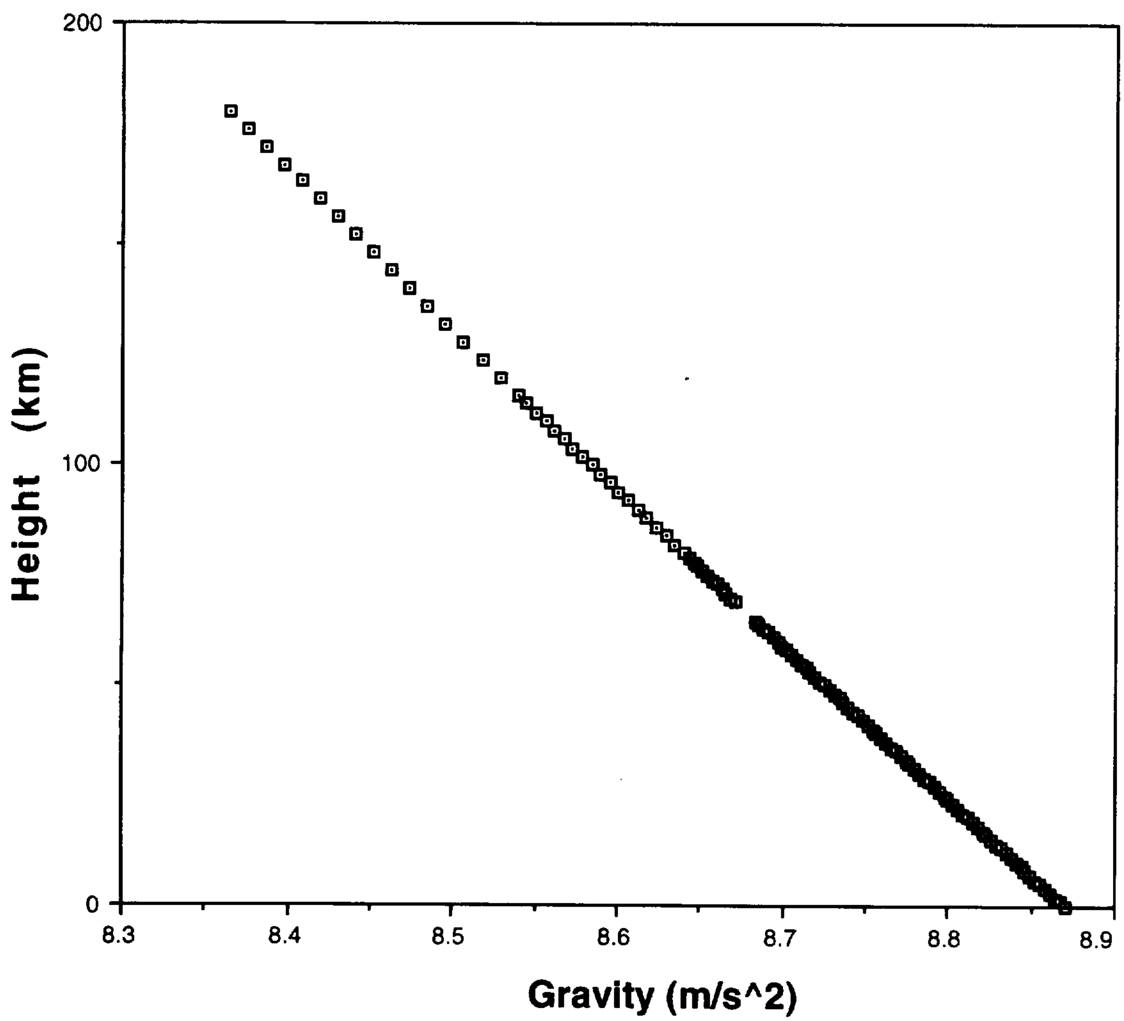


Figure 3c: Variation of Gravity with Height



The density graph is similar to an exponential atmosphere. The gravity graph has nearly a linear look, since the distance covered is much smaller than the planetary radius. The temperature graph is disjointed somewhat at the spots where the mathematical model and the probe data are supposed to mesh, but it does not have a significant effect on the deceleration and heatng profiles.

The model used to calculate deceleration and heating rates has values for pressure, density, temperature, gravity, viscosity, and molecular weight of the Venusian atmosphere in discrete height steps that traverse the lower 200 km of the atmosphere. In reality, the atmosphere extends upwards of 500 km; significant deceleration and heating do not occur above 200 km for this vehicle. The atmospheric properties allow calculation of a deceleration profile with respect to height; the velocity and time are found by integration assuming a step deceleration function. The velocity profile enables calculation of the convective heat rate from the atmosphere to the craft (Dueber). The time profile allows the use of an energy method in determining the necessary shield and aeroshell thicknesses. Sensors on the skin of the vehicle could provide valuable data to help confirm current models of the Venusian atmosphere, as well as increase understanding of the entry heating problem.

Shape Selection

Four basic craft shapes were considered and are shown in Figures 4a-4d. The shape of the craft is important, since it directly influences the deceleration and heating profiles. A trend emerged from comparisons of the different shapes at a set volume: truncated and blunted cones produce significantly lower heating rates and lower amounts of total heat that the craft must deal with. Between these two shapes, four elements determined the final shape selection. The blunted cone had smoother heating and deceleration profiles due to a higher drag and a lower area. The truncated cone had reduced entry times and could endure greater entry angles due to a smaller drag and an increased area. The final decision came down to the preference of reduced peak heating rates over reduced entry time, in addition to the minimization of the necessary aeroshell and shield thicknesses. The blunted cone became the chosen shape of the vehicle, but now materials and dimensions needed to be optimized for the package that must be protected inside the vehicle. See Appendix C for the numerical analysis of the four shell shapes.

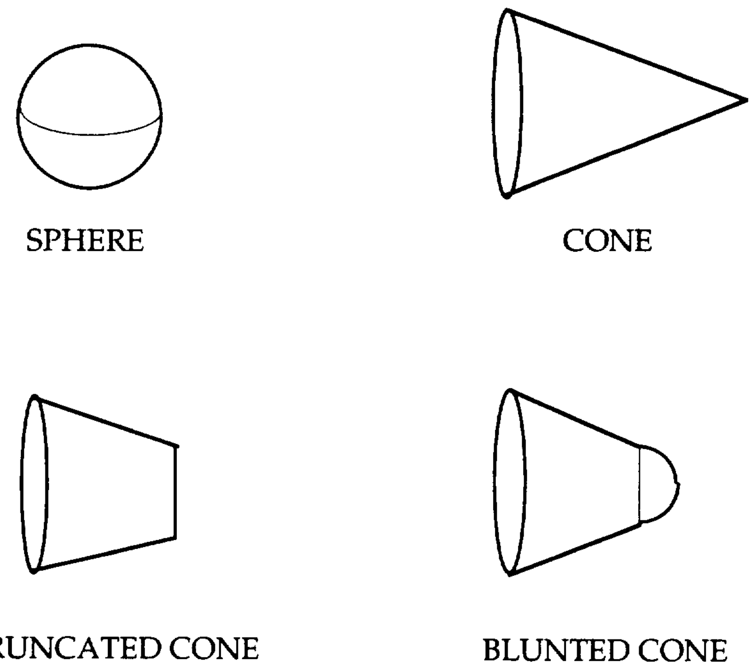


Figure 4a-4d: The four shapes considered
for the entry vehicle

At the time of design, the dimensions of many internal components were tenuous at best. Other criteria were used, however, to select optimal cone half angles and bluntness ratios. A high drag coefficient is desirable to ensure that the vehicle decelerates to an acceptable speed in a limited amount of time. A large surface area can also aid deceleration, with a penalty of increased heat transfer. The entry constraints were assumed to be a maximum deceleration of 500 g's and an entry time close to 5 minutes. Four size iterations produced the optimal cone angle of 45 degrees and the bluntness ratio of one half. This is the same basic shape as the Pioneer small probe, with only a difference in scale (JPL).

Material Selection

Two important aspects of the vehicle needed to be determined. The heat shield and aeroshell of the vehicle will be subjected to the most adverse conditions, and must be designed properly to insure protection of the survey package. The heat shield and shell must be able to handle high dynamic and thermal loadings. The heat shield ideally has the properties of low density, low thermal conductivity, high heat of vaporization, and high emissivity (Dueber). Whether AVCOAT was charred or virgin material, it ranked higher than other candidates in almost all of these properties. The only directly determinable input is the convective heating from the atmosphere to the craft (Regan). This input can be converted to a total energy transfer to the vehicle. An approximation was made that the required mass of ablative heat shield material equals the total energy transferred, divided by the heat of vaporization for the shield. After finding that the mass required was probably too small, a more conservative approach was taken. The initial and final kinetic energies of the vehicle were calculated, and under JPL advice the heat shield mass was taken to be approximately 20% of the total craft mass. Under these conditions, the craft will empty 15% of the kinetic energy through mass loss. The remaining 85% will have to be radiated away or conducted through the aeroshell. Appendix C has the numerical results of shell and shield material studies.

Dimensioning the Entry Vehicle

The first obstacle in finding the optimal dimensions of an entry vehicle is the establishment of a complete equipment list. Once this list has been made to the best possible accuracy, the total mass and volume are used in the spreadsheet to set up a 500g entry. The spreadsheet returns values of the maximum convective heat flux, the convective energy seen by the craft, and the angle at which the entry occurs. These values are used in heat transfer and stress calculations to determine if the shield and aeroshell thicknesses are accurate. The process is quite iterative, and time consuming unless computer aids are used. A detailed explanation of the heat transfer and stress calculations are found in Appendices D and E. The current equipment list is shown on Table 1 and the spacecraft dimensions are shown in Figure 5.

TABLE 1: CURRENT MASS AND VOLUME ESTIMATES

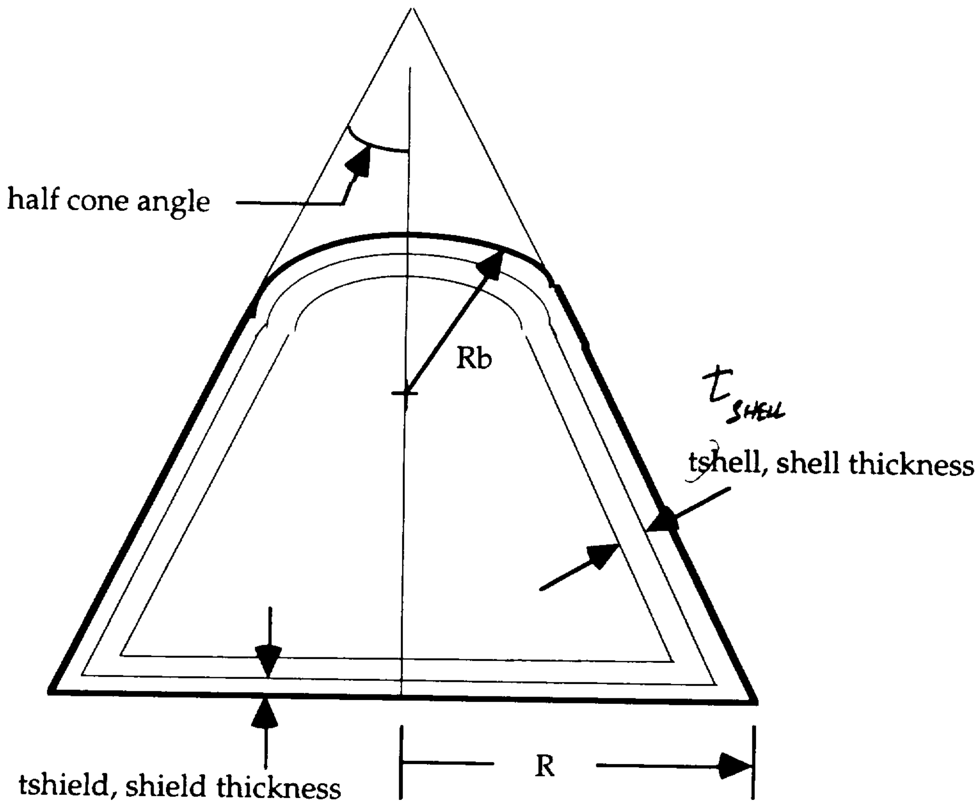
Hard font to read

WHERE DO THESE NUMBERS COME FROM?

COMPONENT	MASS		VOLUME	
SURVEY PACKAGE	89 kg	(196 lbm)		
Gondola	27 kg	(59 lbm)	0.0351 m^3	(2140 in^3)
Balloon Skins	27 kg	(59 lbm)	0.0223 m^3	(1360 in^3)
Heat Exchanger	8.5 kg	(19 lbm)	0.0128 m^3	(781 in^3)
Connector Cables	5 kg	(11 lbm)	1.85e-3 m^3	(113 in^3)
Phase Change Material	4.2 kg	(9.2 lbm)	accounted for above	
Primary Gas	17 kg	(37 lbm)	accounted for above	
AEROSHELL	44 kg	(97 lbm)		
Avcoat 5026-39 H/CG Shield	30 kg	(66 lbm)	0.0568 m^3	(3480 in^3)
Titanium (6Al-4V) Shell	9.1 kg	(22 lbm)	2.07e-3 m^3	(127 in^3)
Thermal Blanket	5 kg	(11 lbm)	negligible	
Adhesive Film	0.1 kg	(0.22 lbm)	negligible	
DEPLOYMENT SYSTEMS	24 kg	(53 lbm)		
Gas Canisters	10 kg	(22 lbm)	0.0334 m^3	(2040 in^3)
Valves	1 kg	(2.2 lbm)	negligible	
Explosive Bolts	5 kg	(11 lbm)	negligible	
Cutters	1 kg	(2.2 lbm)	negligible	
Computer	0.5 kg	(1.1 lbm)	negligible	
Accelerometer	0.1kg	(0.22 lbm)	negligible	
Altimeter	1kg	(2.2 lbm)	negligible	
Parachute	5 kg	(11 lbm)	0.015 m^3	(1220 in^3)

Totals Allocated	157 kg	(345 lbm)	0.179 m^3	(11040 in^3)
Craft design based on	150 kg	(330 lbm)	0.180 m^3	(11100 in^3)

SHOULD BE PUT ON PREVIOUS PAGE (IF POSSIBLE THROUGH SHRINKING)



SPACECRAFT DIMENSIONS

Base Radius, R:	0.482 m (19.0 in)
Nose Radius, Rb:	0.241 m (9.49 in)
Half Cone Angle:	45 degrees
Shell thickness, tshell:	0.416 cm (0.164 in)
Shield thickness, tshield:	7.14 cm (2.81 in)

Figure 5: Exterior dimensions of the vehicle

O.K.

DOES NOT APPEAR IN REFERENCE LIST!

The aeroshell is the next line of defense. Since temperature distribution through the thickness is unknown, the criteria that drive shell selection are basic: Low coefficients of thermal expansion, good buckling resistance, low oxidation rates, low thermal conductivity, and lightweight material (Jaworski). A worst case heat transfer scenario was developed, using the peak convective transfer rate as a steady state input to the exterior of the shell. The interior temperature was set at the desired level, while the exterior was treated as a hot spot at an arbitrary high temperature. At the time, this seemed extreme, but it turns out that the dynamic loads cause the shell to be even thicker than calculated here. Only two of four material candidates had desirable properties; between titanium and stainless steel, titanium handles large pressure vessel stresses with lightweight, thin sections. Titanium was chosen to be the aeroshell material, and was designed to sustain a deceleration induced hoop stress of 0.8 yield and handle thermal hoop stress of 0.25 yield (Fortescue). Since peak deceleration and peak heating do not occur at the same time, it is reasonable to assume that no combination of the two stresses causes failure.

AWKWARD FOR A FORMAL REPORT

BUT CAN THEY COUPLE? IF SO BOTH MUST BE TAKEN INTO ACCOUNT WHEN CALCULATING σ_y.

It is regrettable that the depletion profile of the heat shield could not be established. It leaves some doubts about the safety of the survey package should the thermal conditions prove to be worse than anticipated. This drove the decision to adhere a thermal blanket as a final line of defense. (see Figure 6) This is the same thermal blanket that was used on the Magellan orbiter. From the figure, it is noted that the thickness of the blanket is greater than the aeroshell thickness. It is a small price to pay for added thermal protection. Originally, the interior of the vehicle had been partitioned by shelves; at JPL's behest these have been removed and it is assumed that there will be attachment points on the inside of the shell for the survey package and the rest of the deployment equipment.

WHO AT JPL?

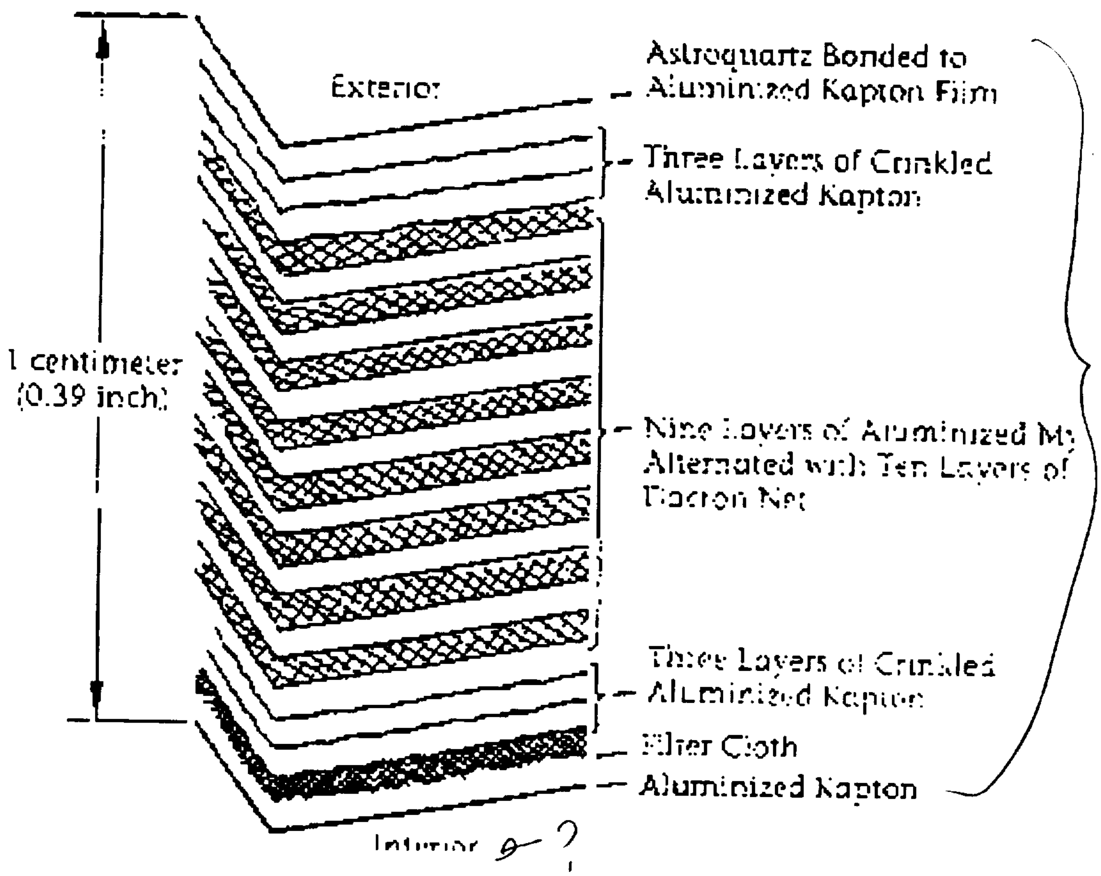


Figure 6: Suggested thermal blanket
(Miller, p.8)

Assumptions: A General Disclaimer

Entry calculations and the design of an entry vehicle are invariably a very complicated problem. It is important to realize the many simplifications and assumptions made during the design process, as the accuracy and reliability of the design will be directly dependent upon them. Let's begin the discussion by examining the accuracy of the atmospheric model. The most important portions of the model are dependent upon the accuracy of Pioneer sounder probe data. It would be prudent to expect cyclical variations in the physical characteristics of the atmosphere (Hunten). The magnitude of these variations, while unknown, could have a sizable influence on the heating and deceleration profiles in the middle altitudes. Gravity has been approximated using the inverse square law for a surface value of the Venus gravitational acceleration, and the angle of entry has been assumed to be constant for the entire entry. The spacecraft mass and cross sectional area have been assumed to be constant during entry. In reality, neither the angle, mass, nor area will remain constant. The drag coefficient, which should vary over the entire trajectory, has instead been taken as an average value over the entire flight. The time elapsed is based on integrating stepped deceleration values between heights. Convective heating is based on an average skin coefficient for the entire vehicle, although this parameter is allowed to vary with respect to height. The viscosity of the atmosphere is linearly interpolated at heights of 0-50 km, and assumed to be linearly decreasing from 51-200 km (Vargaftik).

Heat trans. is assumed steady, 1-D!

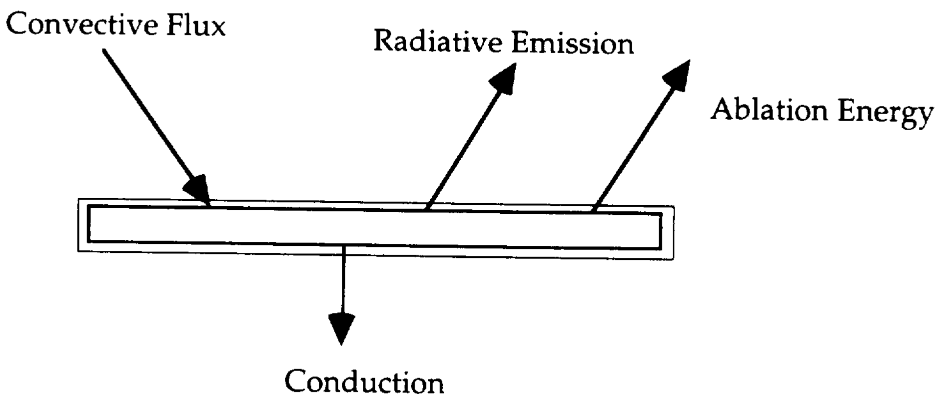
Good summary, but what does this mean about your design.

Sensitivity Overview

The design of the craft suffered with respect to thermal modelling. The true energy balance for the craft should look like Figure 7. Although factors relating to the mass flux can be calculated, the mass flux itself is a function of vehicle wall temperature (Kays). The problem is essentially a fourth order nonlinear nonhomogeneous transient partial differential equation. If it sounds difficult, try solving it and find out what the designer faced. The energy lost to radiative emission should reduce the conductive energy transferred through the wall. The design has an ample amount of shielding for design conditions where ablative dissipation accounts for up to 15% of the total dissipation requirement. Beyond that, hopefully the aeroshell and thermal blanket can keep the interior temperature at a safe level. The use of a temperature and composition variant atmosphere increased the accuracy of the deceleration and heating profiles. Only further testing of the Venusian atmosphere and direct recording of flight data can increase the accuracy of that part of the design. The use of pressure vessel analogies to quantify the stress behavior of the aeroshell may come into question: worst case scenarios involve limited yielding of the titanium aeroshell with an acceptably low risk of failure. The shearing of the shell has not been directly considered, as the dynamic loading is a distributed one and does not solve easily for this shape. The location of components, which was not readily established, could greatly affect the dynamic stability of the craft.

No place for this in a formal report!

Good point!



q" = Convective Flux
A*T^4 = Radiative Emission
Ablation Energy = mf*hvap
Conduction = -k*(dT/dx)

where mf is the mass flow of the heat shield
hvap is the heat capacity of the wall
k is the thermal conductivity of the wall
dT/dx is the thermal gradient across the wall
A is a constant based on emissivity

Rate Balance: -k*(dT/dx) = q" - A*T^4 - mf*hvap
where q" and mf are unknown functions of T

Figure 7: The energy flux balance of the vehicle wall
(Incropera, Regan) → which one? You list 2 references by Regan.

Expansions of Work

While much has been done, many aspects of vehicle design have not been covered completely. The thermal balance of the spacecraft needs refinement. Layout and interfacing of equipment needs to be developed. Calculations of dynamic and thermal loadings have been greatly simplified and warrant closer inspection. The design of the entry vehicle can really be broken down into four sections: aeroshell design, heat shield design, selection of subsystems, and internal layout. Each one of these subjects is interrelated and would be best addressed by a one year developmental effort. It is hoped that further investigative work will be done by future students.

Knowledge Gained

In learning how to design an entry vehicle, the designer gained some proficiency in certain topics. The creation of an accurate atmospheric model was undertaken successfully, as was an alternative material selection process in the absence of some useful data. The theory behind heat shield selection and ablation physics was understood, if not successfully applied. Conversations with JPL revealed the tendency for designers to stick with existing shapes in vehicular design. A significant improvement was made in the acquisition and use of resources for research. The truth is that more time and experience will produce a better design, but the effort described here is by no means a token one.

Transitional

The entry vehicle requires little or no power during descent and deployment phases. During descent, atmospheric data will be sent to instruments onboard the gondola for storage. With the deployment completed, the next design obstacle is a heat exchanger that will regulate the survey package's altitude. The development of a gondola package is considered next.

Gondola

The gondola for the Venus balloon is a complex problem, because of the necessity of keeping temperatures inside the gondola below 20° Celsius while the surface temperature of Venus is 460° C. This is necessary because the electronic equipment within the gondola cannot be subjected to cyclic high temperatures without sustaining damage. Also, the gondola must be strong enough to withstand a pressure of up to 92 atm.

The first steps in designing the gondola were to estimate the size of it and to decide upon a shape. A list of equipment for the gondola is shown in Table 2. We then obtained volume and mass data for the chosen equipment. Some of the data we obtained was estimated or abridged in order to obtain what we felt were more accurate numbers. Based on these dimension values, a total payload area was found to be 726.6 in^3. At this point, we decided that due to

GONDOLA MASS ESTIMATE

COMPONENT	MASS
Power Distributor	3.5 kg
Charge Regulator	3.0 kg
Battery	3.3 kg
Antenna	0.7 kg
Transmitter	3.5 kg
Camera	2.0 kg
Command and Data Storage	2.4 kg
Shell	5.234 kg
Insulation	0.6902 kg
Foam	.3195 kg
PCM and Heat Pipes	1.5 kg
Miscellaneous	0.5 kg
TOTAL MASS =	26.64 kg

DID YOU ASSUME A TOTALLY SYMMETRIC SPHERE? IF SO, YOU SHOULD LOOK INTO THE POSSIBILITIES OF MOVING MORE MATERIAL AT KEY POINTS OF SPHERE?

(NO TRADE-OFFS SHOWN!)

Table 2. Gondola Equipment Mass Estimates

it's simplicity, aerodynamic features, and capabilities as a pressure vessel, a sphere would be the best shape to make the gondola. With this in mind, we worked backwards from our payload volume estimate to find that the sphere should have a minimum radius of 5.6 in. To make room for insulation, support structure, and other added volumes, our selection for the sphere size was a radius of 8.0 in.

The next step in our design process was to select the material and thickness of the gondola. Due to it's excellent strength to weight ratio a titanium alloy (6% Al, 4% V) was chosen. Titanium resists buckling in struts and thin plates better than other common materials, such as stainless steel and aluminum. Titanium also has a high yield point for axial stress. Based on these material properties, the atmospheric pressure of Venus, and the thin-walled pressure vessel formulas, a thickness of 0.04508 in. was found to be the critical value. In order to protect against atmospheric pressure variations, possible internal point loads, and thermal deformations, a safety factor of 2 was used to bring the thickness of the sphere to 0.09016 in. Based on this number and the density of the material, a mass value of 5.234 kg was obtained for the sphere.

is this the governing mode of failure?

THIS DESIGN IS NEITHER SUPPORTED NOR SHOWN - THEREFORE IT IS INCOMPLETE!

At this point in our design, there were two basic structures that were being considered. One type consisted of two concentric spheres with a vacuum in between as an insulator (JPL). This vacuum insulation would be very effective at preventing both conduction and convection, and also would be very lightweight. One problem with it is the fact that the two spheres would have to be attached in order to provide structural stability and support. Using these supports undermines the conduction resistant properties of the vacuum, as well as applies unwanted point loads to each sphere. It also maximizes the pressure difference acting on the sphere because one side of the sphere is at approximately 92 atm and the other side (the vacuum) is at 0.0 atm. In addition, having two shells would increase the weight of the gondola considerably.

The second structure considered was just to use one spherical shell, and line it with enough insulation so that the heat transfer to the equipment would be minimal. With this type of structure there would only be one shell, so there would be a weight decrease of the titanium used. In addition, this type of gondola design makes supporting structures much simpler and more efficient. The main drawback is that there is a weight gain due to the insulation used. Based on the advantages and disadvantages of these two designs, we chose to pursue the single-sphere model.

Insulation

The next step in the design process was to determine the type and thickness of the insulation material. The driving factor was the weight vs. the insulating ability, but a high maximum service temperature was also required. Based on these factors, we chose to use an alumina-silica fiber as the insulating material. Using the material properties of this fiber, the temperature difference from the Venusian atmosphere, and the desired operating temperature inside the gondola of 15° Celsius, it was calculated that the thickness of the insulation would have to be 1.41 in. Using this number and the density of 48 kg/m^3, the mass of the insulator is 0.6902 kg (Incropera and Dewitt). This proved to be much less than the mass of the additional shell which would have been needed to provide vacuum insulation, so the choice to discount the vacuum insulation seems reasonable.

Support

The next part of the problem was to design some sort of supporting structure to hold the equipment in place. In addition to support, other needs were to absorb shock and dampen vibrations. We chose to use a molded polystyrene foam material for this. We decided to envelope the equipment and phase changing material completely in foam so that the entire otherwise unoccupied area inside the shell would be polystyrene. This foam was of suitable stiffness and is operable in somewhat higher temperatures (Klempner and Frisch, p. 175). This serves the needs stated above as well as adds another insulating layer. After subtracting the volume of the equipment, phase change material, insulation, and all other components from the available space inside the gondola, we found that there were still .019966 m^3 of volume left over. This volume of the chosen foam has a mass of .3195 kg.

Cooling

Despite having sufficient insulation from outside heat, it is important not to forget about the considerable amount of heat that the electronic equipment itself can generate. Because of this, we also need to include some type of cooling device. We decided to use n-octadecane as the phase changing material, along with a pair of miniature diode reflux heat pipes. The phase change material (pcm) will be contained in two lightweight heat conducting plastic containers and placed around parts of the equipment. The pcm will absorb heat from the equipment. When the temperature of the equipment reaches the melting point of the pcm, it will melt and by doing so absorb a greater amount of the heat energy. The heat pipes will be used to cool off the phase change material (pcm) when the balloon is in the upper atmosphere. They will conduct heat from the pcm through the foam and insulation and onto the shell, where it will convect into the atmosphere. This heat transfer will continue until the pcm has reached a much lower temperature and has re-frozen. The mass of the pcm and heat pipes is estimated at 1.5 kg.

Extra Mass (Equipment)

In addition to all of the previously detailed equipment, there are also several other sources of mass and volume to consider. There will be weight for electrical wires to connect each piece of equipment. There will also be a need for a small length of fiber optics cabling to allow the camera to take pictures outside of the gondola. These additional masses are estimated to be 1.0 kg.

Power Generation

Due to the large power requirement of the Venus balloon and the small allowable mass of the gondola, power must somehow be generated on Venus during the mission. The initial step taken was to determine how much energy would be needed to operate the balloon during one cycle. The equipment is already known and also the power needed to operate each piece of equipment. This data is shown in Table 3. As shown in this table, the estimated power requirements of each piece of equipment are multiplied by the estimated operating times. These estimations are based on the length of one cycle of the balloon being 24 hours long. This gives the energy requirement per cycle for each piece of equipment. These numbers were summed to find the total energy requirement of the gondola per cycle, which is 908.7 kJ.

GONDOLA EQUIPMENT

POWER	OPERATION TIME PER CYCLE	ENERGY USE PER CYCLE
0.5 W	86400 sec	43200 J
4.0 W	3600 sec	144000 J
N/A		
N/A		
40 W	7200 sec	288000 J
5.0 W	300 sec	1500 J
2.4 W	86400 sec	432000 J
	TOTAL ENERGY PER CYCLE =	908.7 kJ

Table 3. Gondola Equipment Power Consumption

The next step in our design was to find a good method of power generation. We looked into using solar power, wind power, and thermal power. Solar power was the first option looked into. Although it is often used in space applications, that is typically on orbitting sattelites. It was discarded fairly quickly for a number of reasons. For instance, solar arrays, despite continuing improvements, have low output. They are typically 12-15% efficient (Boer). Also, the cloudy atmosphere, combined with the facts that it will be night for roughly half of each cycle and that there is a loss of solar radiation flux for a tilted solar panel, means that the solar intensity, and therefore the power output will be very minimal and sporadic (Rapp, p. 37). In addition, high temperatures cause damage to solar arrays and loss of efficiency.

Turbine power was thought to be an option for use due to the fact that the gondola would have constant vertical motion. The vertical air flow caused by this motion would then be able to drive vertical wind turbines. We did not look closely at the power capabilities of this option. We decided that we did not want to have a moving mechanical part like a turbine due to the vibrations and cyclic stresses that would be present, affecting both the turbine and the gondola. It would add difficulty to the design of other components, such as the gondola shell and the equipment. In addition the vertical velocity of the wind could often be as low as 1 m/s, which would not seem to offer a great supply of energy. Finally, using wind turbines would add extra weight by requiring the use of a generator.

Therefore, we concluded that we should try to harness some of the vast thermal energy found on the planet Venus. The method we decided to use was a thermocouple. The thermocouple device shown can be used to create a hot and cold node to which a thermocouple can be attached. The thermocouple itself has not been designed, although an efficiency value of 6% was assumed. Although an efficiency value of 10-20% is possible in a thermocouple, the chosen value to use in calculations is taken to be 6% due to the harsh operating conditions in the atmosphere of Venus. Using this efficiency, it can be calculated that 16333 kJ of heat energy would need to be converted into electrical energy in order to sufficiently power the balloon. A summary of the work accomplished in designing this method follows.

The model shown is a device that can be used to store this heat energy while it is being converted into electrical energy. Exact numbers have not yet been worked out, but this analysis shows the scope of the problem. Water has been chosen as a working fluid, although there may be much better options.

In stage one, as shown, the fluid is contained in section A. As the water is heated up it evaporates and raises into an adiabatic section, B. Once this happens, the valve is closed and the balloon rises to the upper atmosphere. It has been estimated that an average temperature of 350 Celsius will be maintained in section B. That would give the water vapor a specific energy of 2877.4 kJ/kg (Moran and Shapiro p. 700). A thermocouple is connected between section B and an arbitrary cold point, which can be basically anywhere in the upper atmosphere, perhaps on the gondola. At this point the balloon may oscillate in the upper atmosphere. According to this model, the majority of heat lost would be through the thermocouple and approximately 6% of that would be converted to electrical energy. If the heat energy loss were to occur over time until the water vapor became a saturated liquid at 100 C, where latent energy of vaporization could be taken advantage of, it would prove to be beneficial. At this point the specific energy of the water would be 418.94 kJ/kg (Moran and Shapiro p. 700). This is a difference of 2458.46 kJ/kg between the two states. Based on this number and the total heat energy needed, 6.16 kg of water would be needed to insure proper power generation. This is probably not a very reliable number, but there are many things which can be done to improve upon it.

Many assumptions have been made due to lack of availability of accurate heat transfer modelling through the adiabatic section of the thermocouple device. Therefore there are many ways to improve this model. The working fluid and pressure can be changed to take greater advantage of specific internal heat energy. Also, the process can be reversible to some extent when the balloon descends. The adiabatic section will keep the water cooler than the surrounding atmosphere until the valve is open, so the thermocouple will have a temperature difference. Possibly the efficiency of the thermocouple can be approved. It is also possible to link the thermocouple directly to the heat exchanger of the secondary balloon. This would save weight for the overall design. It is too soon to predict how that would affect the power output of the thermocouple.

In conclusion, having previously looked into solar arrays and wind turbines, the thermocouple seems to be the most promising choice for power generation and it warrants further study. The heat exchanger that will control the altitude of the balloon is now discussed.

Most of this section of the report is a conceptual design. Many more details should have been determined. The next team should design the gondola since this team certainly didn't bother.

Actually, THIS TEAM SHOULD HAVE DESIGNED A GONDOLA!

IN THE ENTIRE GONDOLA / POWER GENERATION SECTION, THERE IS NO REFERENCES TO THE APPENDIX WHATSOEVER! UNACCEPTABLE!

(THE PREVIOUS 7 PAGES REPRESENT 2 STUDENTS WORK OVER THE ENTIRE SEMESTER FOR A 3 CREDIT CLASS. DISAPPOINTING & POOR.)

THERE ARE FAR TOO MANY ASPECTS THAT WERE NOT LOOKED IN TO. HOW CAN YOU USE A HEAT PIPE WHEN LITTLE OR NO CALCULATIONS HAVE BEEN MADE?

INTRODUCTION TO THE VERTICAL MODEL

Objectives

The purpose of this section of the project is to investigate the performance of the proposed Venus Balloon for exploring the deep atmosphere of the planet. Knowledge of the vertical motions of the balloon system is important for three reasons. First, to effect a desired ascent profile, we need to understand how the balloon responds to its lift force, drag force and changes in its operational environment. Second, to initiate ascent or to vary the rate, we must be able to predict the effects of gas valuing.

Third, to provide adequate cooling for the onboard instruments and sufficient communication time, the altitude versus time plots must be carefully and accurately determined.

Background and Challenges

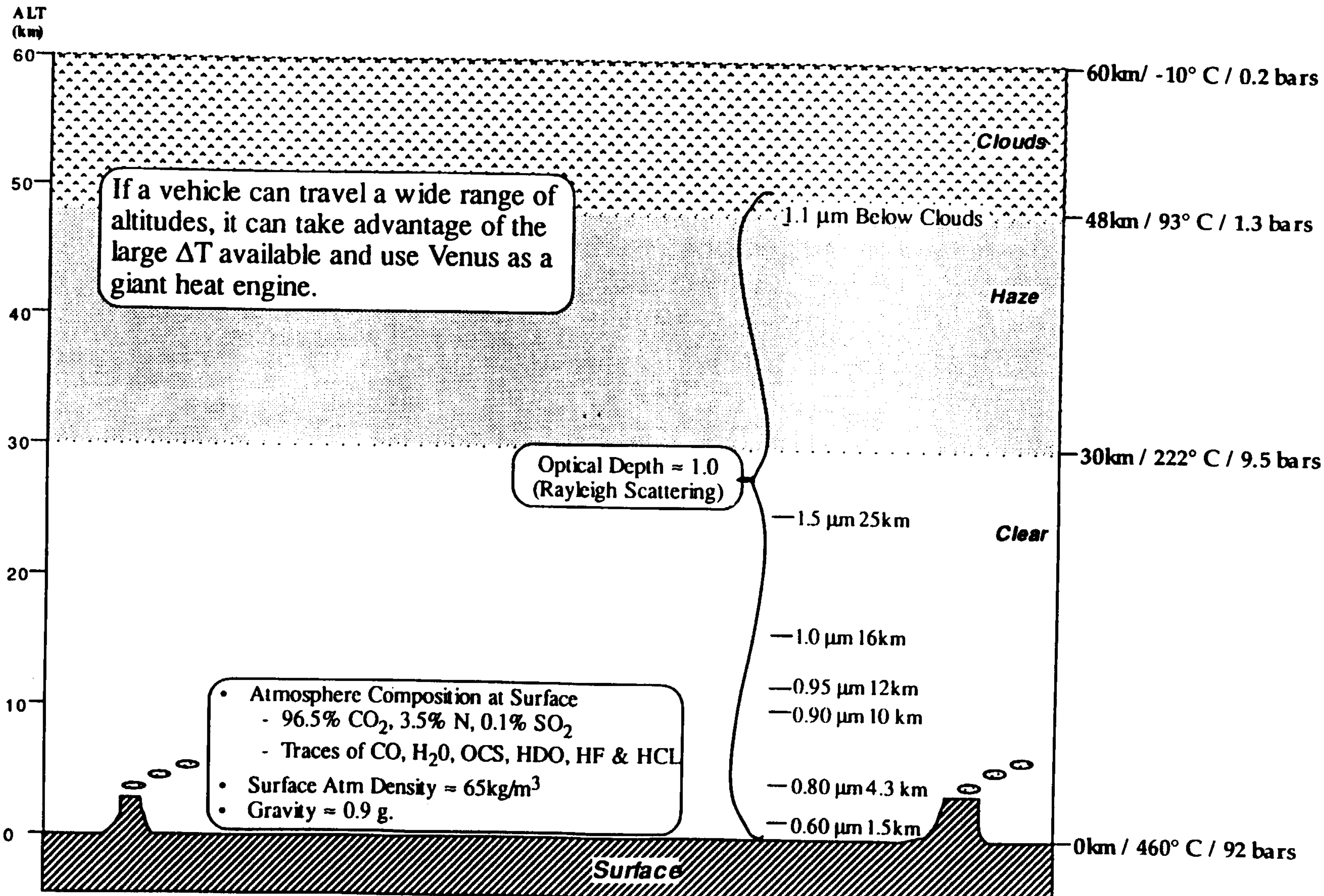
The high temperature Venus atmosphere of mostly carbon dioxide poses a great challenge to reconnaissance work on the planet. Intensive and prolonged exploration of the planet surface and atmosphere have been impeded by the unfriendly atmosphere of Venus. The only balloons ever flown in the planet were the fixed altitude Soviet Vega Balloons which lasted for about two days.

The opacity of the thick cloud layer; 48 km to 60 km above ground level (a.g.l.), and the haze layer; 30 km to 48 km a.g.l., precludes any clear imaging from a higher altitude where the temperature and pressure is more moderate. The dense atmosphere also precludes the transmission of signals to Earth based stations (see Fig. 8a). In order to obtain clear images of the terrain, the balloon has to descend to altitudes where temperatures of 460 Celsius and pressures of 92 bars prevail. well worded!

To communicate, the balloon has to ascend above the cloud layer.

Excellent!

VENUS ENVIRONMENT



KTN/JAJ-4
5/27/93

Fig 8α [REFERENCE #]

Sources of Information

The first step towards achieving our objectives was to review the rather extensive literature in one of three problem areas that deal with balloon ascent. The first area is the Venus atmospheric conditions. Sources consulted include:

- Hunter et al., 1983
- Fimmel, 1983
- Lide, 1992
- Nock and Jones, 1993
- JPL correspondence:
  JPL scientists, Jay Wu and Jack Jones

The second area deals with balloon ascent, weather balloon trajectory modelling, space exploration vehicles, float motion and aerodynamics of free pressure balloons:

- Soviet Vega Balloon Report, 1982
- Boaz, 1983
- Dwyer, 1985
- Ward and Kincaid, 1985
- Boyce, 1986
- Zak, 1988
- Greenberg, 1988

- UW-Faculty consulted with:
  Professor Fieriesen, Fluid Mechanics, M.E. Dept.
  Professor R. Reitz, Fluid Mechanics, M.E. Dept.
  Professor G. Meyers, Thermodynamics, M.E. Dept.
  Professor P. Cheng, Thin Shells, E.M. Dept.
  Professor Johnson, Mechanics, E.M. Dept.
  Professor J. Kuelbs, System of Eqns. Math Dept.
  Professor Frosteric, Diff. Equations Math Dept.

- JPL correspondence:
  JPL scientist, Jay Wu (Trajectory)

The third area, heat transfer (internal and external) encompasses some of the principal concerns that compelled this study. The altitude control of the balloon is directly related to the overall heat exchange rate of the system.

Of the three problem areas, this is by far, the most complex. Without performing actual experiments, most heat exchange perimeters cannot be determined to any level of fair accuracy. The closest thing to performing an actual experiment on expensive prototypes is computer simulation. Fluent, a commercial fluid dynamics package was used to investigate the heat exchange rate and the bulk temperature of the balloon as a function of time and altitude. Sources on heat exchange consulted include:

- Seigel et al., 1981
- Vargaftik, 1983
- Dwyer, 1985
- Blamont et al., 1985
- Incropera et al., 1990
- Fluent Manuals., 1993

- UW-Faculty consulted with:
  Professor Mitchell, Heat Transfer, M.E. Dept.
  Professor Meyers, Thermodynamics, M.E. Dept.
  Professor R. Reitz, Fluent, M.E. Dept.
  Ms. C. Maul (T.A.), Fluid Mechanics Chem.E.Dept.

Scope of Investigation

This project involved seeking information on/designing for the following:

- Balloon design
  Selection of working fluids for the balloon system
  Selection of balloon skin material
  Shape and dimensions of balloon

- Kinematics of the balloon system
  Altitude as a function of time
  Velocity as a function of time
  Acceleration as a function of time
  Balloon cycle design (Cooling instruments and transmission of data to earth)

- Dynamics of the balloon system
  Buoyancy force as a function of time and altitude
  Drag force as a function of time and altitude
  Volume as function of time and altitude
  Stability

- o Valving

    Condensation rate of R30 in the secondary balloon
    Gas valving rate

- o Heat exchange phenomenon of balloon

    Computer simulation of flow conditions and heat transfer as a function of time using Fluent

    a Convectional heat transfer
    b Conductive heat transfer
    c Radiative heat transfer

    Bulk temperature as a function of time and altitude
    Overall Buoyancy as a function of bulk temperature

SOME FORMAT TROUBLES

Report Format

This report includes these four main sections:

1. Technical Approach:

    - o A complete discussion of the trajectory model.
    - o A complete discussion of the heat exchange model.

2. Difficulties involved and assumptions made: a discussion on how some hard-to-find data and equations were quantified and estimated.

3. Results: a presentation and discussion of the overall performance and deficiencies of the balloon system. Errors involved are analyzed and discussed.

4. Conclusion and recommendation: A summary of the possible effects of the outcome of the investigation; a recommendation for further study and design refinement.

FORMAT CHANGES SHOULD BE AVOIDED

TECHNICAL APPROCH

A Word About The Weather

The Venus Atmosphere Model (0 to 70 km)

The mostly carbon dioxide atmosphere (98%) acts as a huge thermal blanket, trapping most of the impinging thermal radiation from the sun. Surface temperature is as high as 460 Celsius. Thick layers of sulphur dioxide cloud exist up to an altitude of about 60 km (Hunter 1983). Immediately above the cloud layer, the temperature drops to about -10 Celsius. Pressure and density also drops significantly (see Fig 8c.1 - 8c.3 on the following page).

Double Balloon System and Reversible Fluid

In order to ensure a long duration operation, good altitude control design is essential . The life-span of the entire system depends on how well the onboard instruments are insulated and maintained. Temperature control of the interior of the craft is directly related to altitude control (buoyancy control). Our design uses a double balloon system. The primary balloon is filled with hydrogen while the secondary balloon uses a reversible refrigerant R. Fig. 8b shows an estimation of the condensation rate of R versus altitude. As reported by JPL, R begins to condense at an altitude of about 56 km above the surface of Venus.

The balloon system continues to rise until the its net buoyancy is less than its entire weight. The liquid refrigerant is trapped in a small heat exchanger at the base of the secondary balloon. A closed valve prevents the R from evaporating back into the secondary balloon. The balloon system continues to descend below the 56 km altitude until the valve is re-opened; the superheated R evaporates instantaneously into the secondary balloon - restoring the buoyancy of the secondary balloon. The whole cycle is repeated until a) the onboard instruments have cooled sufficiently and b) transmission data to Earth is completed.

Specifications

As suggested by JPL, the balloon skin is to be manufactured out of polyethyene. The balloon is a free pressure system. It is entirely free to expand and there are no stresses on its skin.
Both balloons are designed to have a fixed diameter of four meters; only the lengths of the balloons change as the system ascends or descends. Its cigar shape is designed for drag reduction. See appendix M for detailed specification and dimensions of the balloon system.

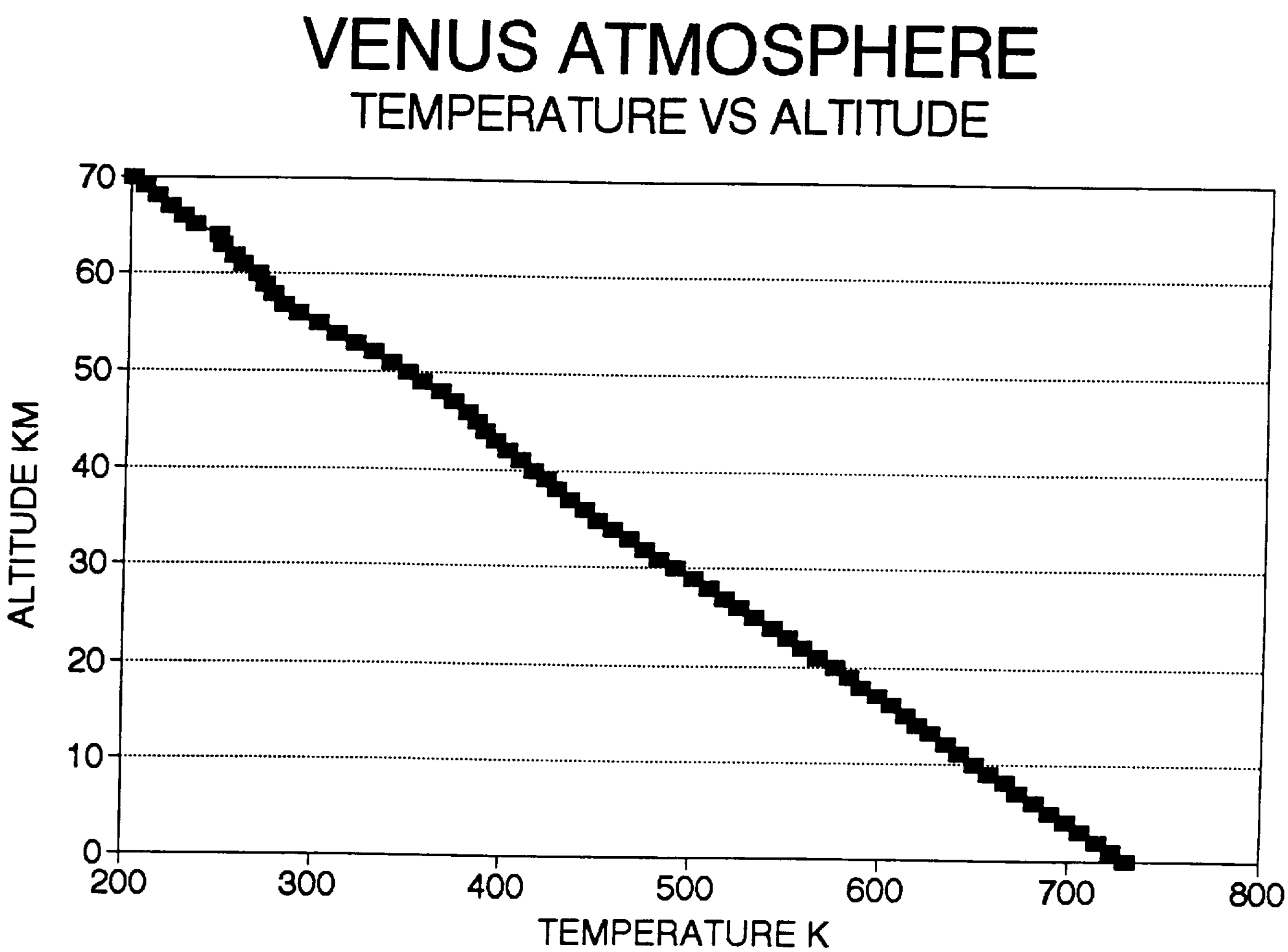

VENUS ATMOSPHERE
TEMPERATURE VS ALTITUDE
ALTITUDE KM
0
10
20
30
40
50
60
70
200
300
400
500
600
700
800
TEMPERATURE K

Fig 8c.1

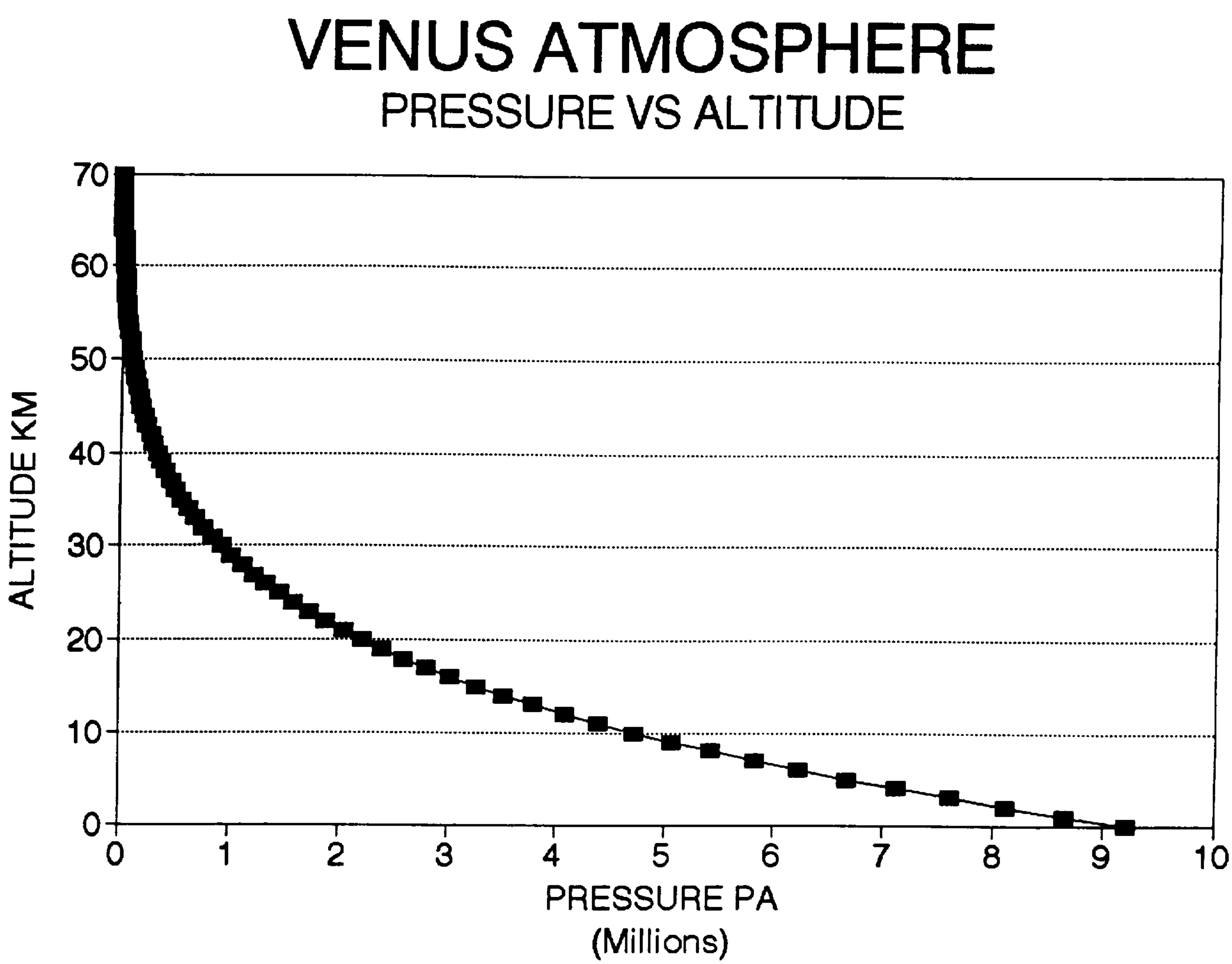

VENUS ATMOSPHERE
PRESSURE VS ALTITUDE
ALTITUDE KM
0
10
20
30
40
50
60
70
0
1
2
3
4
5
6
7
8
9
10
PRESSURE PA
(Millions)

Fig 8c 2

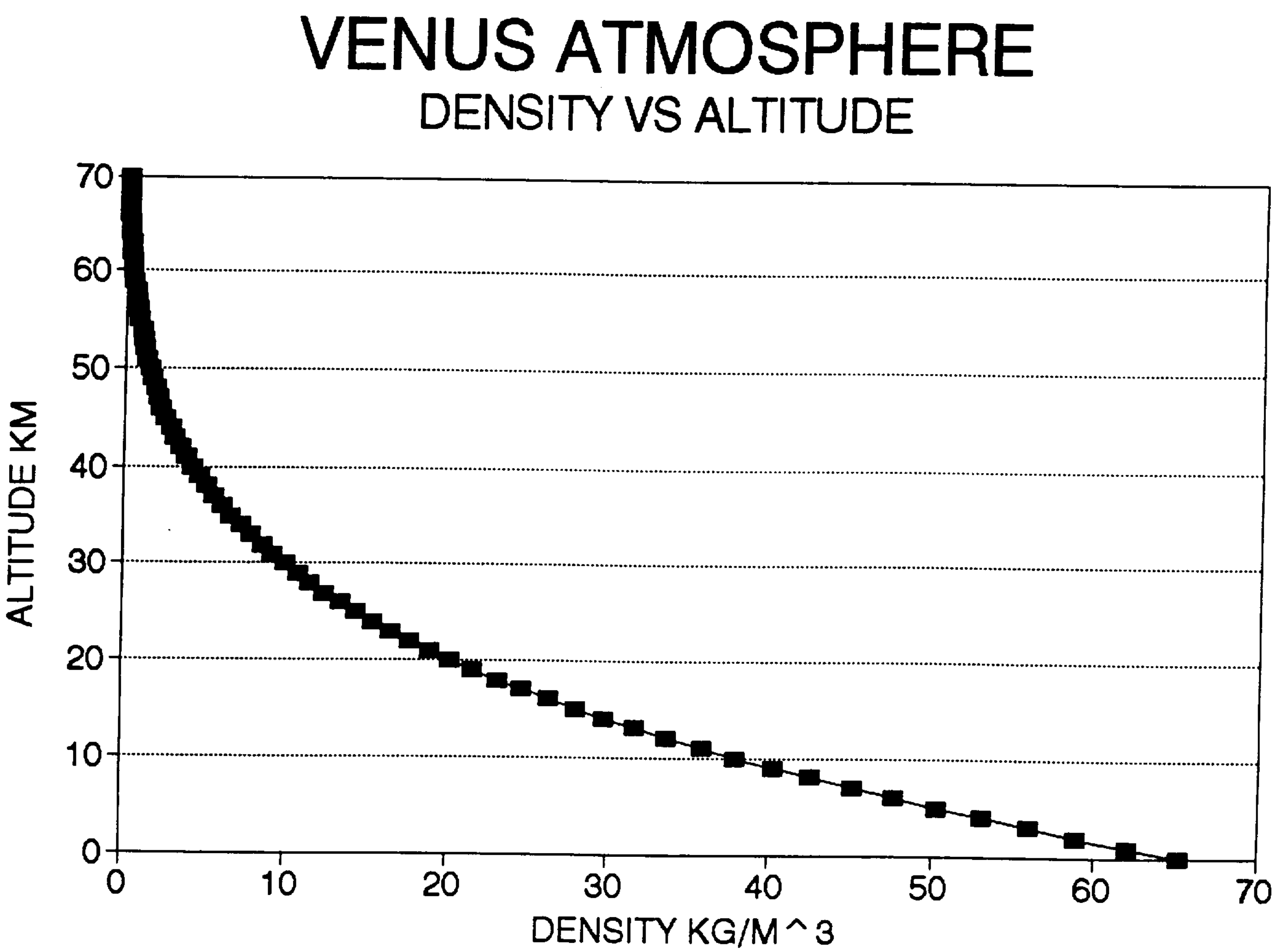

VENUS ATMOSPHERE
DENSITY VS ALTITUDE
ALTITUDE KM
DENSITY KG/M ^ 3
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70

Fig 8c.3

CONDENSATION OF R30 IN 2ND BALLOON
(ESTIMATION)

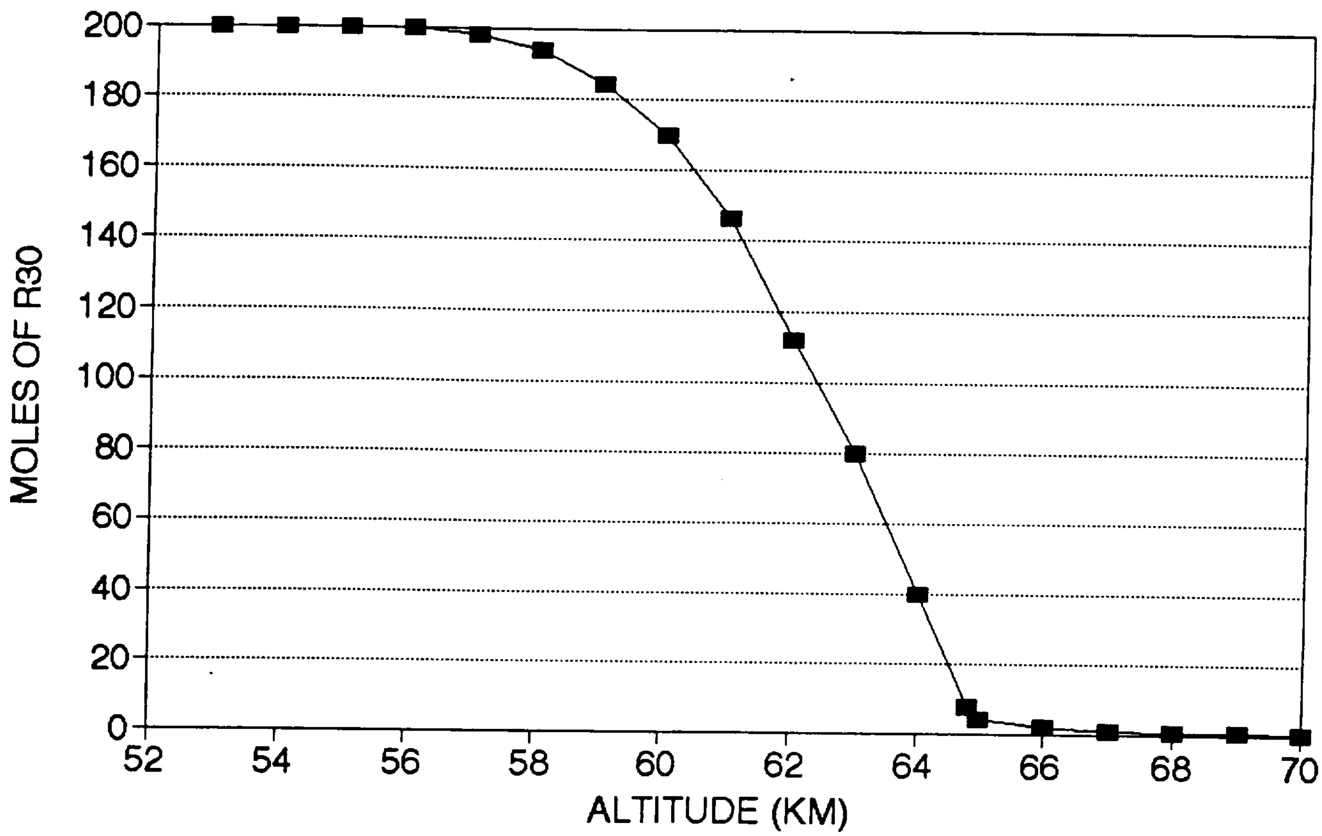


Fig. 8b

The Mathematical Model

Earlier balloon users sought mathematically simple models for predicting balloon ascent rate. The earlier equations were purely dynamics equation. These equations did not include thermodynamic and heat transfer effects and were thus not very accurate.

In our Model, heat transfer effects within the balloon, on the balloon skin and outside the balloon are carefully analyzed. Due to the size of the two balloons, the temperature of the entire system can neither be considered uniform nor equal to that of its immediate environment. A separate section is devoted entirely to the investigation of the transient heat transfer phenomenon of the balloon (see next section). The purpose of this investigation is to obtain a bulk interior temperature as a function of time. This bulk temperature is then incoperated into the set of differential equations of motion to solve for its flight path.

If we assume that the balloon trajectory problem is two-dimensional in nature, then the following differential equations define the model when the balloon is partially full; either when it is floating or when it is moving vertically, upward or downward. As mentioned earlier, the balloon is a free pressure system. Its bulk pressure is assumed to be that of its surroundings at all times. O.K

The differential equations:

(1) $$dV/dt = \{1/(mtot + k*rhog*Vol)\}*[g(rhog*Vol2 + rhogVol1 \; mtot) - 1/2*rhog*Cd*V*|V|*Ap$$

(2) $$V = dh/dt$$

(3) $$Vol1 = n1*R*Tbulk1/P \qquad Vol2 = n2*R*Tbulk2/P$$ (The gas law is assumed)

where:

V = velocity of balloon
mtot = total mass of balloon system
rhog = density of atmosphere at altitude h
g = acceleration due to gravity
Vol1 = volume of hydrogen balloon
Vol2 = volume of R balloon
Tbulk1 = bulk temperature of interior of hydrogen balloon
Tbulk2 = bulk temperature of interior of R balloon
P = external pressure at altitude h
n1,n2 = number of moles of gas
Cd = coefficient of drag
Ap = projected area of balloon
h = altitude of balloon
R = gas constant
k = Virtual mass coefficient

GOOD.

The Drag Coefficient

As advised by Jay Wu of JPL, the drag coefficient of the balloon was assumed to be 0.8 at all altitudes. ±10%?

The Added Mass (Virtual Mass)

The conditions under which the added mass term applies are not too well defined. Generally, the added mass term becomes important when the density of the working fluid (inside the balloon) is lower than that of its environment's (Poter 1993, P97). No data on the mass coefficient was available for balloon shape. We estimated the coefficient to be 0.01. O.K. what is a "mass coefficient"?

Solving the Differential Equation on Quattro Pro

(IT IS A COEFFICIENT DESCRIBING THE MASS OF THE ACCELERATED FLUID)

Equations (1), (2) and (3) were solved simultaneously using the Runge-Kutta Method of order 4. Equation (1) is a second order, non-linear, non-homogeneous differential equation. A step-wised iterative process was used to solve for the velocity and displacement of the balloon system as a function of time.

The time step was staggered from 0.05 sec to 4 sec in successive blocks to ensure convergence. The initial conditions were:

At time t = 0 :

displacement (t=0) = 40000m (balloon is released from entry vehicle)

velocity (t = 0) = -11m/s (as determined from entry calculations)

For a more detailed description, see spreadsheet on appendix N - P.

The generalization of the R-k method for the initial value problem $x' = f(t,x,y)$, $y' = g(t,x,y)$ with $x(t_0) = x_0$, $y(t_0) = y_0$ is :

$$x_{n+1} = x_n + \frac{1}{6}h(k_{n1} + 2k_{n2} + 2k_{n3} + k_{n4})$$
$$y_{n+1} = y_n + \frac{1}{6}h(l_{n1} + 2l_{n2} + 2l_{n3} + l_{n4})$$

where :

$$k_{n1} = f(t_n, x_n, y_n)$$
$$k_{n2} = f(t_n + \tfrac{1}{2}h, x_n + \tfrac{1}{2}hk_{n1}, y_n + \tfrac{1}{2}hl_{n1})$$
$$k_{n3} = f(t_n + \tfrac{1}{2}h, x_n + \tfrac{1}{2}hk_{n2}, y_n + \tfrac{1}{2}hl_{n2})$$
$$k_{n4} = f(t_n + h, x_n + hk_{n3}, y_n + hl_{n3})$$

$$l_{n1} = g(t_n, x_n, y_n)$$
$$l_{n2} = g(t_n + \tfrac{1}{2}h, x_n + \tfrac{1}{2}hk_{n1}, y_n + \tfrac{1}{2}hl_{n1})$$
$$l_{n3} = g(t_n + \tfrac{1}{2}h, x_n + \tfrac{1}{2}hk_{n2}, y_n + \tfrac{1}{2}hl_{n2})$$
$$l_{n4} = g(t_n + h, x_n + hk_{n3}, y_n + hl_{n3})$$

SHOULD BE TYPED (= ERASED)

HEAT TRANSFER

Computer Simulation

The commercial fluid dynamics software, Fluent was used to investigate the heat transfer that occurs between:

a) The balloon skin and the exterior of the balloon
b) The balloon skin and the interior of the balloon
c) The overall heat transfer; the bulk temperature of the balloon system as a function of time

Because of the numerous variables involved and the complexity of the problem, a simplification was made. The balloon was treated as a 2-dimensional object. The problem's complexity arises from the fact 1) that the environmental conditions are constantly changing and 2) the conditions within the balloons are also changing with time. To further simplify the problem, the environmental temperature was held constant. Only the internal conditions of the balloon system were permitted to vary.

A Grid of the balloon was initially created (see Fig 8f). The inlet conditions were taken to be those found at an altitude of 56 km above the Venusian surface. This altitude is crucial because this is the point where the R30 begins to condense. The condensation rate will provide an insight into how much and how soon the balloon loses buoyancy once it passes the 56 km point.

Fluent uses the conventional fluid mechanics equations (Navier- Stokes) and heat transfer equations (Free and Force convection) to generate results. A radiation file was also created in Fluent to model the radiative effects of the balloon and its surroundings. Heat transfer data for R114 was provided by Jay Wu. The overall heat transfer coefficient of the balloon was found to be 4.4 (For computation, see appendix Q). Laminar flow was assumed because of the low velocity of the flow.

Snapshots of the bulk balloon temperatures were taken every 15 minutes (see figures 8 g.1-.5). The whole program took about 8 hours to run and many more hours to create.

Fluent uses a finite difference method to compute results. A time step of 0.1 second was specified initially.

Due to a limitation of the resolution capabilities in Fluent, the skin of the balloon cannot be made as thin as that specified in the actual design specifications. To compensate for this, the thermal conductivity was proportionally increased.

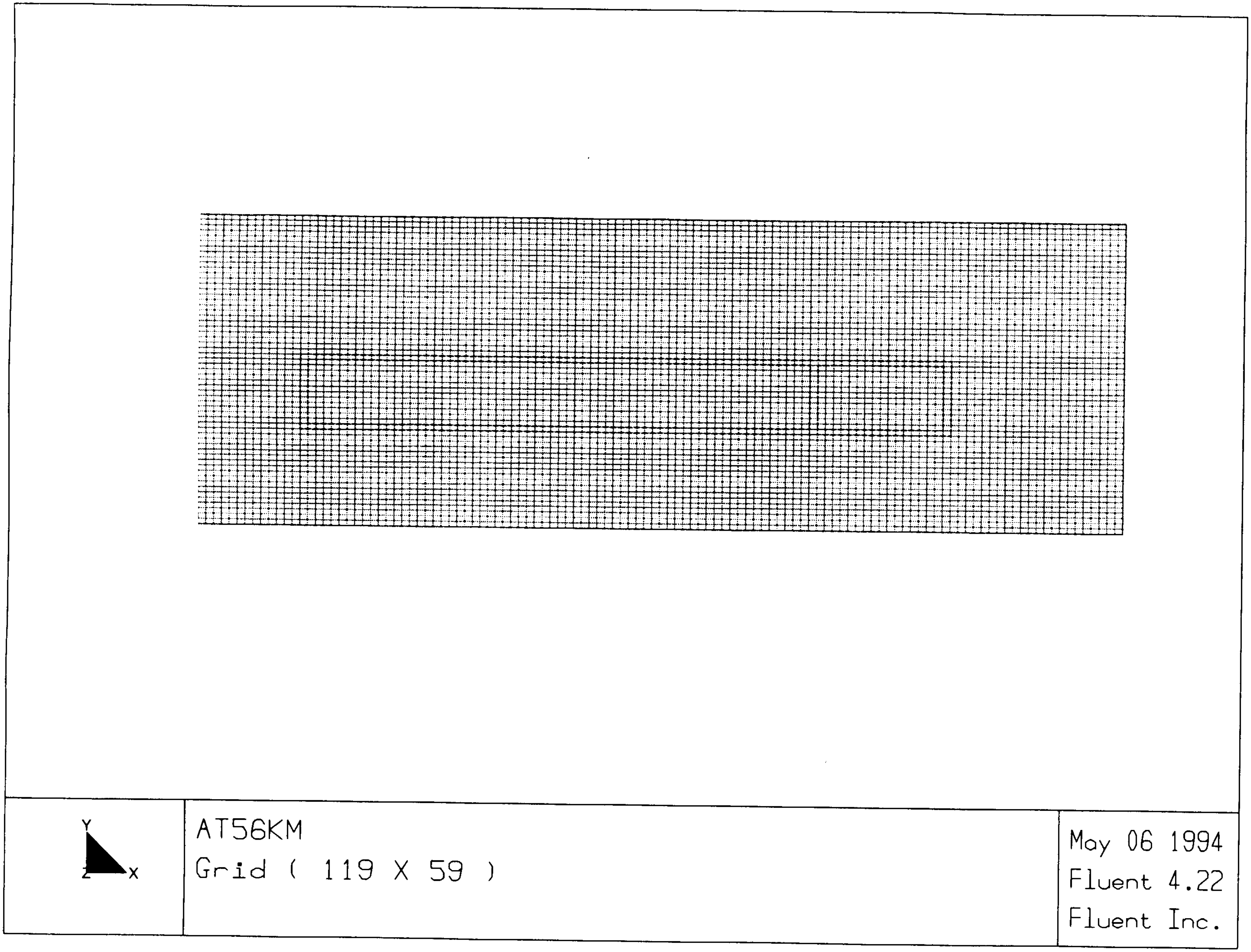
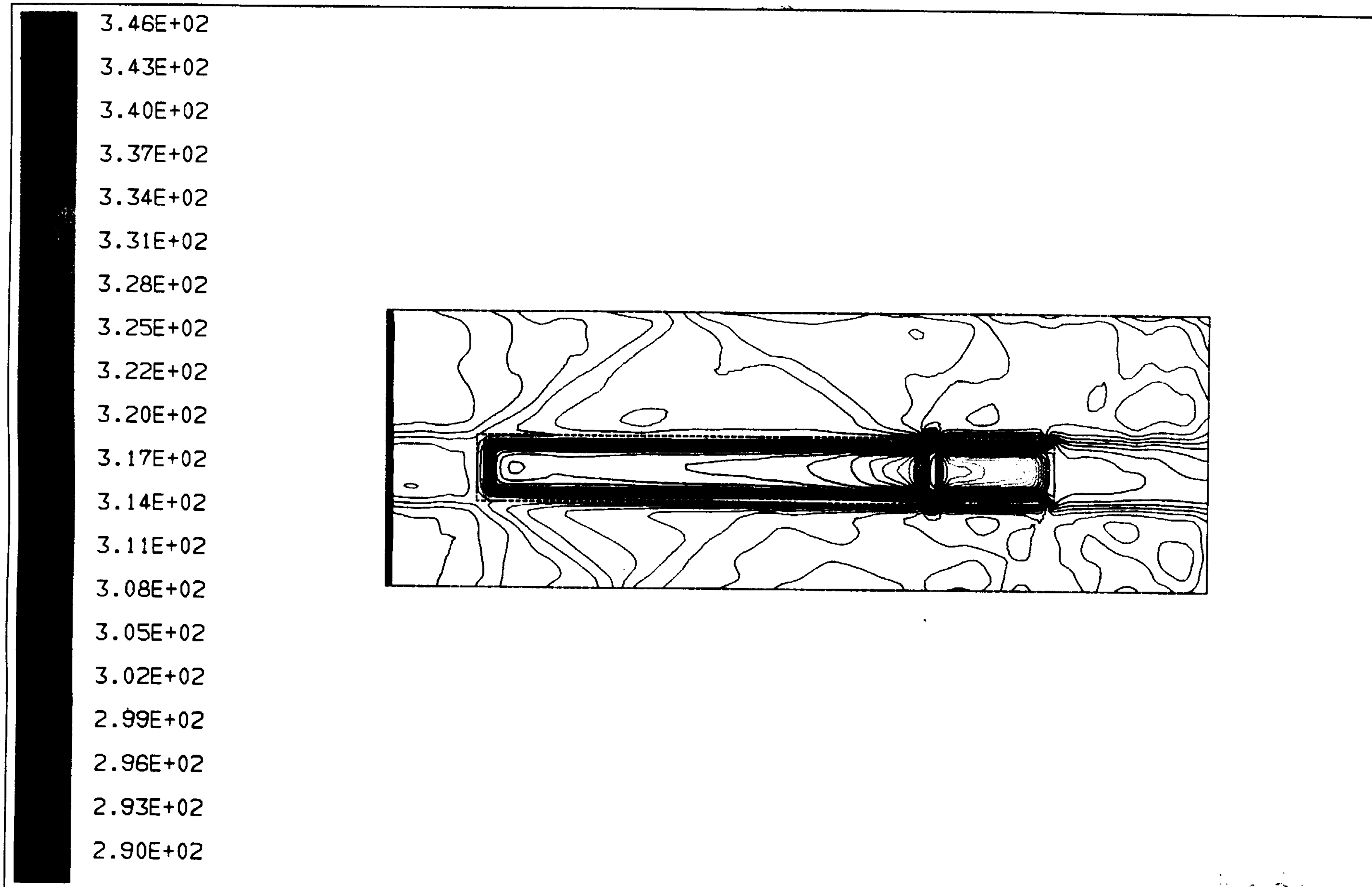
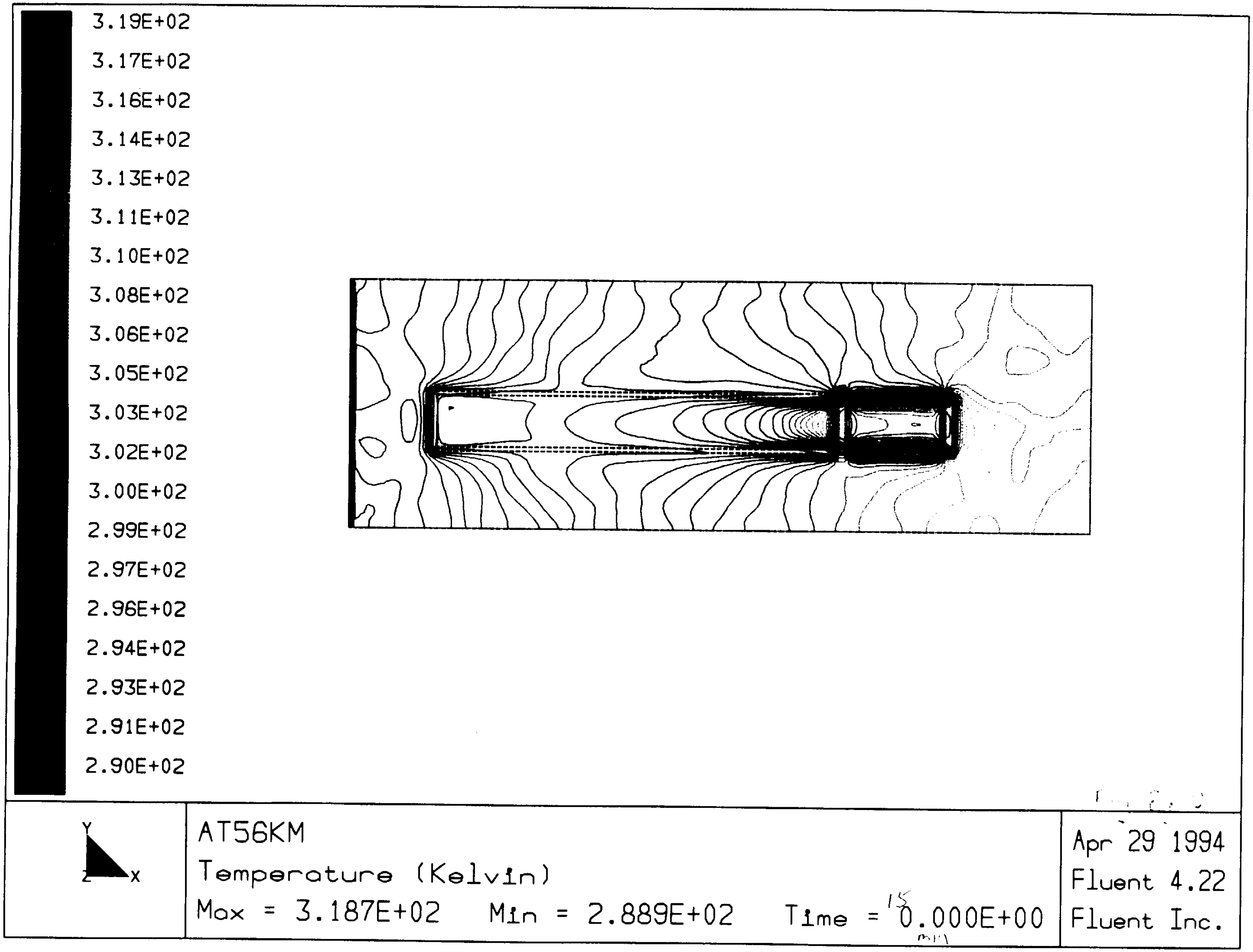


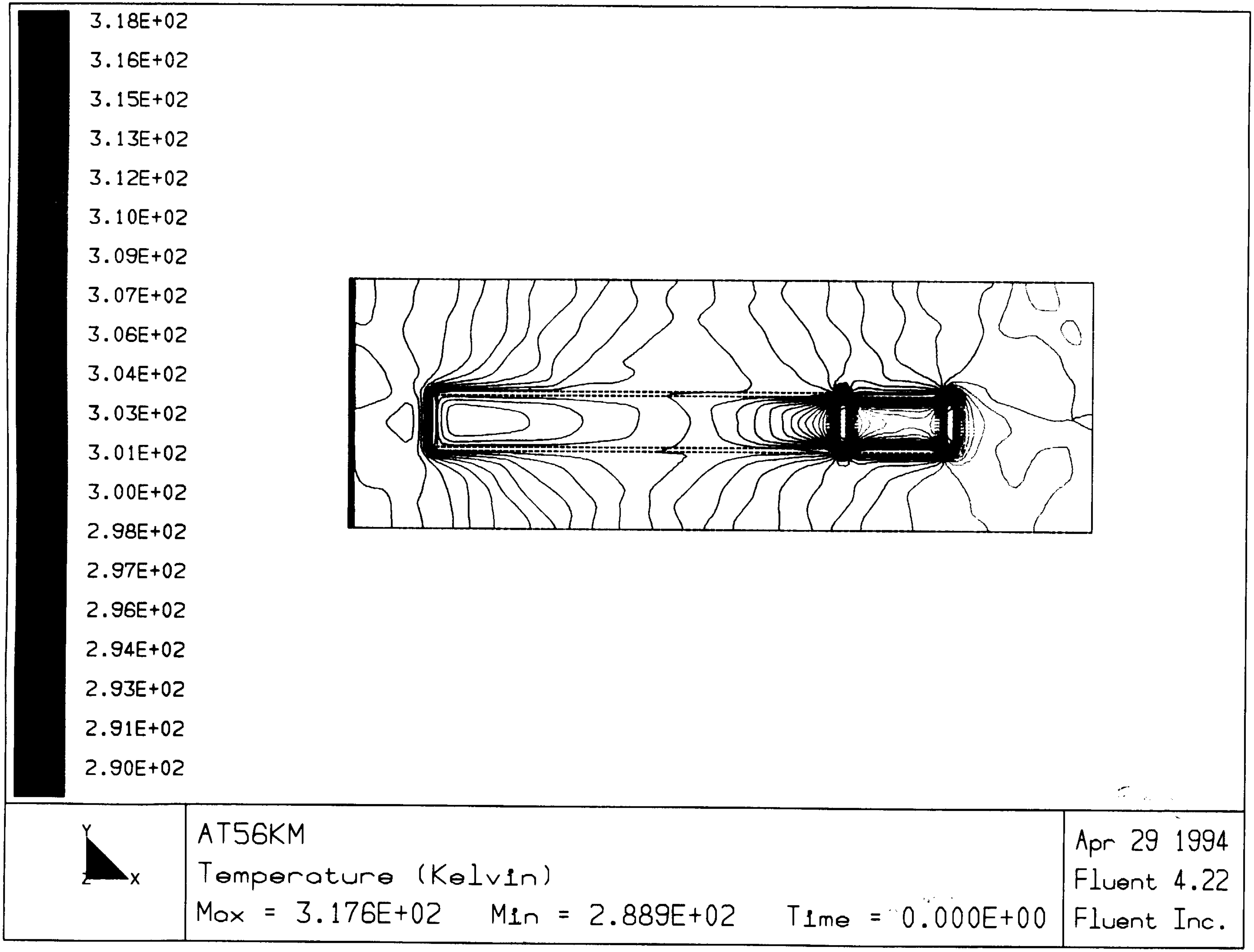
Fig 8 f

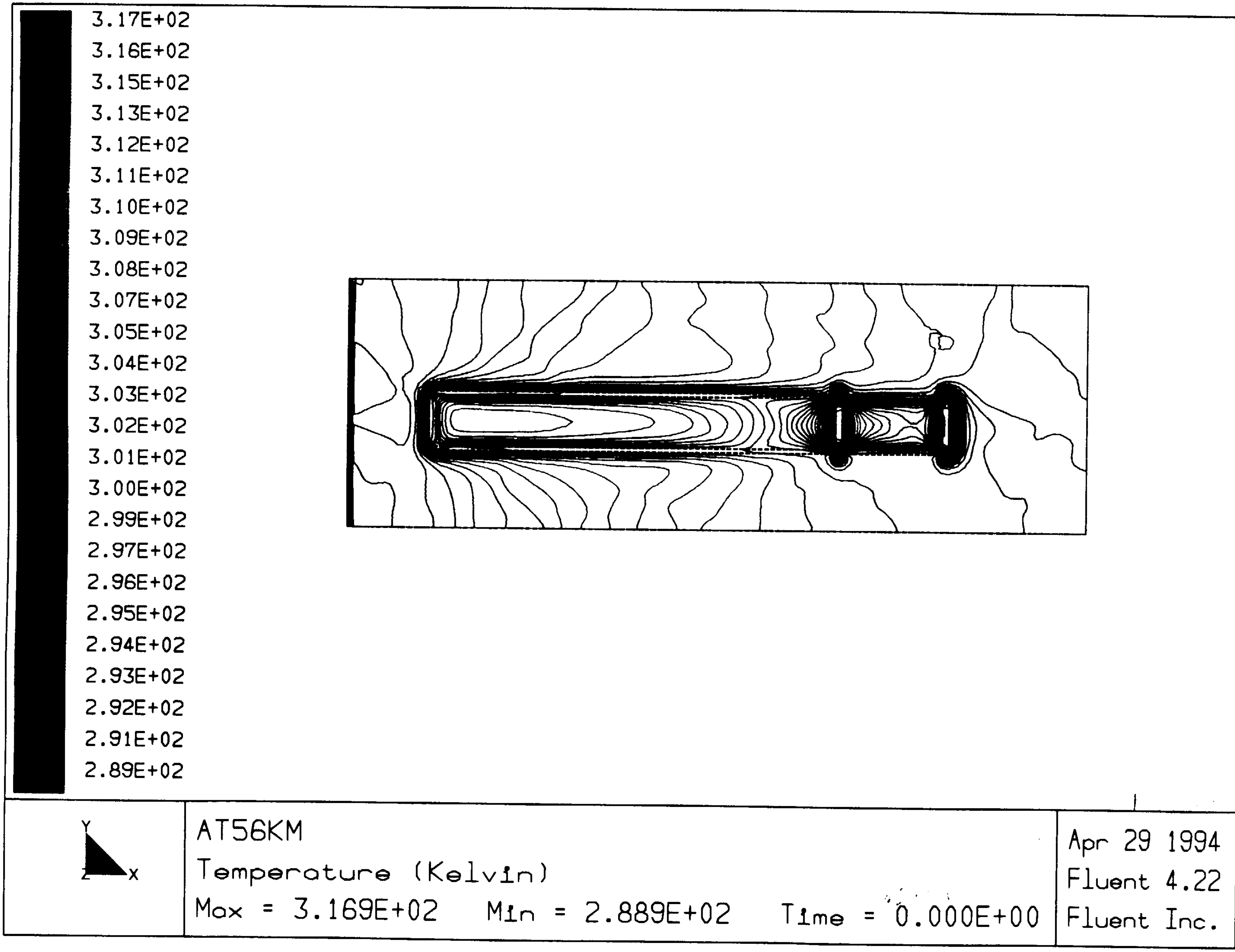


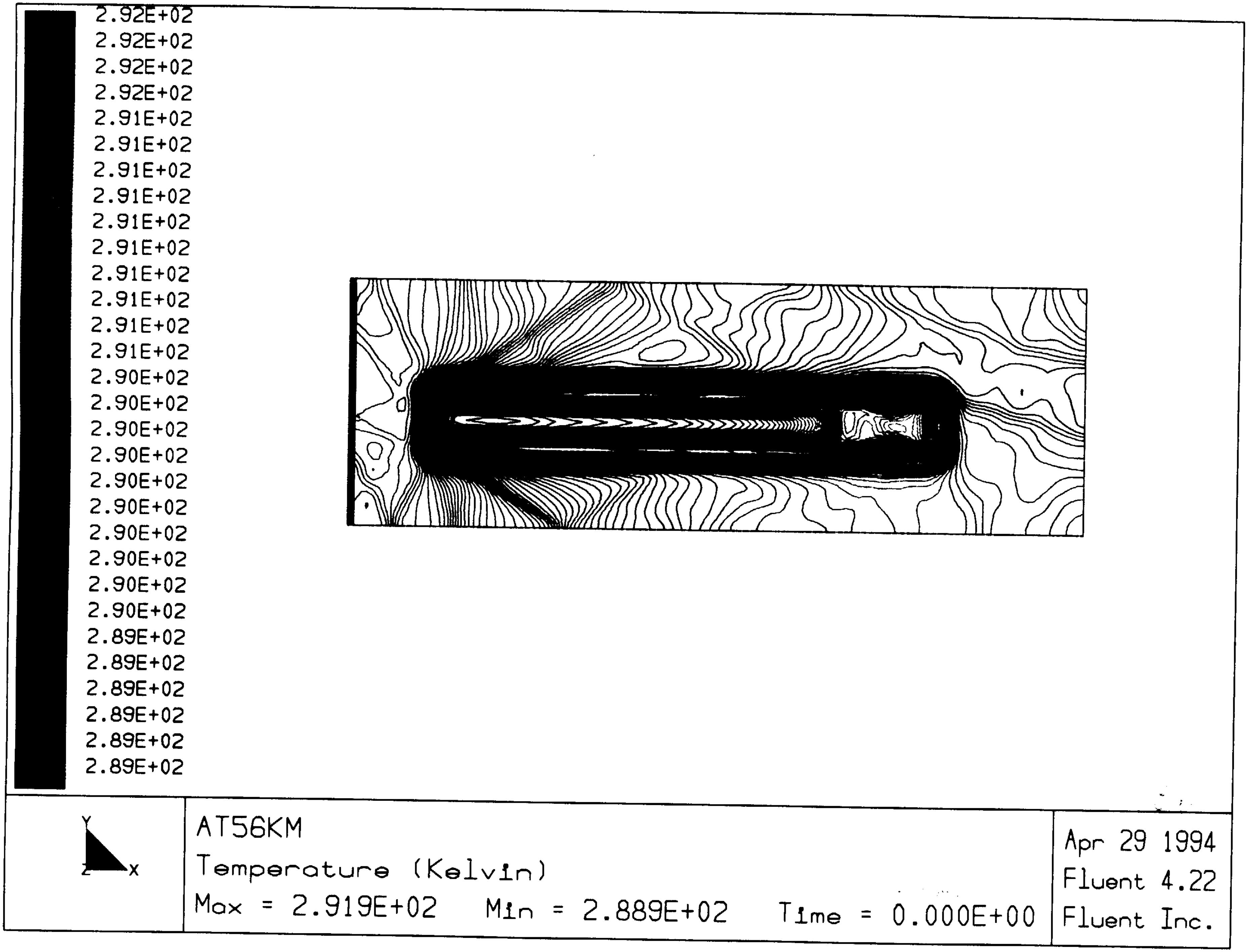
	AT56KM Temperature (Kelvin) Max = 3.458E+02 Min = 2.889E+02 Time = 0.000E+00	Apr 29 1994 Fluent 4.22 Fluent Inc.



3.19E+02
3.17E+02
3.16E+02
3.14E+02
3.13E+02
3.11E+02
3.10E+02
3.08E+02
3.06E+02
3.05E+02
3.03E+02
3.02E+02
3.00E+02
2.99E+02
2.97E+02
2.96E+02
2.94E+02
2.93E+02
2.91E+02
2.90E+02
Y
X
Z
AT56KM
Temperature (Kelvin)
Max = 3.187E+02 Min = 2.889E+02 Time = 15 0.000E+00 min
Apr 29 1994
Fluent 4.22
Fluent Inc.


3.18E+02
3.16E+02
3.15E+02
3.13E+02
3.12E+02
3.10E+02
3.09E+02
3.07E+02
3.06E+02
3.04E+02
3.03E+02
3.01E+02
3.00E+02
2.98E+02
2.97E+02
2.96E+02
2.94E+02
2.93E+02
2.91E+02
2.90E+02
Y
X
Z
AT56KM
Temperature (Kelvin)
Max = 3.176E+02 Min = 2.889E+02 Time = 0.000E+00
Apr 29 1994
Fluent 4.22
Fluent Inc.


3.17E+02
3.16E+02
3.15E+02
3.13E+02
3.12E+02
3.11E+02
3.10E+02
3.09E+02
3.08E+02
3.07E+02
3.05E+02
3.04E+02
3.03E+02
3.02E+02
3.01E+02
3.00E+02
2.99E+02
2.97E+02
2.96E+02
2.95E+02
2.94E+02
2.93E+02
2.92E+02
2.91E+02
2.89E+02
Y
X
Z
AT56KM
Temperature (Kelvin)
Max = 3.169E+02 Min = 2.889E+02 Time = 0.000E+00
Apr 29 1994
Fluent 4.22
Fluent Inc.


2.92E+02
2.92E+02
2.92E+02
2.92E+02
2.91E+02
2.91E+02
2.91E+02
2.91E+02
2.91E+02
2.91E+02
2.91E+02
2.91E+02
2.91E+02
2.91E+02
2.90E+02
2.90E+02
2.90E+02
2.90E+02
2.90E+02
2.90E+02
2.90E+02
2.90E+02
2.90E+02
2.90E+02
2.89E+02
2.89E+02
2.89E+02
2.89E+02
2.89E+02
2.89E+02
Y
X
Z
AT56KM
Temperature (Kelvin)
Max = 2.919E+02 Min = 2.889E+02 Time = 0.000E+00
Apr 29 1994
Fluent 4.22
Fluent Inc.

Results

The Table below shows the bulk temperature of the system as a function of time.

TIME (mins)	HYDROGEN BALLOON (K)	R30 BALLOON (K)
0	315	328
15	304	314
30	300	308
60	291	301
180	291	292

Table 4. The bulk temperature as a function of time.

Fig 8h on the following page shows a plot of the above results. As expected, the R30 balloon took a longer period of time to equilibrate thermally (compared to the H2 balloon).
Looking at the curves of the temperature vs. time plots, it can be inferred that the bulk temperature of the hydrogen balloon is about 20 Celsius higher than the surrounding during its ascend and about 20 Celsius lower during its descend.

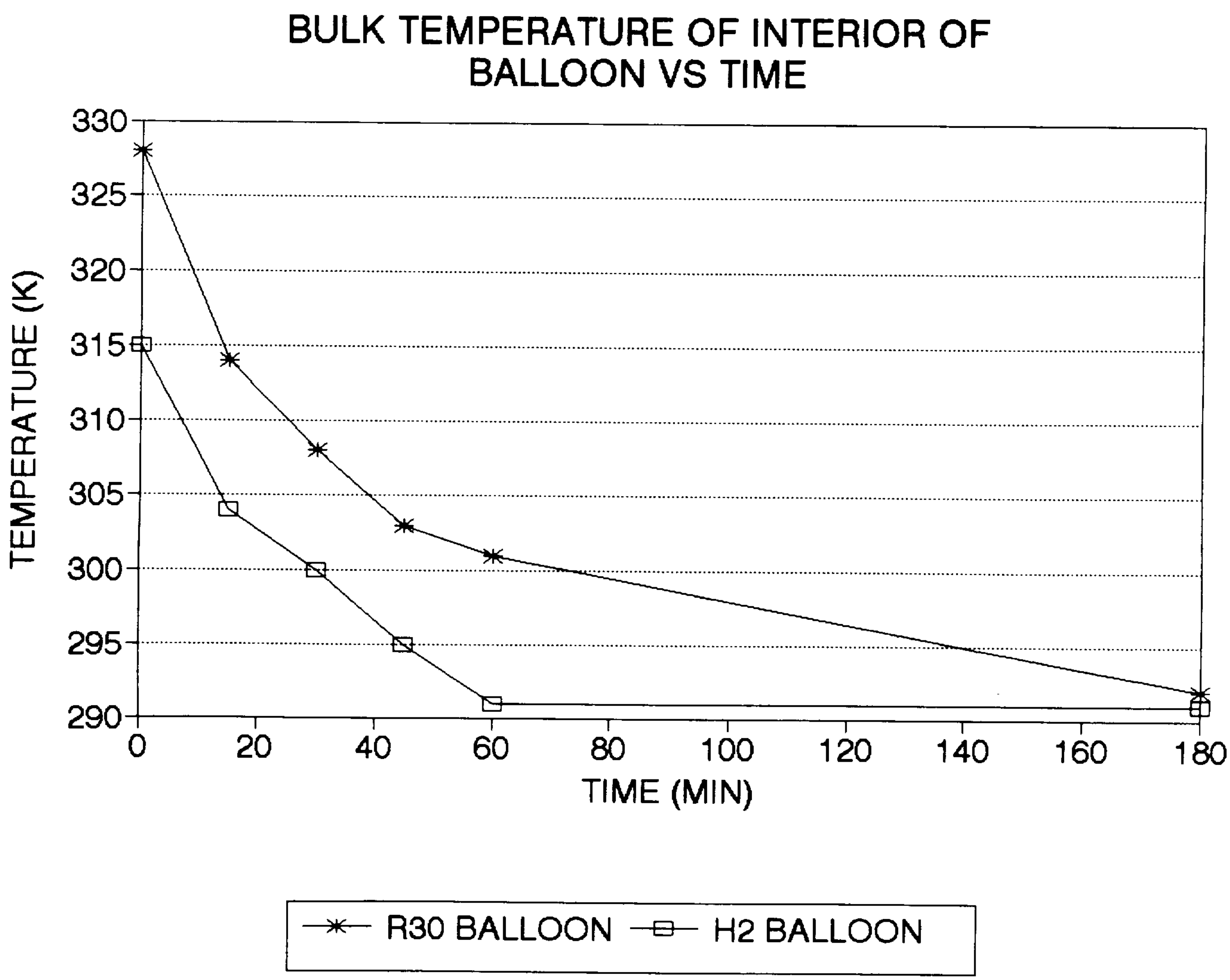
This is how it is approximated:

At altitude = 56 km and at time t = 0
Environment Temp. = 289
H2 Balloon Temp. (initial guess) = 315 K
Temperature difference = 25 degrees
At time = 20 minutes later, balloon temperature has dropped to 303 Celsius.

O.K.

At altitude = 59 km and at time t = 20 minutes
(Based on an ascend rate of 3 m/s at that height)
Environment Temp. = 282 degrees
H2 Balloon Temperature = 303 Celsius
Temperature difference = 21 degrees

At altitude = 64 km and at time t = 40 minutes
(Based on an ascend rate of 4 m/s at that height)
Environment Temp. = 276 degrees
H2 Balloon Temperature = 296 degrees
Temperature difference = 20 degrees



BULK TEMPERATURE OF INTERIOR OF
BALLOON VS TIME
TEMPERATURE (K)
330
325
320
315
310
305
300
295
290
0
20
40
60
80
100
120
140
160
180
TIME (MIN)
R30 BALLOON
H2 BALLOON

Fig 8h

Hence it can be seen from the reasoning in the preceding pages that the difference between the interior bulk temperature of the H2 balloon and the environment will converge to approximately 20 degrees. Following the same line of reasoning, it was found that the bulk temperature of the R30 balloon is about 22 degrees higher than the surrounding at all altitudes during the ascend cycle.

HOW MANY RETURNS WERE USED? THIS SHOULD COMPLY WITH THE FORMAT OF THE ENTIRE REPORT.

On the descend cycle, the temperature difference is reversed. With this knowledge, we went back to the initial spreadsheet (see appendix N) to create the 'columns' for the 'bulk H2 balloon temperature' and 'bulk R30 balloon temperature'. The Runge-Kutta algorithm addresses these cells during its iterative process. This is how we incooperate the Fluent results into Runge-Kutta process.

AVOID USING 1ST PERSON IN FORMAL WRITING.

Difficulties involved and assumptions made: Good Summary!

The difficulties involved in modelling the balloon trajectory are numerous:

- o Lack of data on condensation of R30 above 56 km
- o Lack of data on important heat transfer coefficients
- o Lack of precise formulas for calculating drag coefficients
- o Lack of data on R30 (JPL was unable to forward any data on R30 to us; however, data on Freon R114 was forwarded instead.) } Is it in CRC Book of Chemistry?
- o Lack of references on space balloon trajectories
- o Lack of data on Venusian wind conditions
- o Scope of problem was too wide
- o Initial velocities had to estimated for the calculation of the Reynold's number
- o Lack of information on dimensions of system
- o Difficulties in solving a system of non-linear differential equations
- o Radiative properties of R30 were not available
- o No data on solar intensity below the 60 km was available

Assumptions

- o Initial mass of various components were estimated
- o 3-dimensional problem was reduced to 2-dimensional for ease of treatment
- o Wind forces were ignored
- o Condensation rate of R30 was estimated
- o Initial gas requirements (no. of moles required) were estimated
- o Initial velocities were estimated
- o Both internal and external flow were estimated to be laminar
- o Balloon skin thickness was estimated
- o Radiative properties of R30 were estimated
- o Fluent has a great deficiency; it cannot model a balloon that changes in size constantly. As the balloon rises, its bulk temperature will decrease. If the volume of the balloon remains constant, the interior of the balloon will develop a negative pressure. In our model, this effect is ignored — interesting

- WAS SOLAR HEATING CONSIDERED? IF NOT, IT SHOULD PLAY A MAJOR ROLE, & THEREFORE SHOULD NOT BE NEGLECTED.

RESULTS

The velocity of the balloon after the initial release stabilizes after 3 seconds (see Fig 8d.1). The balloon continues to rise up to a maximum height of 64 km. At this height it is far enough above the cloud layer to permit clear transmission (see Fig 8d.2). This occurs three hours after deployment. The maximum velocity attained by the balloon was found to be 4 m/s (see Fig 8d.3).

When most of the gas in the secondary balloon has condensed, the downward forces predominate and the balloon system descends. The condensed fluid seeps into a heat exchanger at the base. As the balloon passes the 56 km altitude, the R evaporates again due to the increase in temperature. To prevent this, a valve at the neck of the heat exchanger closes, trapping the condensed R. The balloon continues to descend until the valve opens, releasing the superheated R. For a more detailed trajectory description, see Figs 8e.1-3.

The condensation rate of R30 had to be estimated. No data on this phenomenon was available. This had led to some discrepancies between the predicted result and the actual result generated by the Runge-Kutta algorithm. Figure 8d.2 shows that the balloon remains afloat at an altitude of about 54 km after its initial deployment. The balloon is expected to descend as it loses buoyancy. This discrepancy cannot be resolved until more information on the condensation rate is made available to us.

How long are we going to stay up there? Period of each cycle? At these point, these answers cannot be answered because JPL has not provided us with any specific requirements. The cycle period can be adjusted according to cooling needs of the instruments within the gondola and transmission requirements. At this point we do not have any information on these requirements.

VENUS BALLOON (VELOCITY VS TIME)

INITIAL RELEASE AT 40 KM AGL

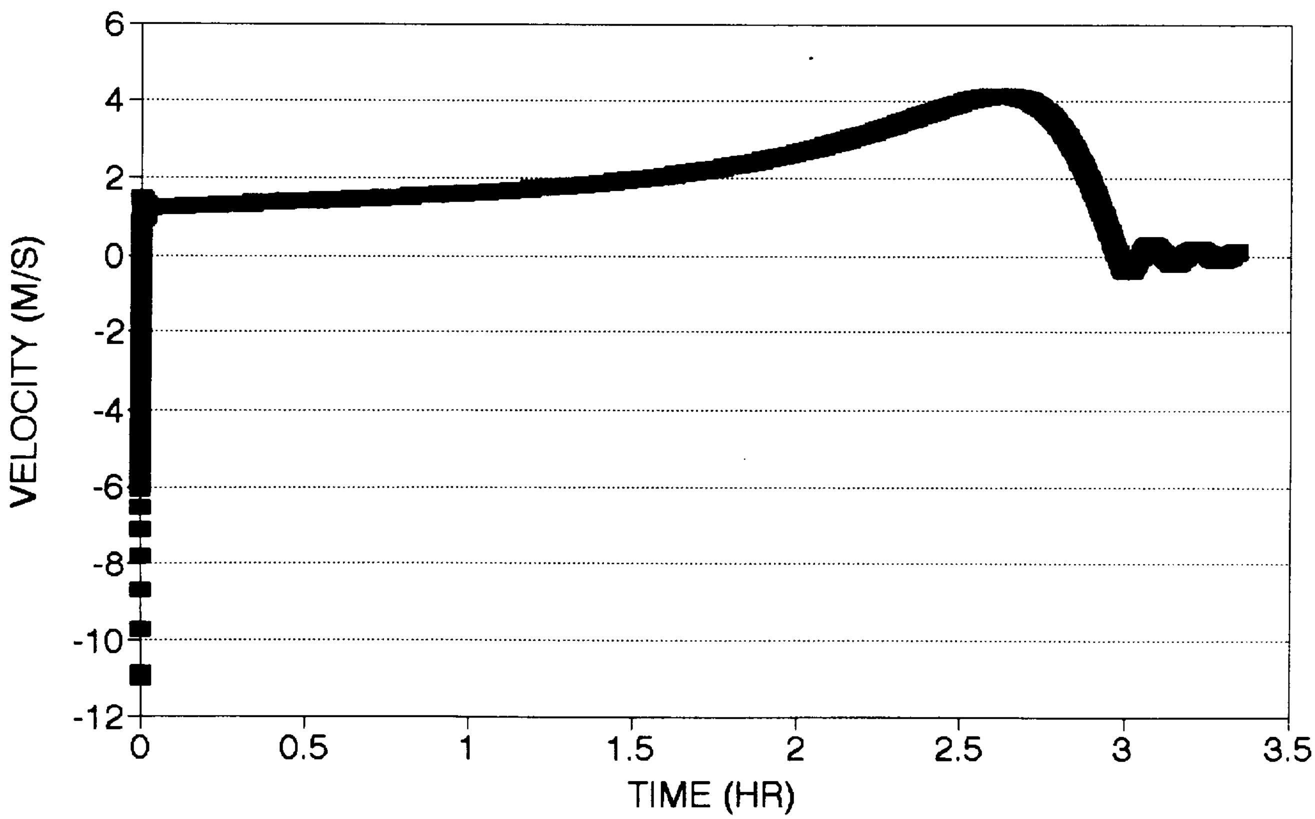


Fig 8d.1

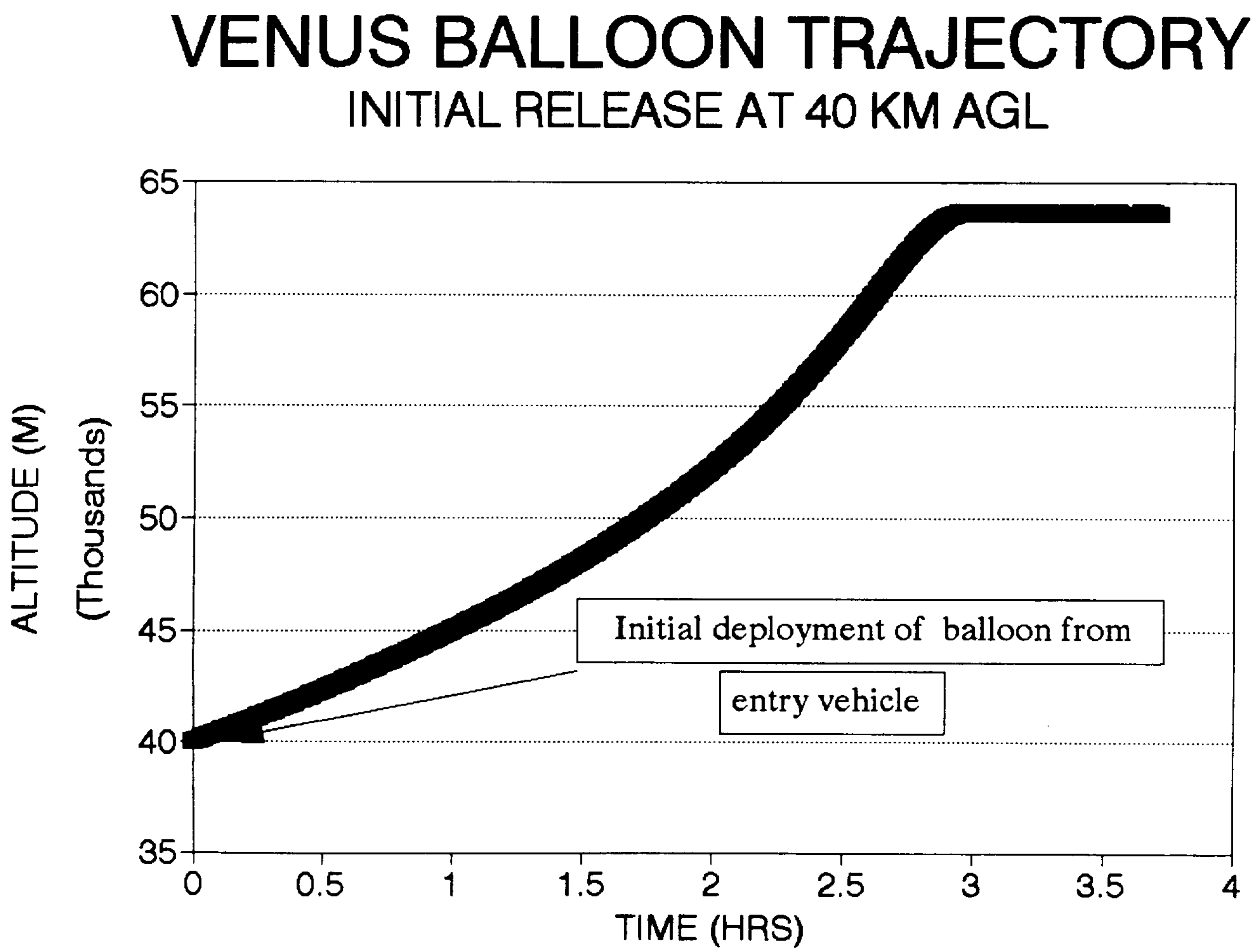

VENUS BALLOON TRAJECTORY
INITIAL RELEASE AT 40 KM AGL
ALTITUDE (M)
(Thousands)
65
60
55
50
45
40
35
0
0.5
1
1.5
2
2.5
3
3.5
4
TIME (HRS)
Initial deployment of balloon from
entry vehicle

Fig 8d.2

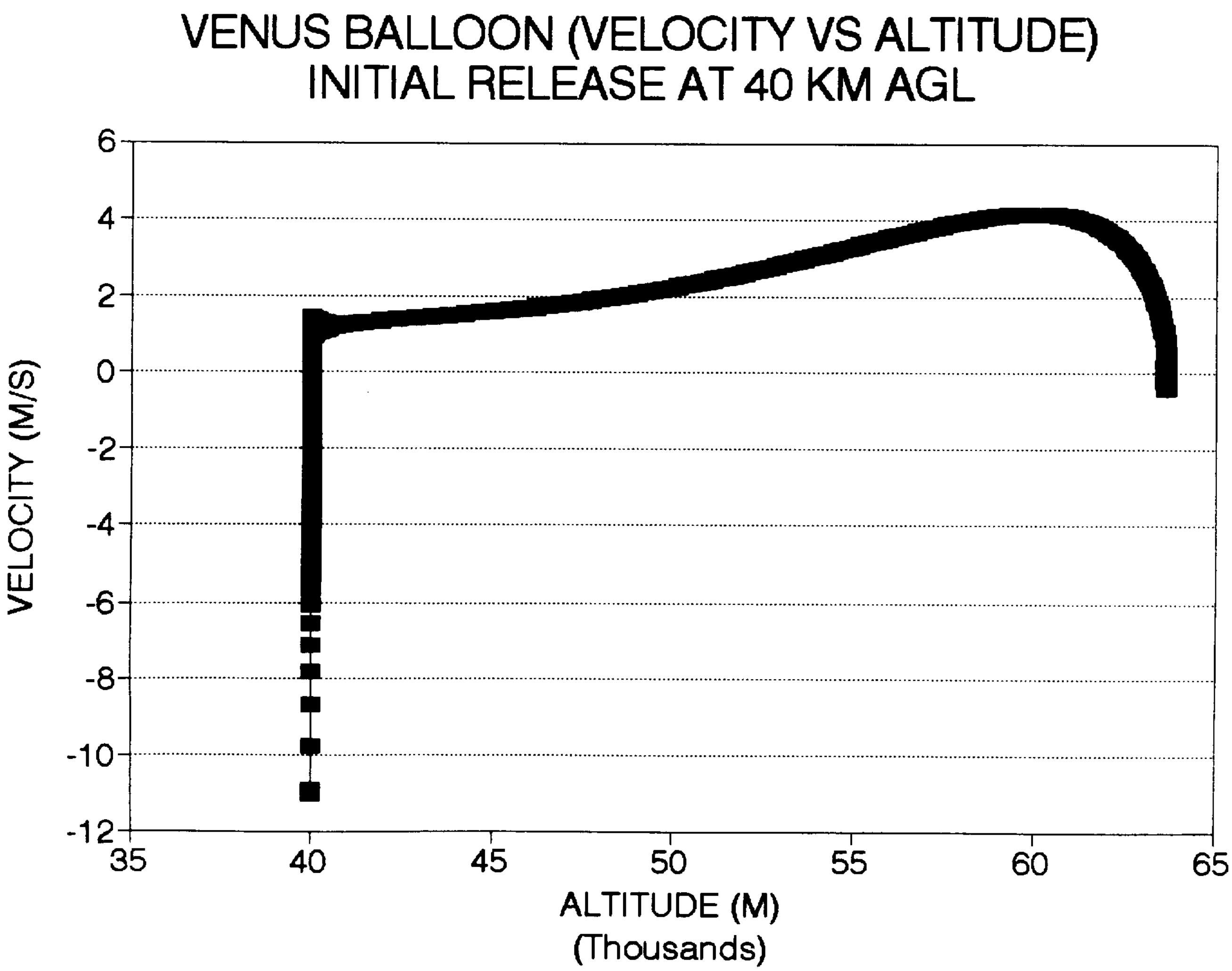

VENUS BALLOON (VELOCITY VS ALTITUDE)
INITIAL RELEASE AT 40 KM AGL
VELOCITY (M/S)
6
4
2
0
-2
-4
-6
-8
-10
-12
35
40
45
50
55
60
65
ALTITUDE (M)
(Thousands)

Fig d.3

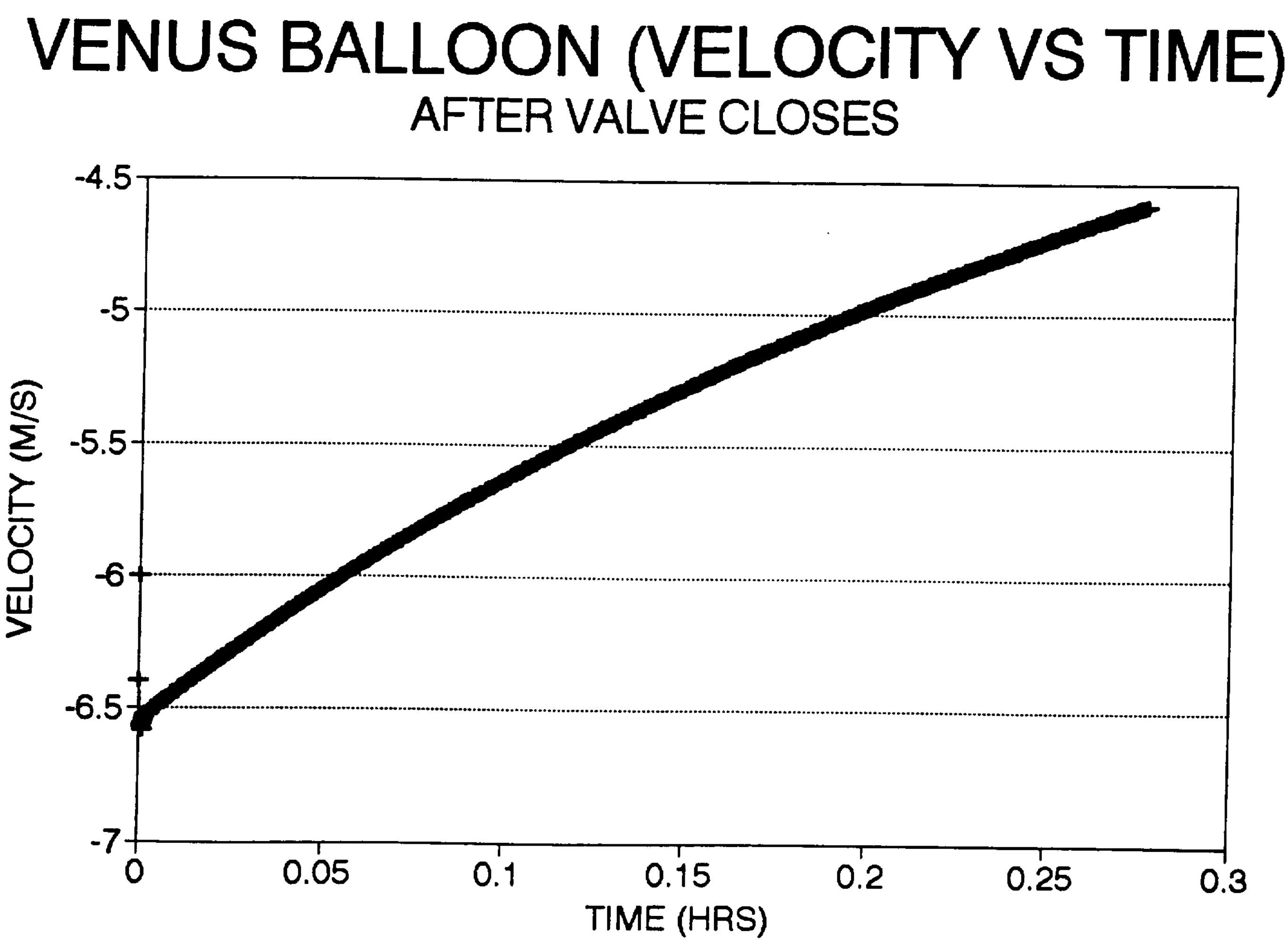

VENUS BALLOON (VELOCITY VS TIME)
AFTER VALVE CLOSES
-4.5
-5
-5.5
-6
-6.5
-7
VELOCITY (M/S)
0
0.05
0.1
0.15
0.2
0.25
0.3
TIME (HRS)

Fig 8e.1

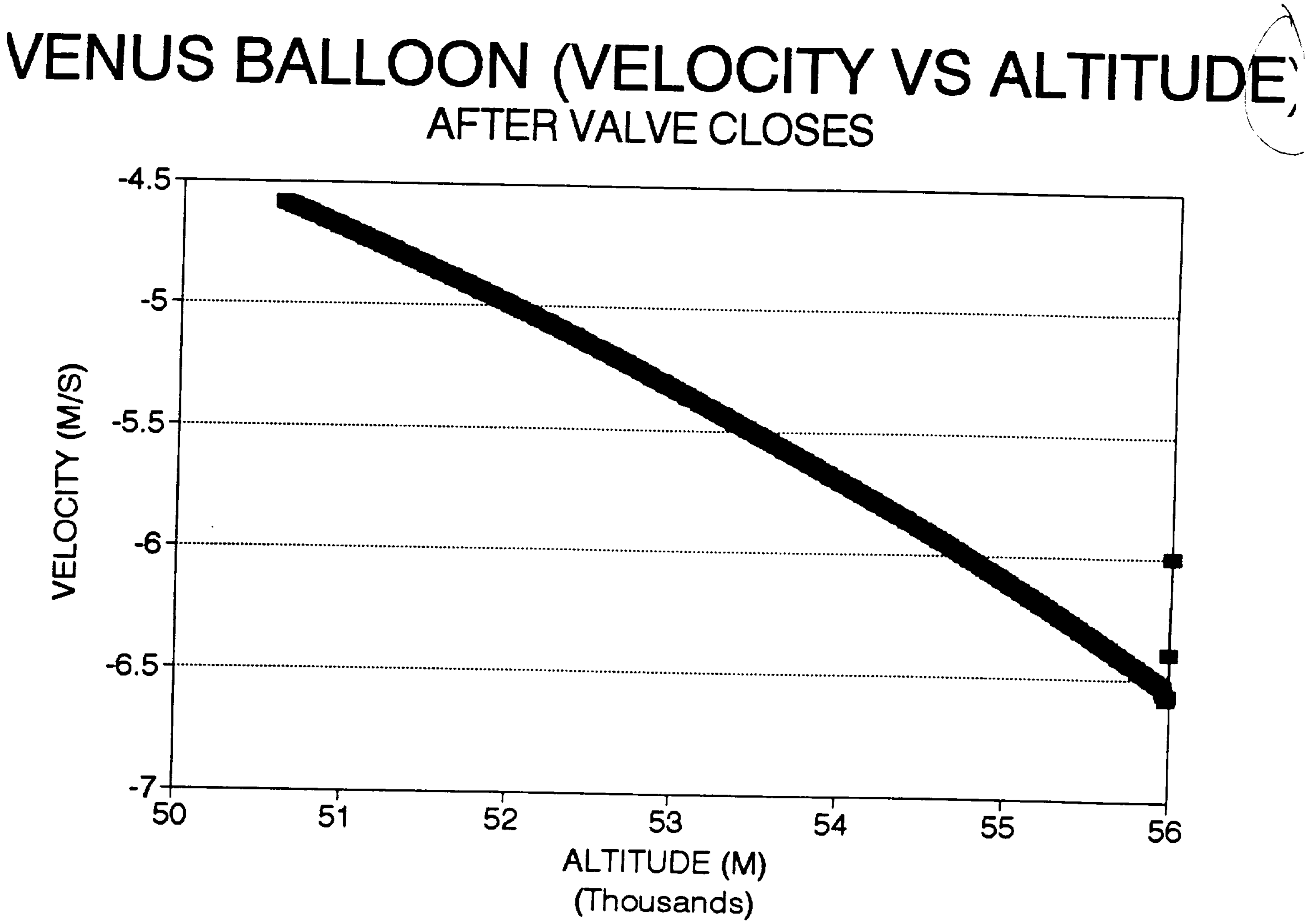

VENUS BALLOON (VELOCITY VS ALTITUDE)
AFTER VALVE CLOSES
VELOCITY (M/S)
-4.5
-5
-5.5
-6
-6.5
-7
50
51
52
53
54
55
56
ALTITUDE (M)
(Thousands)

Fig 8e.2

VENUS BALLOON TRAJECTORY
AFTER VALVE CLOSES

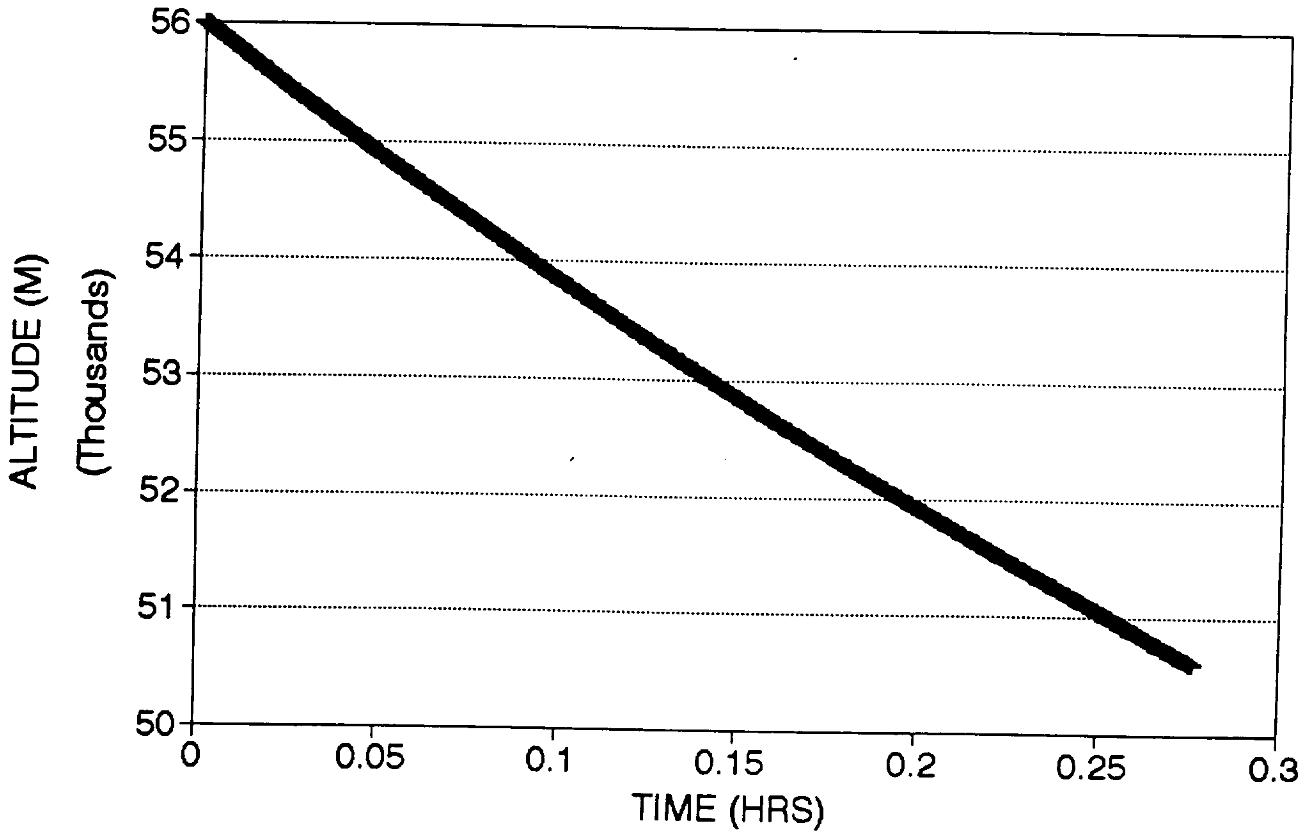


Fig 8e.3

The Need for a Heat Exchanger

To accurately control the height of the balloon versus time a heat exchanger was added to the system. When the balloon reaches a height of 56 km, the gaseous methylene chloride, which was providing buoyancy, will condense into a liquid. This reduces the lift force and the balloon will fall. It is the job of the heat exchanger to capture the condensed liquid and provide enough heat where the liquid will turn back into a gas. A valve will control the flow of the vaporized or condensed liquid.

Vaporizing the Phase Changing Material

The first step is to calculate the energy required to vaporize the liquid. To find the heat of vaporization (ΔH_V) we can use the 2 point form Clausius - Clapeyron Equation.

$$\log (P_2 / P_1) = (\Delta H_V / 2.303 * R) * (1/T_1 - 1/T_2)$$

where P is the pressure,
T is the temperature,
R is the gas constant.

The 1 and 2 represent different states as found on the Van't Hoff plot. The heat of vaporization is found to be 31682.5 Joules / mole (Appendix R- U). To vaporize all 200 moles of methlyene chloride it would take 6336.5 KJ.

Now we want to calculate the energy required to heat the fluid from 333K to 366 K. This energy is given by

$$E = \Delta T * \text{heat capacity}$$

The heat capacity for methylene chloride is 99997.6 J/degree. The total energy to heat the fluid is 3299.9KJ. Now we need to put in 9636.4 KJ of energy to ~~heat the fluid up and to~~ vaporize it to a gas.

Size of Heat Exchanger and Stresses Involved

One limiting factor in the size of the heat exchanger is the space that it will require inside of the entry vehicle. For this reason it must be smaller than 13.8 inches long. By knowing the density of the liquid and the mass of the liquid, the volume can be found. In this case it was 0.013 m^3. Next an optimizing sequence was done to find the best radius, length, and thickness that would hold the liquid and resist the pressure involved from the phase change (Appendix V-X).

In this analysis of the stresses we will treat it as a thin walled cylindrical pressure vessel. The stress that we are concerned with is the hoop stress given by

$$\sigma_1 = P * r / t$$

Where P is the gage pressure,
r is the radius,
t is the thickness.

THERMAL STRESSES & STRAINS ?

The gage pressure is the difference in pressure between the inner pressure and the atmospheric pressure. For this model we will be using an aluminum shell with a yield stress of 416 M Pa. The final dimensions of the heat exchanger is a 0.1143 m inner radius cylinder 0.3117 m in length with a thickness of 0.0138 m. The final mass of this unit is 8.5 kg.

WHAT TYPE OF AL?

Concept of a Heat Exchanger

At low altitudes we have a hot fluid, the carbon dioxide atmosphere flowing across a vertical tube which contains the phase changing material, methylene chloride. The temperature difference between the atmosphere and the inner fluid will cause energy to transfer and heat up the methylene chloride changing it from a liquid to a vapor. The three types of heat transfer present are conduction, radiation, and convection. For all three types of transfer we assumed a one dimensional, steady state, vertical cylinder without fins. Other assumptions made are noted in the sections.

Conduction

Conduction will tell how much heat is lost through the walls of the heat exchanger.
This is given by

$$q = -k A (dT / dx)$$

where q is the heat rate in Watts,
k is the thermal conductivity of the material,
A is the exposed area,
dT/dx is the temperature gradient (Incropera).

The negative sign shows that heat is transferred to the cooler side of the material. For a thin member we can assume this to be negligible but in our case this was calculated. In reality this is a two dimensional transient problem but due to the slow velocity, the material will have time to come to equilibrium with the surroundings. The calculations to prove this assumption can be found in Appendix Y.

JUSTIFY (YOU DON'T PROVE ASSUMPTIONS) (IF YOU CAN PROVE IT, IT ISN'T AN ASSUMPTION)

Radiation

Radiation will tell how much heat is gained and reflected to the atmosphere. The general equation is given by

$$q = A\,\varepsilon\,\sigma\,(T_s^4 - T_{sur}^4)$$

where q is the heat rate in Watts,
A is the exposed area,
ε is the emissivity of the material,
σ is the Stefan-Boltzmann constant,
T_s and T_{sur} are the temperatures of the atmosphere and surface of the material respectively (Incropera).

This equation will give us the heat rate from the atmosphere to the balloon, but it can also give us the heat rate from the balloon to the methylene chloride gas by changing the subscripts on the temperature to surface and gas respectively. We also need to consider the amount that is absorbed from solar radiation. The solar flux Venus receives is 2600 W/m^2 of which 132 W/m^2 is absorbed. It is the latter number that we use to calculate how much solar flux is absorbed by the heat exchanger. The calculations can be found in Appendix Z.

GOOD!

Forced Convection

This is the greatest source of heat transfer to the cylinder. The heat rate for convection is given as

$$q = h\,A\,(T_{sur} - T_s)$$

where q is the heat rate in Watts,
A is the exposed area,
h is the convection coefficient,
T_s and T_{sur} are the temperatures of the atmosphere and surface of the material respectively (Incropera).

WHICH WOULD BE MUCH GREATER IF A FINNED TUBE WAS USED.

In order to find the convection coefficient we need to calculate the Reynolds (R_e) and Nusselt (N_u) numbers. This will be treated as external flow over a cylinder where the following equations apply

$$R_e = V D / v$$

$$N_u = C R_e^m Pr^{(1/3)}$$

$$h = N_u \ k / D$$

where V is the velocity of the wind,
D is the diameter of the tube,
v is the viscosity of the atmosphere,
Pr is the Prandtl number,
k is the thermal conductivity.

C and m are constants dependent on the Reynolds number. Numerical calculations can be found in Appendix AA - AB.

Free Convection

from what?

This is a source of heat transfer to the inside gas. The same general equation applies to free convection. The difference is in the method to find the convection coefficient, h . This is modeled as laminar flow on a vertical isothermal plate where the following equations apply

why not a pipe flow?

$$Gr = g \beta (T_{sur} - T_{gas}) L^3 / v^2$$

$$Nu = (4 g(Pr) / 3) (Gr / 4)^{(1/4)}$$

$$h = Nu \, k / D$$

which quantity?

where Gr is the Grashof number,
β is the volume coefficient of expansion (Incropera).

Calculations for this quantity were not done due to the lack of information of the properties of methylene chloride. Inside the heat exchanger the liquid is boiling and thus the above equations are no longer valid. The equation for pool boiling is

Poor excuse! An effort should have been made with some assumptions

$$q'' = m_l h_{fg} [g (\rho l - \rho v) / \sigma]^{1/3} [Cpl \Delta Te / C_{s,f} (h_{fg}) Pr^n]^3$$

was this solved? - No!

where q'' is the heat flux,
ml is the mass of the liquid,
h_{fg} is the latent heat of vaporization,
σ is the surface tension,
ρ is the density.

The letters v and l represent the vapor and liquid states, $C_{s,f}$ and n are constants (Incropera). (See Appendix AC)

why present this if it was never used?

Problems With Heat Transfer

By doing all of the above calculations, the balloon will receive enough energy to heat and vaporize the liquid that has condensed after two hours. All the calculations done have been based on a steady state model floating between the altitude of 48 to 60 km. This time would actually be longer due to the fact that this is a transient problem and the heat rate is proportional the temperature difference. Another problem is calculating the horizontal winds. The graph in Appendix shows a broad spectrum for the velocity of the wind. The stress calculations show that the heat exchanger will be safe for cycling about the 56 km mark but might not withstand the pressure near the surface. Future work should be done to fully calculate the stresses depending on what range the balloon system will see. The material for the heat exchanger must be lightweight, have a high thermal conductivity and also be able to withstand the pressure near the surface.

CONCLUSION

We believe that our investigation and design as it is defined will provide an added source of literature to the Venus balloon concept. Our preliminary study will lay the ground work to further refinement of the trajectory model. We recommend that actual heat transfer experiment be conducted and results compared against those generated by computer simulation.

Bibliography

Boaz, Mary L., *Mathematical Methods in Physical Sciences,* John Wiley and Sons, Canada, 1983.

Boer, Karl W., ed., *Advances in Solar Energy, volume 7,* Plenus Press, NewYork, 1991.

Boyce, William E., and Diprima, Richard C., *Elementary Differential Equations and Boundary Value Problems, 4th edition,* John Wiley and Sons, New York, 1986.

Camarda, Charles J., *Anaysis and Radient Heating Tests of a Heat-Pipe-Cooled Leading Edge,* National Aeronautics and Space Administration, Springfield Virginia, 1977.

Cheney, Ward, and Kincaid, David, *Numerical Mathematics and Computation, 2nd edition,* Brooks / Cole Publishing Company, California, 1985.

Clark, R. C., and Meinecke, E.A., *Mechanical Properties of Polymeric Foams,* Technomic Publishing, Westport Connecticut, 1973.

Cook, Robert D., and Young, Warren C., *Advanced Mechanics of Materials,,* Macmillan Publishing Company, New York, 1985.

Dike, Paul H., *Thermoelectric Thermometry,* Leeds and Northrup Company Tech. Publishing, Philadelphia Pennsylvania, 1954.

Dueber, Ross E., *Chemical Principles Applied to Spacecraft Operations,* Krieger Publishing Company, Malabar Florida, 1993.

Duncan, Robert C., *Dynamics of Atmospheric Entry,* McGraw-Hill, New York, 1962.

Dwyer, James F., *Factors Affecting the Vertial Motion of a Zero Pressure Polyethylene Free Balloon,* Air Force Geophysics Laboratory, 1985.

Ely, Lawrence D., *Return From Space: An Explanation of Re-entry Problems and Factors of Re-entry Vehicle Design and Performance*, C. C. Thomas, Springfield Illinois, 1966.

Fimmel, Richard O., *Pioneer Venus*, 1983.

Fortescue, Peter W., and Stark, John P.W., ed., *Spacecraft Systems Engineering*, John Wiley and Sons, New York, 1991.

Frisch, Kurt C., and Klempner, Daniel, *Handbook of Polymeric Foams and Foam Technology*, Hanser Publishers, New York, 1991.

Griffin, Michael D., *Space Vehicle Design*, American Institute of Aeronautics and Astronautics, Washington D.C., 1991.

Greenberg, Michael D., *Advanced Engineering Mathematics*, Prentice Hall, Inc., New Jersey, 1988.

Hunten, D.M., Colin, L., Donahue, T.M., Moroz, V.I., editors, *Venus*, The University of Arizona Press, Tucson, Arizona, 1983.

Incropera, Frank P., and DeWitt, David P., *Introduction to Heat Transfer*, John Wiley and Sons, 1990.

Kays, William M., *Convective Heat and Mass Transfer*, 3rd edition, McGraw-Hill, New York, 1993.

Lenk, John D., *ABC's of Thermocouples*, Sams Publishing, 1967.

Lide, David R., ed., *CRC Handbook of Chemistry and Physics, 73rd edition*, CRC Press, Boca Raton, Florida, 1992.

Moran, Michael J., and Shapiro, Howard N., *Fundamentals of Engineering Thermodynamics*, 2nd Edition, John Wiley & Sons, Inc., New York, 1992.

Pollock, Daniel D., *Thermocouples : Theory and Properties*, ASTM, Philadelphia Pennsylvania, 1971.

Pollock, Daniel D., *Thermoelectricty : Theory, Themometry, Tool*, ASTM, Philadelphia Pennsylvania, 1985.

Rainville, Earl D., *Elementary Differential Equations, 7th edition*, Macmillian Publishing Company, New York,

Rapp, Donald, *Solar Energy*, Prentice - Hall, Inc., Englewood Cliffs New Jersey, 1981.

Regan, Frank J., *Dynamics of Atmospheric Re-entry*, American Institute of Aeronautics and Astronautics, Washington D.C., 1993.

Regan, Frank J., *Re-entry Vehicle Dynamics*, American Institute of Aeronautics and Astronautics, Washington D.C., 1984.

Siegel, R., and Howell J., *Thermal Radiation Heat Transfer*, Hemisphere Publishing Corp., Washington, 1981.

Shackelford, James and Alexander, William, ed., *CRC Materials Science and Engineering Handbook*, CRC Press, Boca Raton, Florida, 1992.

Vargaftik, N.B., *Handbook of Physical Properties of Liquids and Gases: Pure Substances and Mixtures, 2nd edition*, Hemisphere Publishing Corp., Washington, 1983.

Weast, Robert C., ed., *CRC Handbook of Chemistry and Physics, 67th edition*, CRC Press, Boca Raton, Florida, 1986.

Wiesel, William E., *Spaceflight Dynamics*, McGraw-Hill, New York, 1989.

Williams, S.D., *Thermal Protection Materials: Thermophysical Property Data*, National Aeronautics and Space Administration, Springfield Virginia, 1992.

Weisel, William E., *Spacecraft Dynamics*, McGraw - Hill, Inc., New York, 1989.

Zak, B.D., *Development of an Adjustable Bouyancy Balloon Tracer of Atmospheric Motion*, 1988.

The Venus Balloon Group had correspondence with the following people.

Professor Fieriesen, at UW-Madison, Mechanical Engineering Department (Fluids)
Professor G. Kulcinski, at UW-Madison, Nuclear Engineering Department
Professor G. Meyers, at UW-Madison, Mechanical Engineering Department (Thermo)
Professor Mitchell, at UW-Madison, Mechanical Engineering Department (Heat Transfer)
Professor R. Reitz, at UW-Madison, Mechanical Engineering Department (Fluid)
Professor Johnson, at UW-Madison, Engineering Mechanics and Astronautics Department
Professor P. Cheng, at UW-Madison, Engineering Mechanics and Astronautics Department
Professor J. Kuelbs, at UW-Madison, Mathematics Department
Professor Frosteric, at UW-Madison, Mathematics Department
Teaching Assistant Ms. C. Maul, at UW-Madison, Chemical Engineering Department
Kerry Nock, Jack Jones, Jay Wu at Jet Propulsion Laboratory

The Venus Balloon used the following computer software packages for modeling.

Excel
Cricket Graph
Quattro Pro
Fluent
Mathematica

APPENDICES

Appendix A: Definition of Symbols

A	Exposed area (length^2), assumed constant
a	Aerodynamic deceleration (length/time^2)
B_o	Energy parameter (mass*length^2/time^2)
C_d	Drag coefficient (unitless), assumed constant
C_f	Skin Friction coefficient (unitless)
D_h	Characteristic length (length)
E_{in}	Convective energy seen by the craft (mass*length^2/time^2)
E_{tot}	Total kinetic energy lost by the craft (mass*length^2/time^2)
e	Euler constant, 0.5772156 (unitless)
e	Thermal strain (unitless)
g	Gravitational acceleration (length/time^2)
H_o	Scale height (length) — what does this mean
h_{vap}	Heat of shield vaporization (length^2/time^2)
K_c	Ratio of specific heats (unitless), assumed constant
K_d	Drag parameter (length^3/mass)
K_g	Universal gas constant divided by molecular weight (length^2*temperature/time^2)
k_{char}	Thermal conductivity of the char layer (length)
k_{shell}	Thermal conductivity of the aeroshell (length)
k_{virgin}	Thermal conductivity of the shield (length)
L	Vehicle length (length)
M	Mach number (unitless)
m	Spacecraft mass (mass), assumed constant
Nu	Nusselt number (unitless)
o_{yield}	Yield stress (mass/length-time^2)
P	Dynamic pressure (mass/length-time^2)
Pr	Prandtl number (unitless)
p	Atmospheric density (mass/length^3)
p_{char}	Char density (mass/length^3)
p_{virgin}	Shield density (mass/length^3)
p_{oe}	Atmospheric density at stagnation point (mass/length^3)
q''	Convective heat flux (mass/time^3)

R	Universal gas constant (length^2/time^2-temp)
R_n	Nose radius of curvature (length)
Re	Reynolds number (unitless)
r	Base radius (length)
T	Atmospheric temperature (temperature)
t	Aeroshell thickness (length)
t_{char}	Thickness of the shield char layer (length)
t_{shell}	Thickness of the aeroshell (length)
t_{virgin}	Thickness of the untouched shield (length)
μ	Viscosity (mass/length-time)
V	Current velocity (length/time)
$\mathbf{V}_{char}$	Volume of the char layer (length^3)
$\mathbf{V}_{shell}$	Volume of the aeroshell (length^3)
$\mathbf{V}_{virgin}$	Volume of the shield (length^3)
V_o	Entry velocity, 11540 meters per second

O.K.

Appendix B: Specific Model of a Venusian Atmosphere

Most models of planetary atmospheres use an isothermal constant composition algorithm. This facilitates the creation of a fictitious reference height that makes the calculations of acceleration, velocity, and position very easy. A summary of the relevant equations for this case is shown below (Weisel). An improvement on the model is to remove the isothermal constraint, adding a lapse rate term to the equations of motion. The lapse rate is the change in temperature with respect to the change in height. To keep calculations manageable, the atmosphere is usually divided into sections that have constant lapse rates (Regan). The designer has not settled for either of these approximations. The model upon which the design is based uses given values of pressure, temperature, and density at each altitude, plus correlations for gravity, viscosity, and chemical composition. A section of the spreadsheet model is shown in Figure B. From this data, a more realistic profile for deceleration can be created. Figures Ba-Bd show comparisons between typical plots from the spreadsheet and general plots of expected entry vehicle results. Accuracy could be further improved by allowing angle, mass, and drag coefficient to vary during entry instead of remaining constant. This model can provide accurate profiles for any ballistic entry to a reasonable degree. It is interesting to wonder how this model would fare against trajectory simulation software.

SUMMARY OF DEVELOPED EQUATIONS

$$K_d = -\frac{C_d*A*H_o}{m*\sin(\text{angle})} \qquad H_o = \frac{k*T}{g}$$

$$B_o = 1/2*m*V_o^2 - m*g*H_o*[e + \ln(K_d*p)]$$

$$1/2*m*V^2 = [B_o + m*g*H_o*(e + \ln(K_d*p))]*\exp[-K_d*p]$$

$$a = \frac{-K_d*\sin(\text{angle})*B_o}{m*H_o} * p * \exp[-K_d*p]$$

FIGURE B

Bluntcricket Sun, May 8, 1994 2:10 PM

	Height (km)	Height (m)	Temperature °K	Gravity ? units m/sec² ?	Density units gm/cm³ ?	Angle (rads)	Mass (kg)
1	180.000	180000.000	125.000	8.365	0.000	-1.274	150.000
2	176.000	176000.000	125.000	8.376	0.000	-1.274	150.000
3	172.000	172000.000	125.000	8.387	0.000	-1.274	150.000
4	168.000	168000.000	126.000	8.397	0.000	-1.274	150.000
5	164.000	164000.000	126.000	8.408	0.000	-1.274	150.000
6	160.000	160000.000	127.000	8.419	0.000	-1.274	150.000
7	156.000	156000.000	129.000	8.430	0.000	-1.274	150.000
8	152.000	152000.000	131.000	8.441	0.000	-1.274	150.000
9	148.000	148000.000	134.000	8.452	0.000	-1.274	150.000
10	144.000	144000.000	140.000	8.462	0.000	-1.274	150.000
11	140.000	140000.000	147.000	8.473	0.000	-1.274	150.000
12	136.000	136000.000	146.000	8.484	0.000	-1.274	150.000
13	132.000	132000.000	142.000	8.495	0.000	-1.274	150.000
14	128.000	128000.000	135.000	8.506	0.000	-1.274	150.000
15	124.000	124000.000	125.000	8.517	0.000	-1.274	150.000
16	120.000	120000.000	117.000	8.528	0.000	-1.274	150.000
17	116.000	116000.000	190.200	8.540	0.000	-1.274	150.000
18	114.000	114000.000	190.200	8.545	0.000	-1.274	150.000
19	112.000	112000.000	190.200	8.551	0.000	-1.274	150.000
20	110.000	110000.000	194.400	8.556	0.000	-1.274	150.000
21	108.000	108000.000	196.300	8.562	0.000	-1.274	150.000
22	106.000	106000.000	190.100	8.567	0.000	-1.274	150.000
23	104.000	104000.000	183.000	8.573	0.000	-1.274	150.000
24	102.000	102000.000	180.700	8.578	0.000	-1.274	150.000
25	100.000	100000.000	174.100	8.584	0.000	-1.274	150.000
26	98.000	98000.000	173.300	8.590	0.000	-1.274	150.000
27	96.000	96000.000	168.900	8.595	0.000	-1.274	150.000
28	94.000	94000.000	168.900	8.601	0.000	-1.274	150.000
29	92.000	92000.000	167.100	8.606	0.001	-1.274	150.000
30	90.000	90000.000	165.400	8.612	0.001	-1.274	150.000
31	88.000	88000.000	165.200	8.618	0.002	-1.274	150.000
32	86.000	86000.000	163.800	8.623	0.003	-1.274	150.000
33	84.000	84000.000	164.700	8.629	0.005	-1.274	150.000
34	82.000	82000.000	181.100	8.634	0.008	-1.274	150.000
35	80.000	80000.000	195.800	8.640	0.012	-1.274	150.000
36	79.000	79000.000	204.100	8.643	0.014	-1.274	150.000
37	78.000	78000.000	212.400	8.646	0.017	-1.274	150.000
38	77.000	77000.000	215.100	8.649	0.021	-1.274	150.000
39	76.000	76000.000	216.900	8.651	0.025	-1.274	150.000
40	75.000	75000.000	221.100	8.654	0.031	-1.274	150.000
41	74.000	74000.000	227.300	8.657	0.036	-1.274	150.000
42	73.000	73000.000	227.800	8.660	0.044	-1.274	150.000
43	72.000	72000.000	233.500	8.663	0.053	-1.274	150.000
44	71.000	71000.000	234.900	8.665	0.063	-1.274	150.000
45	70.000	70000.000	243.500	8.668	0.074	-1.274	150.000
46	69.000	69000.000	230.500	8.671	0.094	-1.274	150.000
47	64.830	64830.000	246.300	8.683	0.196	-1.274	150.000
48	64.000	64000.000	247.000	8.685	0.228	-1.274	150.000
49	63.000	63000.000	249.300	8.688	0.272	-1.274	150.000
50	62.000	62000.000	254.800	8.691	0.318	-1.274	150.000
51	61.000	61000.000	259.700	8.694	0.373	-1.274	150.000
52	60.000	60000.000	268.100	8.697	0.429	-1.274	150.000
53	59.000	59000.000	272.000	8.700	0.500	-1.274	150.000
54	58.000	58000.000	276.000	8.702	0.583	-1.274	150.000
55	57.000	57000.000	281.300	8.705	0.673	-1.274	150.000
56	56.000	56000.000	288.900	8.708	0.769	-1.274	150.000

THIS DOES NOTHING TO AID IN CLARITY WITHOUT SOME EXPLANATION.

Bluntcricket

Sun, May 8, 1994 2:10 PM

	Area (m^2)	Cd	k*T/g	Ho	Kd	Column 13	Deceleration
1	1.214	1.062	277.143	4141.407	37.220	11540.000	0.000
2	1.214	1.062	272.600	4068.287	36.563	11540.000	0.000
3	1.214	1.062	268.203	3997.530	35.927	11540.000	0.000
4	1.214	1.062	259.822	3898.572	35.037	11540.000	0.000
5	1.214	1.062	251.948	3775.573	33.932	11540.000	0.000
6	1.214	1.062	244.538	3688.858	33.153	11540.000	0.000
7	1.214	1.062	237.551	3635.208	32.671	11540.000	0.000
8	1.214	1.062	230.953	3584.401	32.214	11540.000	0.000
9	1.214	1.062	224.711	3562.794	32.020	11540.000	0.000
10	1.214	1.062	218.797	3619.691	32.531	11540.000	0.000
11	1.214	1.062	213.187	3698.442	33.239	11540.000	0.000
12	1.214	1.062	207.857	3576.825	32.146	11540.000	0.001
13	1.214	1.062	202.788	3389.594	30.463	11540.000	0.002
14	1.214	1.062	199.384	3164.309	28.438	11540.000	0.007
15	1.214	1.062	197.021	2891.455	25.986	11540.000	0.029
16	1.214	1.062	195.631	2683.818	24.120	11540.000	0.130
17	1.214	1.062	195.631	4357.271	39.160	11540.000	0.811
18	1.214	1.062	194.259	4323.924	38.860	11540.000	1.288
19	1.214	1.062	194.259	4321.119	38.835	11540.000	2.058
20	1.214	1.062	193.356	4393.144	39.482	11540.000	3.172
21	1.214	1.062	193.356	4433.202	39.842	11540.000	4.958
22	1.214	1.062	193.356	4290.395	38.559	11540.000	8.096
23	1.214	1.062	193.356	4127.472	37.095	11540.000	13.540
24	1.214	1.062	193.356	4072.948	36.605	11540.000	22.414
25	1.214	1.062	192.461	3903.480	35.082	11540.000	38.472
26	1.214	1.062	192.461	3883.017	34.898	11540.000	64.573
27	1.214	1.062	192.461	3781.968	33.989	11540.000	111.662
28	1.214	1.062	192.461	3779.508	33.967	11540.000	188.783
29	1.214	1.062	192.461	3736.796	33.583	11540.000	324.392
30	1.214	1.062	191.574	3679.338	33.067	11540.000	554.407
31	1.214	1.062	191.574	3672.496	33.006	11540.000	935.084
32	1.214	1.062	191.574	3639.001	32.705	11540.000	1556.255
33	1.214	1.062	191.574	3656.611	32.863	11540.000	2503.387
34	1.214	1.062	191.574	4018.098	36.112	11540.000	3415.717
35	1.214	1.062	191.574	4341.417	39.017	11540.000	4277.213
36	1.214	1.062	191.397	4519.809	40.621	11540.000	4575.162
37	1.214	1.062	191.397	4702.079	42.259	11540.000	4745.451
38	1.214	1.062	191.397	4760.297	42.782	11540.000	4886.656
39	1.214	1.062	191.397	4798.566	43.126	11540.000	4858.835
40	1.214	1.062	191.397	4889.888	43.947	11540.000	4558.937
41	1.214	1.062	191.397	5025.368	45.164	11540.000	4016.905
42	1.214	1.062	191.397	5034.778	45.249	11540.000	3408.794
43	1.214	1.062	191.397	5159.073	46.366	11540.000	2627.004
44	1.214	1.062	191.397	5188.310	46.629	11540.000	1885.626
45	1.214	1.062	191.397	5376.505	48.320	11540.000	1191.921
46	1.214	1.062	191.397	5087.801	45.725	11540.000	719.051
47	1.214	1.062	191.397	5429.148	48.793	11540.000	7.728
48	1.214	1.062	191.397	5443.100	48.918	11540.000	1.849
49	1.214	1.062	191.397	5491.988	49.358	11540.000	0.234
50	1.214	1.062	191.397	5611.316	50.430	11540.000	0.019
51	1.214	1.062	191.397	5717.355	51.383	11540.000	0.001
52	1.214	1.062	191.397	5900.352	53.028	11540.000	0.000
53	1.214	1.062	191.397	5984.225	53.782	11540.000	0.000
54	1.214	1.062	191.397	6070.241	54.555	11540.000	0.000
55	1.214	1.062	191.397	6184.782	55.584	11540.000	0.000
56	1.214	1.062	191.397	6349.800	57.067	11540.000	0.000

SHOULD I KNOW THIS? → ?

Bluntcricket Sun, May 8, 1994 2:10 PM

	Deceleration	Bo	Column 17	V^2	V	Time elapsed	Total time
1	0.000	10113000000.	9987870000.0	133171600.00	11540.000	0.347	0.347
2	0.000	10108000000.	9987870000.0	133171600.00	11540.000	0.347	0.693
3	0.000	10104000000.	9987870000.0	133171600.00	11540.000	0.347	1.040
4	0.000	10098000000.	9987870000.0	133171600.00	11540.000	0.347	1.386
5	0.000	10093000000.	9987870000.0	133171600.00	11540.000	0.347	1.733
6	0.000	10088000000.	9987870000.0	133171600.00	11540.000	0.347	2.080
7	0.000	10084000000.	9987870000.0	133171600.00	11540.000	0.347	2.426
8	0.000	10080000000.	9987870000.0	133171600.00	11540.000	0.347	2.773
9	0.000	10076000000.	9987870000.0	133171600.00	11540.000	0.347	3.120
10	0.000	10074000000.	9987870000.0	133171599.00	11540.000	0.347	3.466
11	0.000	10071000000.	9987870000.0	133171599.00	11540.000	0.347	3.813
12	0.000	10064000000.	9987870000.0	133171596.00	11540.000	0.347	4.159
13	0.000	10055000000.	9987870000.0	133171586.00	11539.999	0.347	4.506
14	0.001	10046000000.	9987870000.0	133171554.00	11539.998	0.347	4.853
15	0.003	10036000000.	9987870000.0	133171427.00	11539.993	0.347	5.199
16	0.013	10027000000.	9987870000.0	133170874.00	11539.968	0.347	5.546
17	0.083	10039000000.	9987870000.0	133164247.00	11539.681	0.173	5.719
18	0.131	10036000000.	9987870000.0	133160008.00	11539.498	0.173	5.893
19	0.210	10034000000.	9987870000.0	133153087.00	11539.198	0.173	6.066
20	0.324	10032000000.	9987870000.0	133142579.00	11538.743	0.173	6.239
21	0.506	10030000000.	9987870000.0	133125818.00	11538.016	0.173	6.413
22	0.826	10026000000.	9987870000.0	133099217.00	11536.863	0.173	6.586
23	1.382	10022000000.	9987870000.0	133055068.00	11534.950	0.173	6.759
24	2.287	10019000000.	9987870000.0	132981136.00	11531.745	0.173	6.933
25	3.926	10015000000.	9987870000.0	132858021.00	11526.405	0.174	7.106
26	6.589	10013000000.	9987870000.0	132647481.00	11517.269	0.174	7.280
27	11.394	10009000000.	9987870000.0	132287368.00	11501.625	0.174	7.454
28	19.264	10007000000.	9987870000.0	131673766.00	11474.919	0.175	7.629
29	33.101	10004000000.	9987870000.0	130615885.00	11428.731	0.176	7.805
30	56.572	10001000000.	9987870000.0	128840012.00	11350.771	0.177	7.982
31	95.417	9998726352.0	9987870000.0	125788863.00	11215.563	0.180	8.162
32	158.802	9996085598.0	9987870000.0	120737994.00	10988.084	0.185	8.347
33	255.448	9993514464.0	9987870000.0	112311633.00	10597.718	0.194	8.541
34	348.543	9991360010.0	9987870000.0	99934499.000	9996.724	0.209	8.750
35	436.450	9988948470.0	9987870000.0	83773111.400	9152.765	0.112	8.863
36	466.853	9987678998.0	9987870000.0	74557896.200	8634.691	0.120	8.983
37	484.230	9986352625.0	9987870000.0	64815821.600	8050.827	0.129	9.112
38	498.638	9985034942.0	9987870000.0	54765326.700	7400.360	0.142	9.254
39	495.799	9983708216.0	9987870000.0	44533465.400	6673.340	0.159	9.413
40	465.198	9982317404.0	9987870000.0	34643635.100	5885.884	0.183	9.596
41	409.888	9980846690.0	9987870000.0	25648876.900	5064.472	0.215	9.811
42	347.836	9979539623.0	9987870000.0	17900971.700	4230.954	0.262	10.073
43	268.062	9978029122.0	9987870000.0	11642350.200	3412.089	0.331	10.404
44	192.411	9976668536.0	9987870000.0	6929935.480	2632.477	0.437	10.841
45	121.625	9974945436.0	9987870000.0	3762719.200	1939.773	0.611	11.453
46	73.373	9974369662.0	9987870000.0	1774182.890	1331.985	5.818	17.271
47	0.789	9967807649.0	9987870000.0	9174.546	95.784	8.489	25.760
48	0.189	9966668249.0	9987870000.0	1889.284	43.466	11.087	36.847
49	0.024	9965160683.0	9987870000.0	200.649	14.165	12.049	48.896
50	0.002	9963341776.0	9987870000.0	14.228	3.772	13.040	61.936
51	0.000	9961552112.0	9987870000.0	0.639	0.799	14.051	75.986
52	0.000	9959375786.0	9987870000.0	0.017	0.132	15.119	91.106
53	0.000	9957650679.0	9987870000.0	0.000	0.017	16.318	107.423
54	0.000	9955889390.0	9987870000.0	0.000	0.001	17.572	124.995
55	0.000	9953955595.0	9987870000.0	0.000	0.000	18.837	143.832
56	0.000	9951713072.0	9987870000.0	0.000	0.000	20.066	163.898

For each height listed in the spreadsheet, the values of C_d, A, m, angle, k, T, g, p, V_o, and e are given. There are fifteen parameters, 10 knowns, 5 unknowns, and five equations. This set of equations has a closed form solution. The simple textbook model substitutes in for p:

$$p = p_o * \exp(-H/H_o)$$

This is the exponential atmosphere equation and is only valid for isothermal constant composition atmospheres.

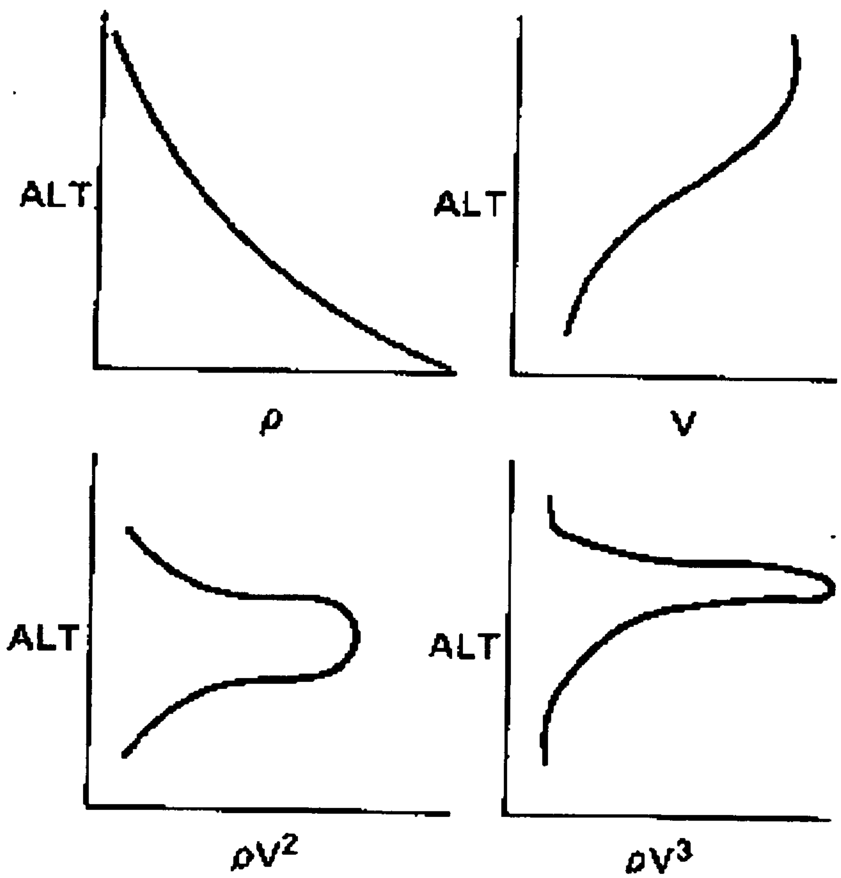
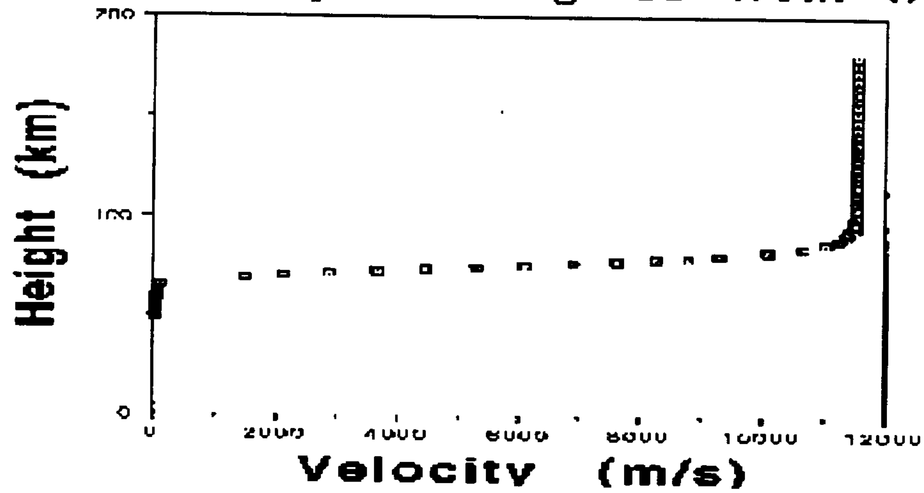


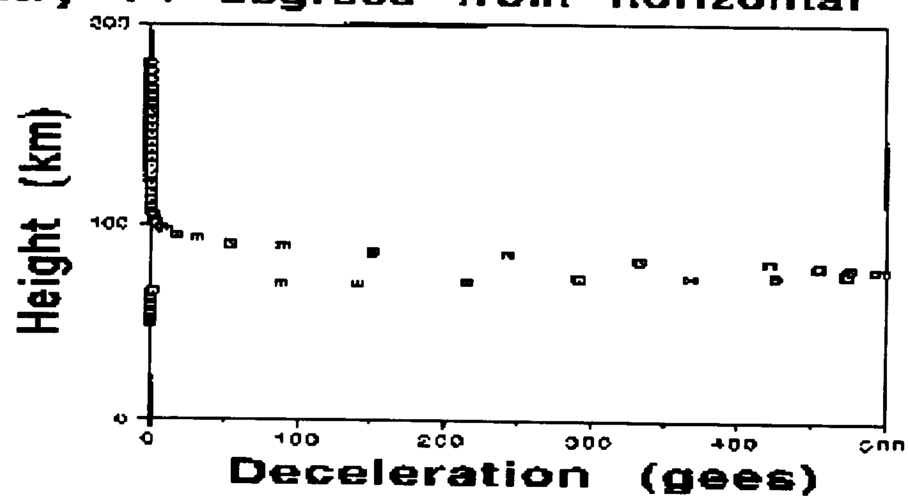
Figure 8a: Typical entry vehicle plots

Velocity profile with respect to height for ballistic entry, 74 degrees from horizontal



HARD TO READ

Deceleration profile for ballistic model with entry 74 degrees from horizontal



Figures 8b and 8c: Plots of designed vehicle parameters
(Compare to . a)

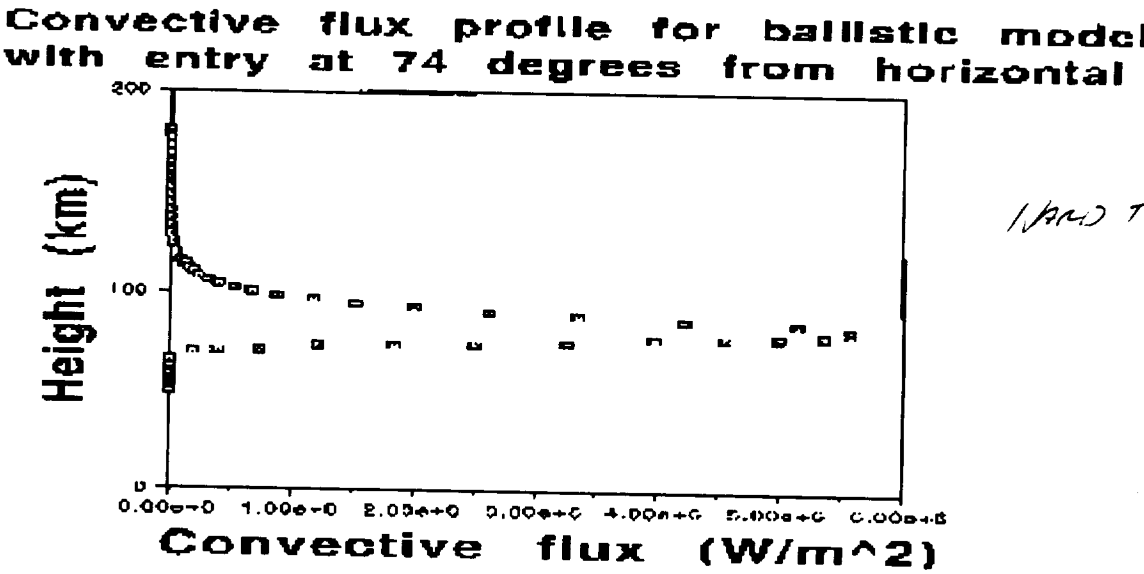


Figure 8d: Another plot to compare to 8a; Figs 8b-8d are similar to those shown in Figure 8a

Appendix C: Numerical Justification of Shape and Material Selection

Please peruse the tables below for the four different shapes evaluated in this design. Each table is based on calculations for a 250 kg vehicle with the areas and drag coefficients for each shape listed. It was desired to maximize the angle for which a 500g entry would occur, while simultaneously minimizing the peak heating rate, the total energy transfer, and the total time of entry. From these and other tables, the shape selection was narrowed down to the two highlighted choices. The worst heat shield material candidate properties were plugged into the conductive heat transfer equations to find which shape required less heat shielding. Some sample calculations follow, from which the reader should convince themselves that the best shape is the blunted cone. The second page of calculations documents the selection process of the shield and shell materials. Although there were only a small scope of materials considered, each one of these materials have been candidates for Venus missions before.

SAMPLE COMPARISON TABLE FOR FOUR SHAPES, ALL OF MASS 250 Kg AND A 500g ENTRY:

SHAPE	C_D	ANGLE OF ENTRY
SPHERE (ALL SHAPES HAVE SAME VOLUME)	1.00	47°
TRUNCATED CONE (20° HALF ANGLE, BLUNTNESS = $\frac{5}{6}$)	1.30	50°
CONE (30° HALF ANGLE)	0.50	59°
BLUNTED CONE (45° HALF ANGLE)	1.06 < 1.3 !	47°

SHAPE	PEAK HEAT FLUX ($\frac{MW}{m^2}$)	TOTAL CONVECTIVE ENERGY ([illegible]
SPHERE	2.59	2.85×10^7
[redacted]	[redacted]	[redacted]
CONE	3.89	4.59×10^7
[redacted]	[illegible]	[redacted]

SHAPE	PEAK HEATING DURATION	TOTAL ENTRY TIME
SPHERE	0.241 s	243 s
[redacted]	[illegible]	[illegible]
CONE	0.224 s	246 s
~~B-CONE~~	[illegible]	[illegible]

T-CONE : $t_{SHIELD} = 800K * 1.38\ W/m\text{-}K \,/\, 1.56 \times 10^6 \frac{W}{m^2} = 7.08 \times 10^{-4} m$

$t_{SHELL} = 207K * 14\ W/m\text{-}K \,/\, 1.56 \times 10^6 \frac{W}{m^2} = 1.86 \times 10^{-3} m$

B-CONE : $t_{SHIELD} = 800K * 1.38\ W/m\text{-}K \,/\, 2.23 \times 10^6 \frac{W}{m^2} = 4.95 \times 10^{-4} m$

$t_{SHELL} = 207K * 14\ W/m\text{-}K \,/\, 2.23 \times 10^6 \frac{W}{m^2} = 1.3 \times 10^{-3} m$

THE CONDUCTIVITIES USED HERE ARE THOSE OF CARBON PHENOLIC AND STAINLESS STEEL, RESPECTIVELY. THE NUMBERS REPRESENT USE OF INFERIOR MATERIALS THAT WOULD INCREASE THE THICKNESS REQUIRED.

MATERIAL	DENSITY ($\frac{Kg}{m^3}$)	THERMAL CONDUCTIVITY ($\frac{W}{m\text{-}K}$)
LOW DENSITY PHENOLIC NYLON	561	0.106
HIGH DENSITY PHENOLIC NYLON	1200	0.268
AVCOAT-5026-39 H/CG	529	0.242
CARBON PHENOLIC	1440	0.571
FOAMED SILICONE ELASTOMER	561	0.211

BEST OF THIS GROUP ARE LOW DENSITY PHENOLIC NYLON AND AVCOAT.

BASED ON WHAT CRITERIA?

AVCOAT: HEAT OF VAPORIZATION : 5.46×10^3 KJ/Kg
DENSITY : 529 Kg/m^3
THERMAL CONDUCTIVITY : 0.242 W/m-K

LOW DENSITY PHENOLIC NYLON: HEAT OF VAPORIZATION: 4.79×10^3 KJ/Kg
DENSITY : 561 Kg/m^3
THERMAL CONDUCTIVITY : 0.106 Kg/m^3

LOW DENSITY PHENOLIC NYLON IS A RELATIVELY NEW SUBSTANCE AND AVCOAT IS READILY AVAILABLE AT AN ASSUMED LOWER PRICE. SO AVCOAT IS CHOSEN TO BE THE HEAT SHIELD MATERIAL. *→ WHY? IS COST A DRIVER? WILL THIS BE BUILT TODAY?*

TWO TYPES OF ALUMINUM ALLOYS, ONE STAINLESS STEEL, AND ONE TITANIUM ALLOY WERE CONSIDERED FOR AEROSHELL FABRICATION. BOTH ALUMINUM ALLOYS HAD UNACCEPTABLE THERMAL CONDUCTIVITIES, SO THE SELECTION PROCESS WAS SIMPLIFIED:

TITANIUM (6Al-4V): DENSITY = 4400 Kg/m^3
THERMAL EXPANSION = 9 μm/m-K
YIELD STRENGTH = 825 MPa
THERMAL CONDUCTIVITY = 7.86 W/m-K

STAINLESS STEEL (17-4PH): DENSITY = 7767 Kg/m^3
THERMAL EXPANSION = 15 μm/m-K
YIELD STRENGTH = 300 MPa
THERMAL CONDUCTIVITY = 15.3 W/m-K

MATERIAL EFFICIENCY CRITERION	TITANIUM	STAINLESS STEEL
STRUT BUCKLING ($E^{1/2}/\rho$)	2.4	1.8
PANEL BUCKLING ($E^{1/3}/\rho$)	1.1	0.75

TITANIUM IS THE BEST MATERIAL FOR THE AEROSHELL

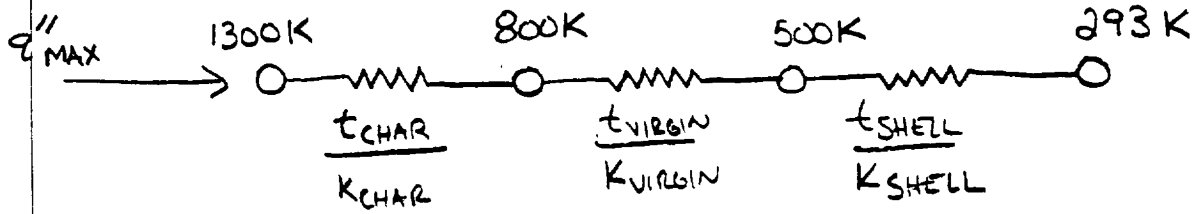
Appendix D: The Heating Problem

The design of the heat shield and aeroshell was influenced by the thermal balance. Figure ? shows the simplified version of the problem. A model of one dimensional steady-state heat transfer was used, incorporating the three knowns of desired interior temperature, maximum heating rate, and total convective energy transferred. The surface temperature of the heat shield was estimated based on the melting point of the material. The ratio of charred material to virgin material at any time was haggled over, and node temperatures were set based on the established conditions. Plugging in all the above values gave the needed thickness of the heat shield for thermal loading. This value was plugged in to volume calculations to find the mass required. Finally, the calculated mass was checked against the total energy transfer term to see if all the material would be vaporized. A sample calculation follows:

Appendix E: The Loading Problem

The design of the aeroshell was affected by the high loadings during descent. A modified approach based on the pressure vessel analogy was used to estimate a suitable thickness. The dynamic pressure was used as the value of the gage pressure in the calculations. A worst case scenario was developed and the thickness solved for. This thickness was compared to the thickness calculated for thermal loading, and the greater of the two values became the final result. A sample calculation follows:

SAMPLE CALCULATION



$q''_{MAX} = 1.31 \times 10^{6}\ W/m^2$

$E_{IN} = 2.78 \times 10^{6}\ J$

$K_{CHAR} = 0.38\ W/m\text{-}K$ $\qquad K_{VIRG} = 0.2421\ W/m\text{-}K$

$\rho_{CHAR} = 264.3\ kg/m^3$ $\qquad \rho_{VIRG} = 528.6\ kg/m^3$

ASSUME $t_{VIRGIN} = 10\, t_{CHAR}$

$$q''_{MAX} = -\frac{K\Delta T}{\Delta x} = \frac{-\Delta T}{\left(\frac{t_{CHAR}}{K_{CHAR}} + \frac{t_{VIRGIN}}{K_{VIRGIN}}\right)} = \frac{-(500-1300)K}{\left(\frac{t_{CHAR}}{0.38\ W/m\text{-}K} + \frac{10\,t_{CHAR}}{0.2421\ W/m\text{-}K}\right)}$$

$\Rightarrow t_{CHAR} = 1.39 \times 10^{-5}\ m$

$t_{VIRGIN} = 1.39 \times 10^{-4}\ m$

$$V_{CHAR} = V - \left[\frac{2\pi}{3}(r_b - t_{CHAR})^3 + \frac{\pi}{3}(R - t_{CHAR})^2 L - \frac{\pi}{3}(r_b - t_{CHAR})^2 \frac{r_b}{\tan 45}\right]$$

$= 5.74 \times 10^{-5}\ m^3$

$$V_{VIRGIN} = V - V_{CHAR} - \left[\frac{2\pi}{3}(r_b - t_{CHAR} - t_{VIRG})^3 + \frac{\pi}{3}(R - t_{CHAR} - t_{VIRG})^2 - \frac{\pi}{3}(r_b - t_{CHAR} - t_{VIRG})^2 \frac{r_b}{\tan 45}\right]$$

$= 1.09 \times 10^{-4}\ m^3$

MASS REMAINING = $\rho_{CHAR} V_{CHAR} + \rho_{VIRGIN} V_{VIRGIN}$ =

$$\frac{5.74 \times 10^{-5}\ m^3 \mid 264.3\ kg}{\mid m^3} + \frac{1.09 \times 10^{-4}\ m^3 \mid 528.6\ kg}{\mid m^3} = 0.073\ kg$$

ORIGINAL MASS COULD BE ASSUMED TO BE TWICE THE REMAINING MASS, IN WHICH CASE THE INITIAL AMOUNT OF HEAT SHIELD MATERIAL WOULD BE

$2 \times 0.073\ kg = 0.146\ kg$

THIS SEEMS LIGHT ??

SAMPLE CALCULATION

AN ALTERNATIVE IS TO CONSIDER THE DISSIPATION OF THE KINETIC ENERGY OF THE VEHICLE. IF IT IS ASSUMED THAT ALL THE CONVECTIVE ENERGY GOES INTO THE SHIELD, THEN THE MASS REQUIRED FOR THE HEAT SHIELD WOULD BE AT LEAST

$$m = \frac{E_{in}}{h_{VAP}} = \frac{2.78 \times 10^6 \ J}{4.77 \times 10^7 \ \frac{J}{Kg}} = 0.058 \ Kg$$

STILL SMALL!

HOWEVER, WHEN THE CONVECTIVE ENERGY IS COMPARED TO THE CHANGE IN KINETIC ENERGY, A DOUBTFUL RESULT OCCURS:

$$E_{TOT} = \frac{1}{2} m V_0^2 - \frac{1}{2} m V_f^2 =$$

$$\frac{E_{IN}}{E_{TOT}} = \frac{2.78 \times 10^6}{9.99 \times 10^9} = 2.78 \times 10^{-4}$$

THIS IS SMALL!

IF WE ARE TO BELIEVE THE RESULTS, THEN RADIATIVE TRANSFER AND CONDUCTION MUST ACCOUNT FOR THE REMAINING 99.99% OF THE TOTAL ENERGY CHANGE. THIS IS NOT GOOD IF CONDUCTION IS TO BE MINIMIZED.

IT HAS BEEN SUGGESTED (JPL) THAT 20% OF THE TOTAL VEHICLE MASS CONSIST OF A HEAT SHIELD.

which reference? You do not reference any of the JPL documents in your Bibliography.

TOTAL MASS = 150 Kg

HEAT SHIELD MASS = 30 Kg

HEAT SHIELD THICKNESS = 0.089 m

$$\frac{m * h_{VAP}}{E_{TOT}} = \frac{30 \ Kg * 4.77 \times 10^7 \ \frac{J}{Kg}}{9.99 \times 10^9 \ J} = 0.143$$

SO THIS MEANS ABLATION WILL HANDLE 14.3% OF THE INCOMING ENERGY TO THE SPACECRAFT. HOPEFULLY THE SKIN TEMPERATURE WILL BE HIGH ENOUGH THAT CONDUCTION WILL BE SMALL. THESE LAST VALUES OF MASS WERE THE LARGEST, AND WERE CHOSEN TO BE THE FINAL VALUES FOR THE VEHICLE.

SAMPLE CALCULATION

DYNAMIC PRESSURE $P = \frac{1}{2}\rho v^2$

MAXIMUM VALUE OF P DURING DESCENT: 6.71 MPa

STRESS APPROXIMATION DUE TO PRESSURE:

$$\sigma = \frac{P * r}{t}$$

WHERE r IS TAKEN TO BE THE BASE RADIUS, AND t IS THE SHELL THICKNESS

DESIRED MAXIMUM STRESS IS $0.8\sigma_{YIELD}$

σ_{YIELD} IS 825 MPA FOR TITANIUM.

NECESSARY THICKNESS $t = \frac{P * r}{0.8\sigma_{YIELD}} = 4.37 \times 10^{-3}$ m

MAXIMUM TEMPERATURE GRADIENT ACROSS THICKNESS IS 207K

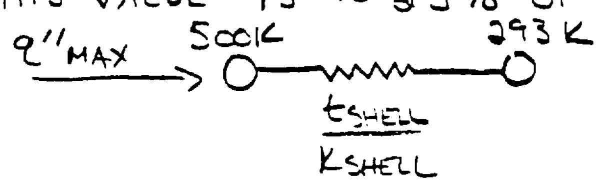
STRAIN CAUSED BY THE GRADIENT IS THE CHANGE IN TEMPERATURE TIMES THE COEFFICIENT OF THERMAL EXPANSION:

$$207\text{K} \left| \frac{9\ \mu\text{m}}{\text{m-K}} \right. = 1.86 \times 10^{-3} = \varepsilon$$

YOUNG'S MODULUS FOR TITANIUM: $E = 110$ GPa

STRESS DUE TO THERMAL EXPANSION $= E\varepsilon = 205$ MPa

THIS VALUE IS ~25% OF YIELD.



THE THICKNESS TO SATISFY CONDUCTIVITY REQUIREMENTS IS FOUND FROM

$$q''_{MAX} = \frac{-k_{SHELL}(-207\text{K})}{t_{SHELL}}$$

WHERE

$k_{SHELL} = 7.86 \frac{W}{m\text{-}K}$ AND $q''_{MAX} = 1.31 \times 10^{6}\ W/m^2$

THIS THICKNESS $= 1.24 \times 10^{-3}$ m

AS WITH THE HEAT SHIELD, THE LARGEST THICKNESS IS CHOSEN TO BE THE FINAL VALUE. THE VOLUME AND MASS OF THE SHELL CAN BE FOUND IN A SIMILAR FASHION.

$V_{SHELL} = 2.22 \times 10^{-3}\ m^3$ $\quad m_{SHELL} = 9.8$ Kg

APPENDIX F

SPHERE THICKNESS, MASS, AND VOLUME

WHERE IS MATERIAL SELECTION CALCULATIONS?

MATERIAL - TITANIUM (6% Al, 4% V)
$\sigma_{yeild} = 120$ ksi

THIN-WALLED SPHERICAL PRESSURE VESSEL

$\sigma = \frac{pr}{2t}$

$p = 92 \text{ atm} \times \frac{14.7 \text{ lb/in}^2}{1 \text{ atm}} = 1352.4 \text{ lb/in}^2$

$r = 8$ in

$\sigma = 120$ ksi

$t = \frac{pr}{2\sigma} = .04508$ in

SAFETY FACTOR = 2

$\therefore$ <u>t = .09016 in</u>

VOLUME (V) = $\frac{4}{3}\pi(r_o^3 - r_i^3)$

$V = \frac{4}{3}\pi(8^3 - (8 - .09016)^3) = 71.7 \text{ in}^3$

MASS (M) = ρV $\rho = .161$ lb/in³

$M = (71.7 \text{ in}^3)(.161 \text{ lb/in}^3)$

$M = 11.54$ lb (5.234 kg)

MASS IS NOT MEASURED IN lbs.
THIS ASSUMES g = g earth!

THIS WAS NEVER REFERENCED IN MAIN BODY OF REPORT!

INSULATION MASS AND VOLUME

$VOLUME(V) = \frac{4}{3}\pi(r_o^3 - r_i^3)$

$r_o = 8 - .09016 = 7.91 \text{ in}$

$t = 1.41 \text{ in}$

$r_o = 7.91 - 1.41 = 6.5 \text{ in}$

$V = \frac{4}{3}\pi(7.91^3 - 6.5)^3$

$V = 922.7 \text{ in}^3 \quad (.01512 \text{ m}^3)$

$MASS(M) = \rho V$

$\rho = 48 \text{ kg/m}^3$

$M = (.01512 \text{ m}^3)(48 \text{ kg/m}^3)$

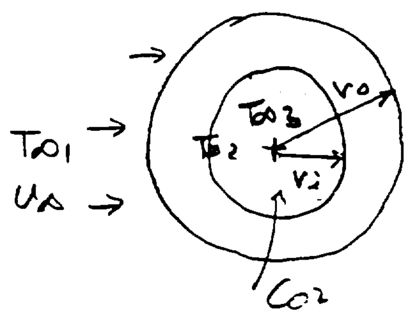
$M = .7258 \text{ kg}$

NEVER REFERENCED
BY MAIN BODY.

Assumptions : 1. Steady-State conditions.

2. Negligible resistance to heat transfer through the outer Shell.

Hard to Read



$r_o = 21.59$ cm

$r_i = ?$

$T_{\infty 1} = 225\ °C$

$= 498$ K

$T_{\infty 2} = 288$ K

- q_1 is heat transfer from out side to inside
- q_2 is heat transfer from inside to out side

Material ; Aluminum Silica fiber

$K = 5.4$ W/m·k (@ 400)

$h = 1.8$ W/m²

$q_1 = q_{cond} + q_{conv}$ (out side to inside)

WHAT ARE YOUR ASSUMPTIONS FOR HEAT TRANSFER ANALYSIS?

- 1-D or 2-D or 3-D ?
- STEADY or TRANSIENT ?
- NEGLECT RADIATION ?

THIS WAS NEVER REFERENCED BY MAIN BODY OF REPORT!

YOU NEGLECT RADIATION! IS THAT A VALID ASSUMPTION?

$$q_1 = q_{conduction} + q_{convection}$$

$$= \frac{T_{\infty 2} - T_{\infty 1}}{(1/4\pi k)[(1/r_i) - (1/r_o)] + (1/h 4\pi r_o^2)}$$

$$= \frac{(498 - 288)}{1/4\pi(5.4)\left((\frac{1}{r_i}) - (\frac{1}{0.216})\right) + \left(\frac{1}{1.84\pi(0.216)^2}\right)}$$

$$= \frac{210}{0.0147\,(\frac{1}{r_i} - 4.63) + (0.947)}$$

$$= \frac{210}{\frac{0.0147}{r_i} - 0.068 + 0.947}$$

$$= \frac{210}{\frac{0.0165}{r_i} + 0.88}$$

$$q_2 = h \Delta T A$$

$$= 1.8(15+273)(4\pi r_i^2)$$

$$= 6514 r_i^2$$

ΔT: 15°C is allowable temperature.
So, q_2 is based on temperature difference 0 to 15°C.

NEVER REFERENCED!

$q_1 = q_2$

$$\frac{210}{\frac{0.0160}{r_i} + 0.88} = 6514\, r_i^2$$

$$210 = 6514\, r_i^2 \times \left(\frac{0.160}{r_i} + 0.88\right)$$

$$0.0322 = 0.160\, r_i + 0.88\, r_i^2$$

$$r_i \approx 18.59 \text{ cm}$$

$\therefore$ thickness of Insulation = 3 cm

NEVER REFERENCED!

FOAM VOLUME AND MASS

$$V_{FOAM} = V_{INSIDE\ SHELL} - V_{INSULATION} - V_{EQUIPMENT} - V_{OTHER}$$

$$V_{INSIDE\ SHELL} = \frac{4}{3}\pi(8-.09016)^3 = 2072.96\ in^3\ (.03397 m^3)$$

$$V_{INSULATION} = 922.7\ in^3\ (.01512\ m^3)$$

$$V_{EQUIPMENT} = 726.6\ in^3\ (.011907\ m^3)$$

$$V_{OTHER} = 128\ in^3\ (.002097\ m^3)$$

$$V_{FOAM} = 2072.96 - 922.7 - 726.6 - 128$$

$$\underline{V_{FOAM} = 295.66\ in^3}\ (.019966\ m^3)$$

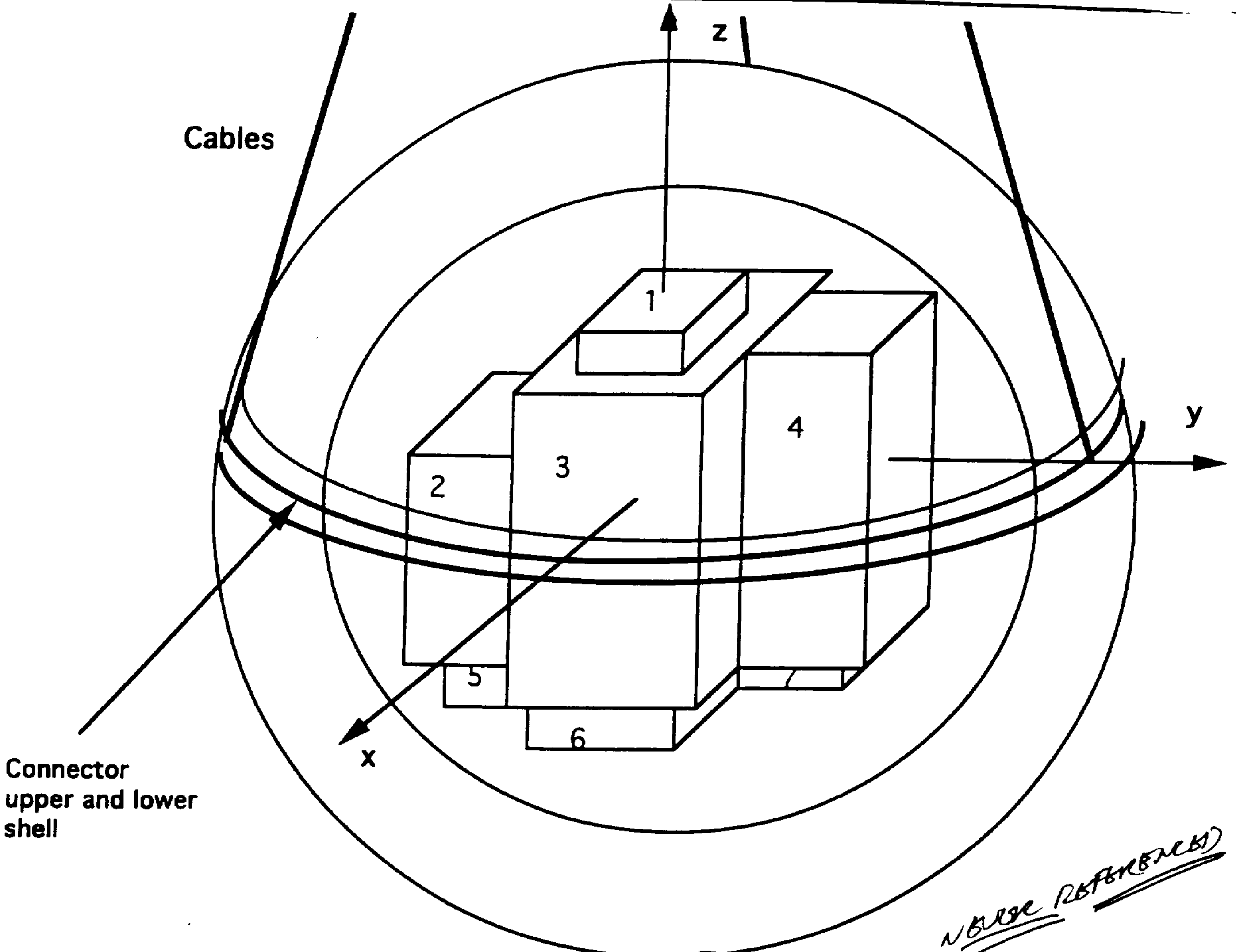
$$MASS\ (M) = \rho V \qquad \rho = 16\ kg/m^3$$

$$M = (16\ kg/m^3)(.019966\ m^3)$$

$$M = .3195\ kg$$

THIS IS VERY FUNDAMENTAL (BASIC) WORK. A MORE THOROUGH ANALYSIS IS REQUIRED.

NEVER REFERENCED!



3 dimensional view

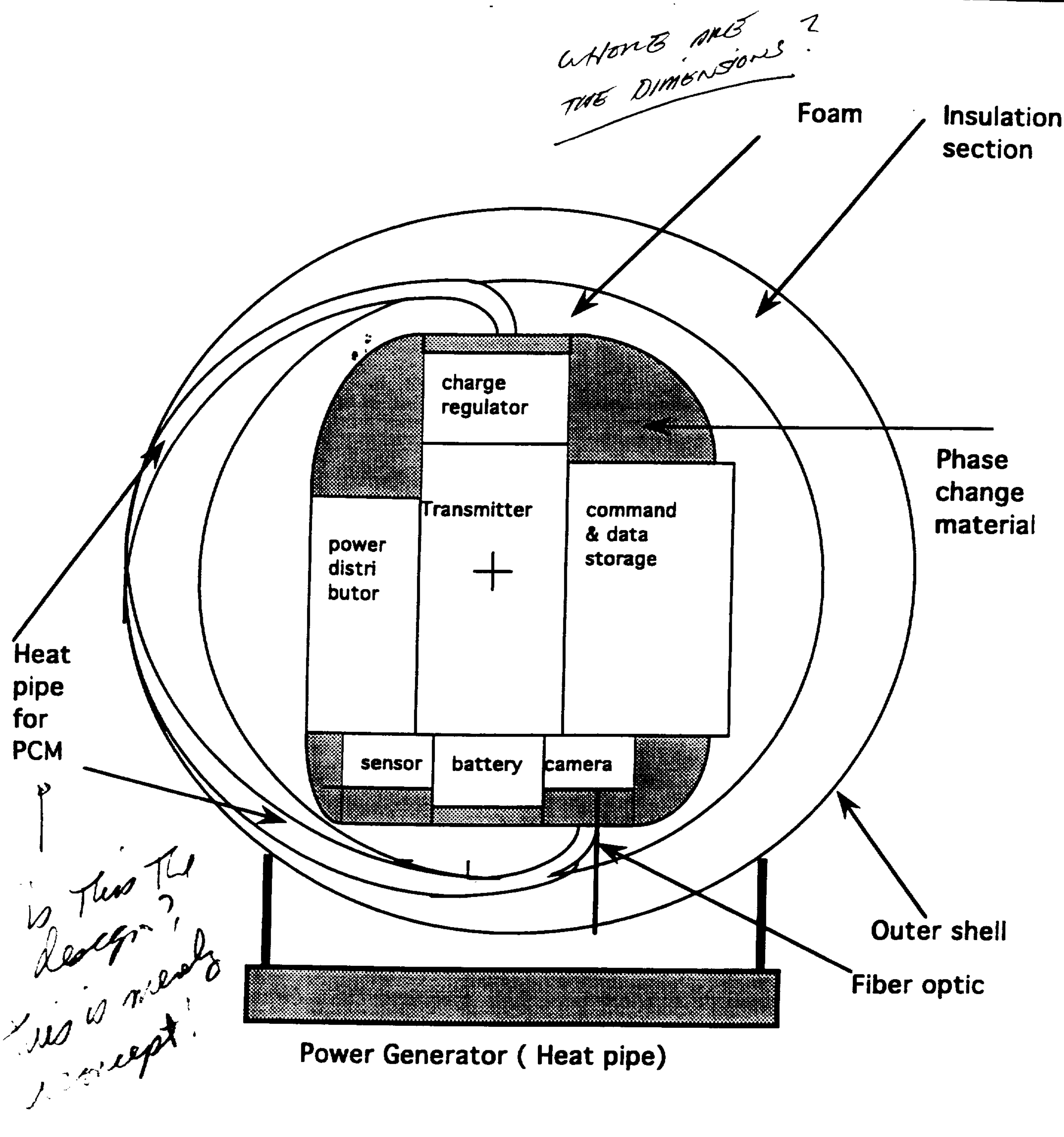
NEVER REFERENCED

THIS IS NOT A 3-VIEW DRAWING.

No.	Equipment	Dimensions L*W*H (in.^3)	Mass (Kg)	Power (W)
1	charge regulator	5 x 4 x 3	3	8.0
2	power distributor	4 x 1.8 x 6	3.5	0.5
3	transmitter	4.7 x 7.1 x 8.72	3.5	3.5
4	command & data storage	8 x 4.3 x 7	2.4	2.4
5	sensor *	2 x 3 x 3	1.5	0.2
6	battery *	3.2 x 3.5 x 5.5	3.3	n/a
7	camera *	2.5 x 3 x 4	2	.5
8	phase change material	1.5 x 1.5 x 1.5	.75	n/a
9	cable 1	5 m Length, 0. 015m radius		
10	cable 2	5 m Length, 0. 015m radius		
11	cable 3	5 m Length, 0. 015m radius		

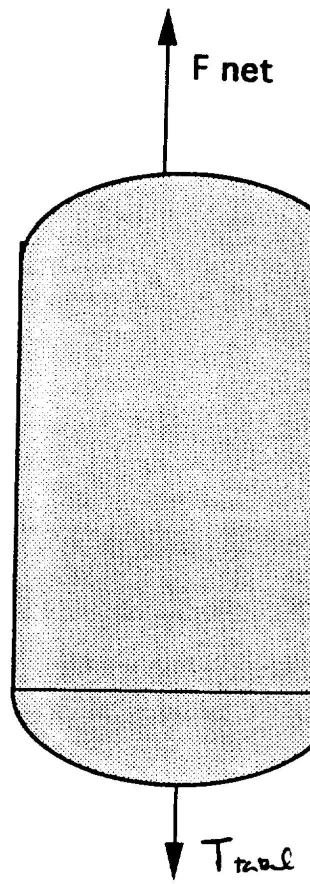
* Assupmtion: no information , The numbers were determined from the Viking lander.

Appendix I	Gondola	

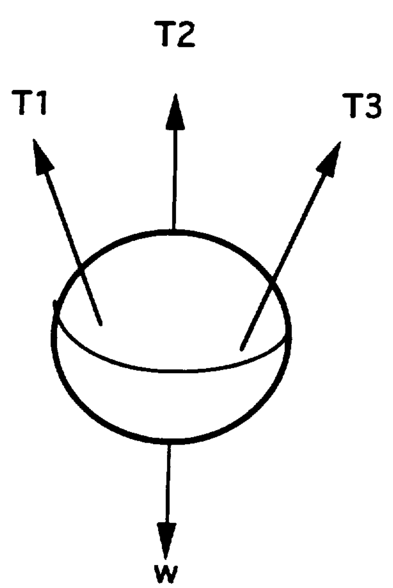


Front View

NEVER REFERENCED!

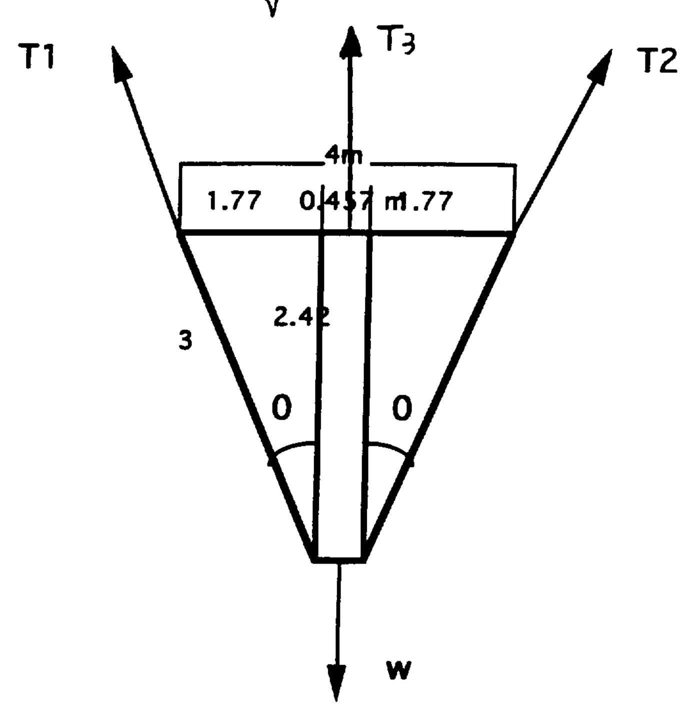


DIMENSIONS?



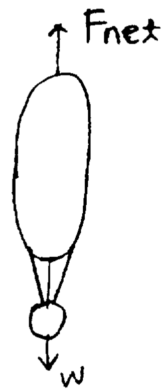
3 dimension

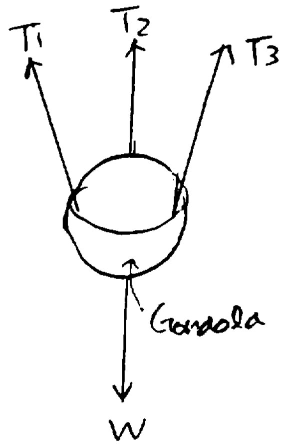
SLOPPY!



2 dimension

NEVER REFERENCED!





$F_{net,\,Max} = 371.46\ N$ at 68km

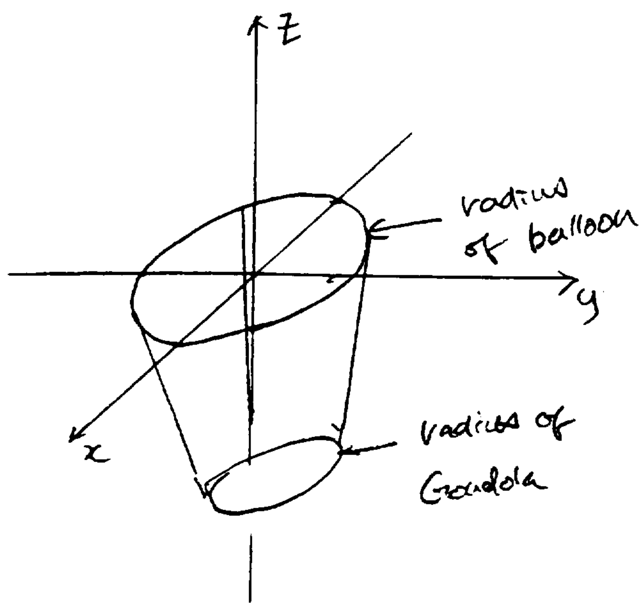
T_1, T_2, and T_3 are placed in the equilibrium.

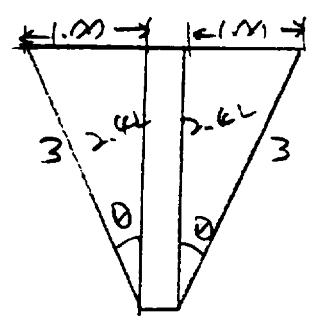
Thus $T_1 = T_2 = T_3$

$$W_{Gondola} = M_{Gon} \times g$$

$$= 37kg \times 8.8$$

$$= 325.6\ N$$





$$\theta = 36.18^\circ$$

$$W = T_1 \cos\theta + T_2 \cos\theta + T_3 \cos\theta$$

$$= 3T_1 \cos\theta = 3T_1 \cos 36.18^\circ$$

$$T_1 = \frac{W}{3\cos 36.18} = 134.6\ N.$$

NEVER REFERENCED!

$T = T_1 = T_2 = T_3 = 134.6\ N$

$F_{net} = (W_{Gon} + W_{HeatEx} + W_{cable} + W_{Balloon})g$

$= 371.46\ N$ @ 68 Km.

$T = F_{net} - W_{Gondola} + T_1$

$= (371.46 - 325.6) + 134.6$

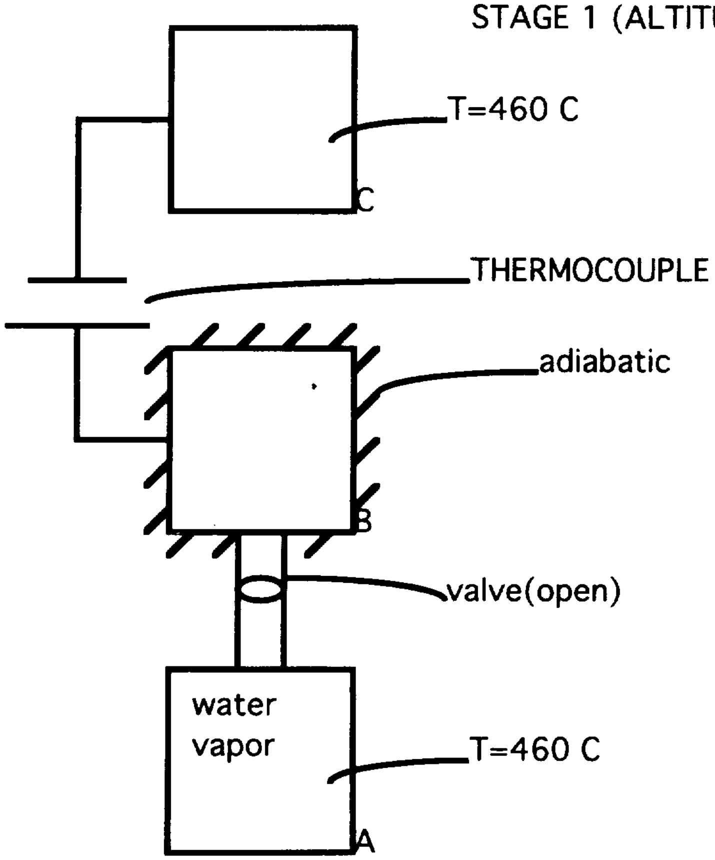
$= 180.46\ N$ for each Cable.

NEVER REFERENCED!

APPENDIX K

MODEL OF THERMOCOUPLE DEVICE

STAGE 1 (ALTITUDE=0 km)



P=.5 MPa v= 0.688m^3/kg

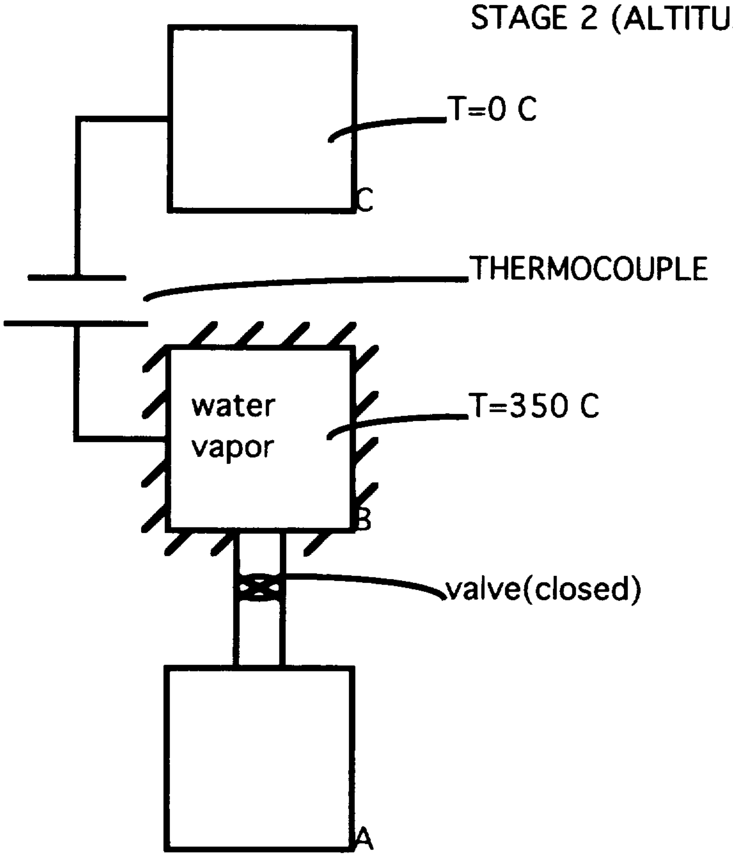
u=3061.7 kJ/kg

NEVER REFERENCED!

APPENDIX K

MODEL OF THERMOCOUPLE DEVICE

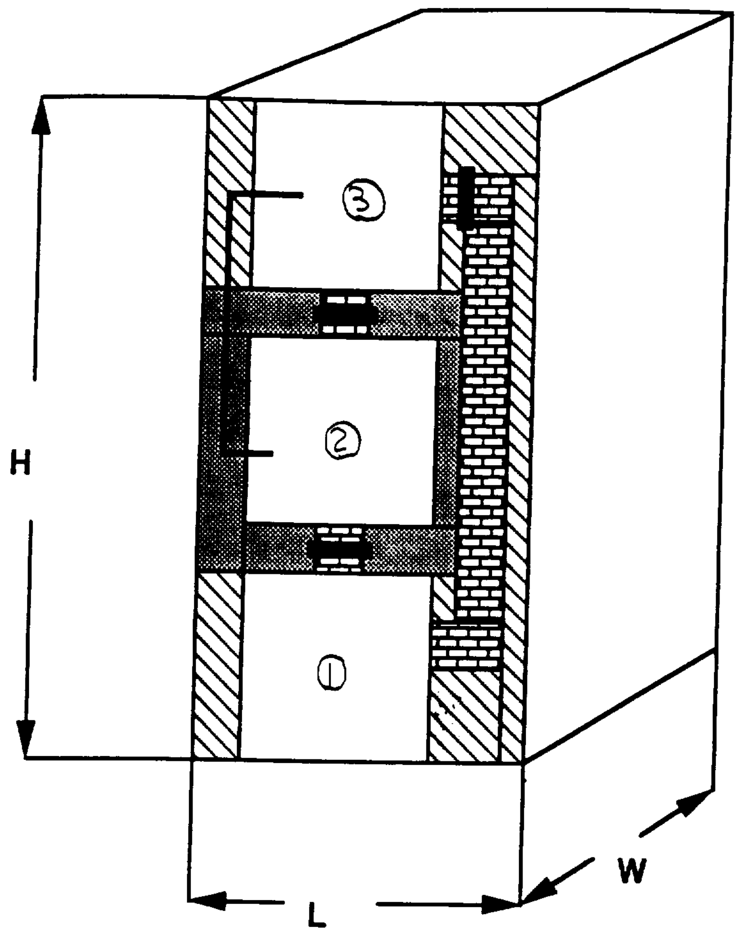
STAGE 2 (ALTITUDE = 60km)



P=.5 MPa   v=0.567 m^3/kg

u=2877.4 kJ/kg

NEVER REFERENCED!



Container section L xW xH = 0.1 x 0.1 x0.1 = 1x10^3 m^3

Insulation section LxWxH = 0.00085 m^3

Pipe section 0.03 m -diameter ,

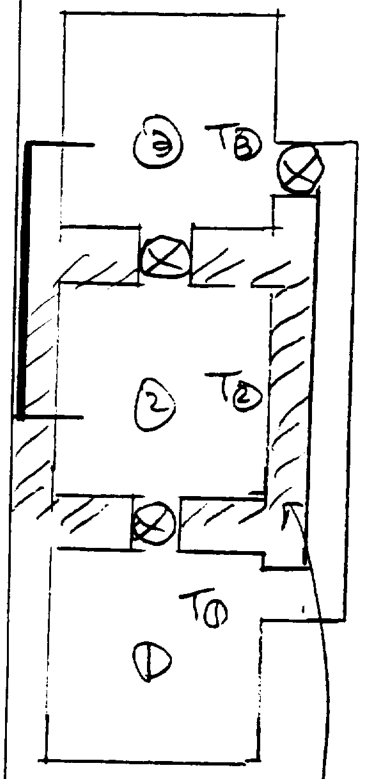
Main container section LxWxH = 0.15x 0.15 x 0. 32 = 7.2x10^3m^3

Valve

Thermo Couple

NEVER REFERENCED!

EXTREMELY POOR DESIGN!



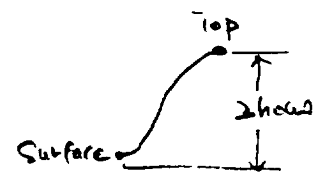
Volume ; $V_1, V_2, V_3 = 0.1 \times 0.1 \times 0.1$

$= 0.001\ m^3$

$= 1 \times 10^{-3}\ m^3$

Mass$_{water}$: $M_W = V_1 \times \rho_{water} = 1 \times 10^{-3} m^3 \times 1000\ kg/m^3$

$= 1\ kg$



Charge time = 2hours.

$K = 30\ W/m \cdot K$;

$T_② = 573\ K \quad T_③ = 273\ K$

$q = K \Delta T A = 30 \times (573 - 273)(0.1 \times 0.$

$= 90\ W$

Power $= I^2 R = q$

$= 90\ W$

Container ①, ③

→ Aluminum Anodized

$\varepsilon = 0.82$ @ 600°C

Container ②

→ copper — WHY?

$\varepsilon = 0.03$

Insulation

Blanket, aluminum Silica fiber

$\rho = 12\ kg/m^3$

NEVER REFERENCED!

Heat pipe (Mass)

$M_{water} = 1\ kg$

$M_{container①} = \rho_{Aluminum} \times V_①$

$= 2790\ kg/m^3 \times [(0.1)^3 - (0.098)^3]\ m^3$

$= 0.16\ kg$

$M_{container③}$ (Same as $M_{con①}$) $= 0.16\ kg$

$M_{container②} = \rho_{copper} \times V_②$

$= 8933\ kg/m^3 \times [(0.1)^3 - (0.098)^3]\ m^3$

$= 0.52\ kg$

$M_{container,total} = M_{con①} + M_{con②} + M_{con③}$

$= 0.16\ kg + 0.52\ kg + 0.16\ kg$

$= 0.84\ kg$

$M_{Main\ Container} = \rho_{Aluminum} \times V_{Main\ Cont.}$

$= 2790\ kg/m^3 \times [(0.15 \times 0.15 \times 0.32) - (0.148) \times (0.148) \times (0.318)]$

$= 0.65\ kg$

$M_{valve} = 0.01\ kg \times 3 = 0.03\ kg$

$M_{thermo\text{-}couple} = 0.001\ kg$

$M_{insulation} = \rho_{alum\ Silica\text{-}fiber} \times V_{insulation}$

$= 12\ kg/m^3 \times 0.00085\ m^3$

NEVER REFERENCED!

$\underline{M_{pipe}} = \rho_{alum} \times V_{pipe} \doteq 0.05kg$

$M_{total} = M_{water} + (M_{con1} + M_{con2} + M_{con3}) + M_{main\ con} + M_{value} + M_{e.c} + M_{ins.} + M_{pipe}$

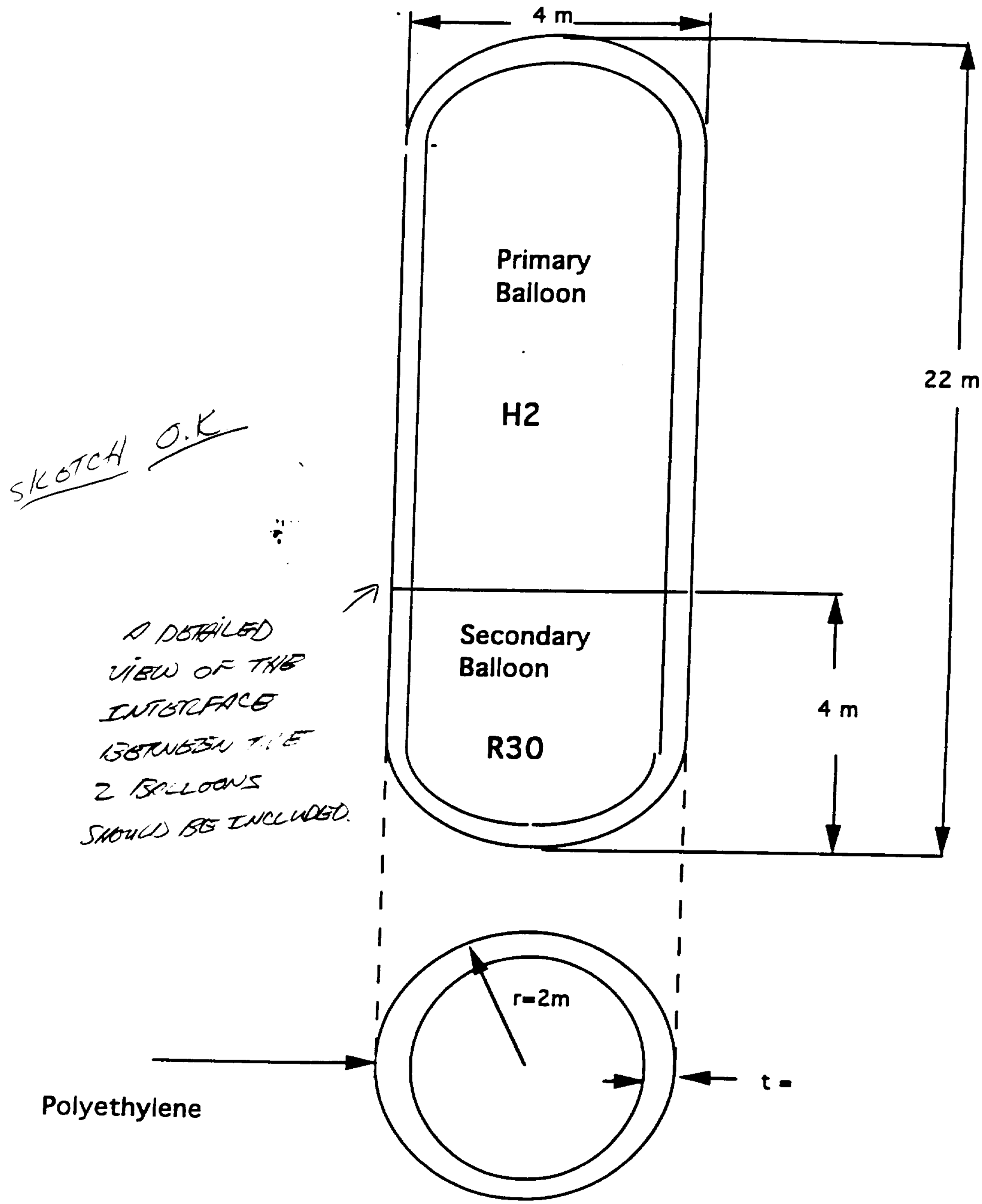
$= 1kg + (0.84\ kg) + 0.65kg + 0.03kg + 0.001\ kg + 0.0102kg + 0.05kg$

$= 2.58\ kg.$

Therefore, Total Mass of Heat pipe, generator, is $\underline{\underline{2.58kg}}$

NEVER REFERENCED!

Appendix M	Balloon dimension	



Appendix N

Altitude km	Altitude m	Venusian Atmospheric conditions Pressure bars (100kpa)	Pressure N/m^2	Temp. T k	Density (rho) kg/m^3	Venusian gravity g m/s^2	Virtual Mass Vitual Mass kg	Bulk Temp of H2 K (extraploated from Fluent results)	Bulk Temp of R30 K (extraploated from Fluent results)
39	39000	3.722	372200	421.6	4.638	8.829	4.803776126212	441.6	441.6
40	40000	3.334	333400	414.7	4.223	8.829	4.806671533164	434.7	434.7
41	41000	2.981	298100	407.9	3.839	8.829	4.810583327934	427.9	427.9
42	42000	2.661	266100	401.4	3.482	8.829	4.813685835986	421.4	421.4
43	43000	2.371	237100	394.8	3.153	8.829	4.815379102775	414.8	414.8
44	44000	2.109	210900	389.4	2.843	8.829	4.817785248336	409.4	409.4
45	45000	1.874	187400	384.4	2.558	8.829	4.818827939936	404.4	404.4
46	46000	1.662	166200	379.4	2.298	8.829	4.820880703755	399.4	399.4
47	47000	1.471	147100	371.8	2.075	8.829	4.82468739259	391.8	391.8
48	48000	1.299	129900	364.9	1.867	8.829	4.829280120485	384.9	384.9
49	49000	1.144	114400	355.3	1.688	8.829	4.834196521049	375.3	375.3
50	50000	1.004	100400	347.3	1.515	8.829	4.838371013098	367.3	367.3
51	51000	0.8788	87880	338.7	1.36	8.829	4.845956998635	358.7	358.7
52	52000	0.7665	76650	329.5	1.219	8.829	4.852192763014	349.5	349.5
53	53000	0.6659	66590	319.8	1.091	8.829	4.86002417399	339.8	339.8
54	54000	0.576	57600	309.5	0.9745	8.829	4.866470535026	329.5	329.5
55	55000	0.4959	49590	299.4	0.8671	8.829	4.875389402456	319.4	319.4
56	56000	0.4247	42470	288.9	0.7694	8.829	4.885253994589	308.9	308.9
57	57000	0.3618	36180	281.3	0.6732	8.829	4.894113035522	301.3	301.3
58	58000	0.3073	30730	276	0.5825	8.829	4.898063371298	296	296
59	59000	0.2606	26060	272	0.5004	8.829	4.894688522487	292	292
60	60000	0.2199	21990	268.1	0.4291	8.829	4.907675767108	288.1	288.1
61	61000	0.1851	18510	259.7	0.3728	8.829	4.917691383857	279.7	279.7
62	62000	0.1551	15510	254.8	0.3183	8.829	4.923125290445	274.8	274.8
63	63000	0.1294	12940	249.3	0.2716	8.829	4.934363754529	269.3	269.3
64	64000	0.1078	10780	247	0.2282	8.829	4.934094463636	267	267
64.83	64830	0.0925	9250	246.3	0.1964	8.829	4.935944142746	266.3	266.3
65	65000	0.095	9500	234.476	0.19154213	8.829	4.479054663739	254.4757175	254.4757175
66	66000	0.09642	9642	227.71	0.16240782	8.829	3.642353840794	247.70970112	247.70970112
67	67000	0.08278	8278.1	220.992	0.13920622	8.829	3.537775962221	240.99222186	240.99222186
68	68000	0.07011	7011.2	214.324	0.12168787	8.829	3.550353354101	234.32429504	234.32429504
69	69000	0.05772	5771.7	207.707	0.10960329	8.829	3.774812774657	227.70693598	227.70693598
70	70000	0.0449	4490	201.141	0.102703	8.829	4.10812	221.14116	221.14116
69	69000	0.05772	5771.7	207.707	0.10960329	8.829	3.11171259136	187.70693598	227.70693598
68	68000	0.07011	7011.2	214.324	0.12168787	8.829	2.944295266356	194.32429504	234.32429504
67	67000	0.08278	8278.1	220.992	0.13920622	8.829	2.950574278297	200.99222186	240.99222186
66	66000	0.09642	9642	227.71	0.16240782	8.829	3.054188932544	207.70970112	247.70970112
65	65000	0.095	9500	234.476	0.19154213	8.829	3.775010331692	214.4757175	254.4757175
64	64000	0.1078	10780	247	0.2282	8.829	4.194904281818	227	267
63	63000	0.1294	12940	249.3	0.2716	8.829	4.201446746801	229.3	269.3

Appendix N

Total Boyant Force g*rho*(V1+V2) N	Gondola	Mass (kg) Heat Exchanger	Misc	Balloon Skin	Total Mass kg	Total Downward force N	Net Force N	Net Acceleration (No Drag) m/s^2	km/hr^2	Height km	Cd	Drag coeff density * Area of Balloon * Cd/ data	calculated
929.0365777347	37	8.5	4	27.29	102.82177612621	907.81346141832	21.223116	0.209407	0.743066	39	0.8	23.31313	
929.59654116675	37	8.5	4	27.29	102.82467153316	907.83802468831	21.757516	0.211596	0.761754	40	0.8	21.22711	
930.35307106656	37	8.5	4	27.29	102.82658332793	907.87356220233	22.479509	0.218611	0.787001	41	0.8	19.29692	
930.95308729168	37	8.5	4	27.29	102.83168583588	907.90085424582	23.052133	0.224173	0.807024	42	0.8	17.50244	
931.28058025072	37	8.5	4	27.29	102.83337910278	907.9158040884	23.364656	0.227209	0.817952	43	0.8	15.84671	
931.74580192742	37	8.5	4	27.29	102.83578524634	907.93714795736	23.808734	0.231522	0.833479	44	0.8	14.29046	
931.94755550378	37	8.5	4	27.29	102.83682783884	907.94635386189	24.001202	0.233391	0.840209	45	0.8	12.85791	
932.34455416126	37	8.5	4	27.29	102.83888070375	907.96447773345	24.380076	0.237071	0.853454	46	0.8	11.55101	
933.0607569058	37	8.5	4	27.28	102.84268738258	907.99808086818	25.08267	0.243894	0.878017	47	0.8	10.43009	
933.9689773586	37	8.5	4	27.29	102.84728012048	908.03863618378	25.930341	0.252125	0.907649	48	0.8	9.394568	
934.91979518081	37	8.5	4	27.29	102.85219652105	908.08204308434	26.837752	0.260935	0.939366	49	0.8	8.464813	
935.7271300159	37	8.5	4	27.29	102.8563710131	908.11898867464	27.60823	0.268415	0.966295	50	0.8	7.615221	
937.19423794449	37	8.5	4	27.29	102.86385686863	908.18587634084	29.008362	0.282007	1.015225	51	0.8	6.836106	
938.40021695886	37	8.5	4	27.29	102.87019276301	908.24083190465	30.159285	0.293179	1.055441	52	0.8	6.127382	
939.91478946633	37	8.5	4	27.29	102.87802417389	908.31007543216	31.604714	0.307206	1.10594	53	0.8	5.483984	
941.16149727251	37	8.5	4	27.29	102.88447063503	908.36686035375	32.794507	0.318751	1.147503	54	0.8	4.898371	
942.80638075101	37	8.5	4	27.29	102.89338940246	908.44573503429	34.440846	0.334722	1.204989	55	0.8	4.35652	
944.79416486498	37	8.5	4	27.29	102.90325388459	908.53282851823	36.261335	0.352383	1.268578	56	0.8	3.867426	
945.68442790915	37	8.5	4	27.29	102.91211303552	908.61104588063	37.073382	0.360243	1.296875	57	0.8	3.383872	
944.80031858916	37	8.5	4	27.29	102.9160633713	908.64592350519	36.154365	0.3513	1.264679	58	0.8	2.927984	
940.03360133464	37	8.5	4	27.29	102.91268852249	908.61612686503	31.417474	0.305283	1.099018	59	0.8	2.515285	
936.75050875706	37	8.5	4	27.29	102.92567578711	908.73079134779	28.019717	0.272233	0.980037	60	0.8	2.156882	
928.73805308819	37	8.5	4	27.29	102.93589138386	908.81821922808	19.918934	0.193506	0.696627	61	0.8	1.873897	
915.68948852205	37	8.5	4	27.29	102.94112529044	908.86719518834	6.8222933	0.066274	0.238586	62	0.8	1.59885	
904.50271184227	37	8.5	4	27.29	102.95238375453	908.96641958873	-4.463708	-0.04336	-0.15609	63	0.8	1.385211	
887.85787468203	37	8.5	4	27.29	102.95208448384	908.96404201945	-21.10617	-0.20501	-0.73803	64	0.8	1.147058	
874.90935583742	37	8.5	4	27.29	102.95384414275	908.9803728383	-34.07102	-0.33093	-1.19136	64.8	0.8	0.967214	
792.41797058595	37	8.5	4	27.29	102.49705486374	904.94846562815	-112.5285	-1.09787	-3.95233	65	0.8	0.962796	
643.77938105614	37	8.5	4	27.29	101.66035384079	897.55829406037	-253.7789	-2.49635	-8.98686	66	0.8	0.816351	
624.99795582772	37	8.5	4	27.29	101.55577586222	896.63584597045	-271.638	-2.67477	-9.62916	67	0.8	0.699727	
627.16022246529	37	8.5	4	27.29	101.5663533541	896.74880176335	-269.5888	-2.65424	-9.55526	68	0.8	0.61167	
666.74668444604	37	8.5	4	27.29	101.79281277466	898.72674386745	-231.9819	-2.27896	-8.20426	69	0.8	0.550826	
725.56035061222	37	8.5	4	27.29	102.12612	901.67151346	-176.1112	-1.72445	-6.20801	70	0.8	0.516242	
549.52968094612	37	8.5	4	27.29	101.12871259136	892.87423246812	-343.3445	-3.39509	-12.2223	69	0.8	0.550826	
519.93351153294	37	8.5	4	27.29	100.98229526636	891.38610480866	-371.4526	-3.67922	-13.2452	68	0.8	0.61167	
521.04215370349	37	8.5	4	27.29	100.9885742783	891.45154230308	-370.4094	-3.66856	-13.2069	67	0.8	0.699727	
539.33930870112	37	8.5	4	27.29	101.07216863254	892.36635608543	-353.027	-3.49282	-12.5742	66	0.8	0.816351	
666.62866662212	37	8.5	4	27.29	101.79301033166	898.73046821651	232.1015	-2.28013	-8.20846	65	0.8	0.962796	
740.77766676919	37	8.5	4	27.29	102.21280428182	902.43773190417	-161.66	-1.5816	-5.69376	64	0.8	1.147058	
741.93285750014	37	8.5	4	27.29	102.2194467466	902.49548653275	-160.5625	-1.57076	-5.65475	63	0.8	1.385211	

Appendix O

* Balloon is released from 4000 km

TRAJECTORY OF BALLOON

Total Mass (Incl.Virtual Mass) kg	wt N	g m/s^2	time s	time hr	h(n+1) m	v(n+1) m/s	v'(n+1) = kn1
			0	0	40000	-11	
102.821776126	907.8135	8.829	0.05	1.39E-05	39999.48	-10.8844	25.2891846257
102.821776126	907.8135	8.829	0.1	2.78E-05	39998.96	-9.75324	24.7681473953
102.821776126	907.8135	8.829	0.15	4.17E-05	39998.5	-8.6816	19.9473404782
102.821776126	907.8135	8.829	0.2	5.56E-05	39998.09	-7.82214	15.8675211978
102.821776126	907.8135	8.829	0.25	6.94E-05	39997.72	-7.12774	12.9381274411
102.821776126	907.8135	8.829	0.3	8.33E-05	39997.38	-6.55316	10.7940890482
102.821776126	907.8135	8.829	0.35	9.72E-05	39997.06	-6.06816	9.1705557285
102.821776126	907.8135	8.829	0.4	0.000111	39996.77	-5.65219	7.9062259327
102.821776126	907.8135	8.829	0.45	0.000125	39996.49	-5.29076	6.89923370404
102.821776126	907.8135	8.829	0.5	0.000139	39996.24	-4.97326	6.08225978938
102.821776126	907.8135	8.829	0.55	0.000153	39995.99	-4.69176	5.4091139172
102.821776126	907.8135	8.829	0.6	0.000167	39995.77	-4.44017	4.84711241197
102.821776126	907.8135	8.829	0.65	0.000181	39995.55	-4.21375	4.37252627913
102.821776126	907.8135	8.829	0.7	0.000194	39995.34	-4.00871	3.96774699806
102.821776126	907.8135	8.829	0.75	0.000208	39995.15	-3.822	3.61945905884
102.821776126	907.8135	8.829	0.8	0.000222	39994.96	-3.65116	3.31742612332
102.821776126	907.8135	8.829	0.85	0.000236	39994.78	-3.49413	3.05366385999
102.821776126	907.8135	8.829	0.95	0.000264	39994.45	-3.2043	2.82186353592
102.821776126	907.8135	8.829	1.05	0.000292	39994.14	-2.94914	2.42077187102
102.821776126	907.8135	8.829	1.15	0.000319	39993.86	-2.72891	2.0963746798
102.821776126	907.8135	8.829	1.25	0.000347	39993.59	-2.53667	1.83800873777
102.821776126	907.8135	8.829	1.35	0.000375	39993.35	-2.36694	1.62885082637
102.821776126	907.8135	8.829	1.45	0.000403	39993.12	-2.21562	1.45687798977
102.821776126	907.8135	8.829	1.55	0.000431	39992.9	-2.07957	1.31359065555
102.821776126	907.8135	8.829	1.65	0.000458	39992.7	-1.95633	1.19283300715
102.821776126	907.8135	8.829	1.75	0.000486	39992.51	-1.84395	1.09004707874
102.821776126	907.8135	8.829	1.85	0.000514	39992.33	-1.74087	1.00179284916
102.821776126	907.8135	8.829	1.95	0.000542	39992.16	-1.64582	0.92543037301
102.821776126	907.8135	8.829	2.05	0.000569	39992	-1.55774	0.85890372459

Appendix P

coefficients used for generating trajectory

Runge-Kutta 4

coefficients used for generating trajectory

v'(n+1) = kn1	kn2	kn3	kn4	coef1	coef2	coef3	coef4	coef5	coef6	ln1	ln2	ln3	ln4	dt
	22.4997	22.79933												
25.2891846257	22.4997	22.79933	-102.021	-10.3678	39999.73	-10.4375	39999.74	-9.86003	39999.48	-11	-10.3678	-10.4375	-9.86003	0.05
24.7681473953	22.06388	22.305	20.37898	-10.2652	39999.21	-10.322	39999.22	-9.74448	39998.96	-10.8844	-10.2652	-10.322	-9.74448	0.05
19.9473404782	17.9899	17.78816	19.91208	-9.25456	39998.72	-9.20164	39998.73	-8.63799	39998.5	-9.75324	-9.25456	-9.20164	-8.63799	0.05
15.8675211978	14.47759	14.29655	15.71152	-8.28491	39998.29	-8.23185	39998.3	-7.79219	39998.09	-8.6816	-8.28491	-8.23185	-7.79219	0.05
12.9381274411	11.91469	11.79575	12.84153	-7.49868	39997.9	-7.4602	39997.9	-7.10731	39997.72	-7.82214	-7.49868	-7.4602	-7.10731	0.05
10.7940890482	10.01463	9.935409	10.73402	-6.85789	39997.54	-6.82987	39997.55	-6.53795	39997.38	-7.12774	-6.85789	-6.82987	-6.53795	0.05
9.1705557285	8.560805	8.505757	9.129414	-6.3239	39997.21	-6.3028	39997.22	-6.05639	39997.06	-6.55316	-6.3239	-6.3028	-6.05639	0.05
7.9062259327	7.418833	7.379192	7.876744	-5.87051	39996.91	-5.85414	39996.91	-5.64287	39996.77	-6.06816	-5.87051	-5.85414	-5.64287	0.05
6.89923370404	6.502648	6.473269	6.877484	-5.47971	39996.63	-5.46672	39996.63	-5.28324	39996.49	-5.65219	-5.47971	-5.46672	-5.28324	0.05
6.08225978938	5.754689	5.732394	6.065832	-5.1387	39996.36	-5.12819	39996.36	-4.96709	39996.24	-5.29076	-5.1387	-5.12819	-4.96709	0.05
5.4091139172	5.135056	5.117799	5.396455	-4.83803	39996.11	-4.82939	39996.12	-4.68664	39996	-4.97326	-4.83803	-4.82939	-4.68664	0.05
4.84711241197	4.615264	4.601677	4.837188	-4.57058	39995.88	-4.56338	39995.88	-4.43587	39995.77	-4.69176	-4.57058	-4.56338	-4.43587	0.05
4.37252627913	4.174467	4.163613	4.364628	-4.33086	39995.66	-4.32479	39995.66	-4.21009	39995.55	-4.44017	-4.33086	-4.32479	-4.21009	0.05
3.96774699806	3.797091	3.788308	3.961379	-4.11456	39995.44	-4.10939	39995.45	-4.00557	39995.34	-4.21375	-4.11456	-4.10939	-4.00557	0.05
3.61945905884	3.471282	3.464095	3.614265	-3.91822	39995.24	-3.91378	39995.25	-3.81929	39995.15	-4.00871	-3.91822	-3.91378	-3.81929	0.05
3.31742612332	3.18788	3.181939	3.313146	-3.73907	39995.05	-3.73522	39995.06	-3.6488	39994.96	-3.822	-3.73907	-3.73522	-3.6488	0.05
3.05366385999	2.9397	2.934745	3.050103	-3.57481	39994.87	-3.57146	39994.87	-3.49206	39994.78	-3.65116	-3.57481	-3.57146	-3.49206	0.05
2.82186353592	2.622274	2.614115	2.818877	-3.35303	39994.61	-3.34714	39994.62	-3.20065	39994.45	-3.49413	-3.35303	-3.34714	-3.20065	0.1
2.42077187102	2.263539	2.25072	2.415945	-3.08326	39994.29	-3.07319	39994.29	-2.94289	39994.14	-3.2043	-3.08326	-3.07319	-2.94289	0.1
2.0963746798	1.970907	1.961096	2.088761	-2.84432	39993.99	-2.83597	39994	-2.72407	39993.86	-2.94914	-2.84432	-2.83597	-2.72407	0.1
1.83800873777	1.736119	1.728885	1.83255	-2.63701	39993.72	-2.63037	39993.73	-2.53281	39993.59	-2.72891	-2.63701	-2.63037	-2.53281	0.1
1.62885082637	1.544847	1.53941	1.6248	-2.45523	39993.47	-2.44987	39993.47	-2.36378	39993.35	-2.53867	-2.45523	-2.44987	-2.36378	0.1
1.45687798977	1.386721	1.382554	1.453788	-2.2941	39993.23	-2.2897	39993.23	-2.213	39993.12	-2.36694	-2.2941	-2.2897	-2.213	0.1
1.31359065555	1.254342	1.251095	1.311191	-2.14995	39993.01	-2.14629	39993.01	-2.07737	39992.9	-2.21562	-2.14995	-2.14629	-2.07737	0.1
1.19263300715	1.142309	1.139743	1.190943	-2.01993	39992.8	-2.01685	39992.8	-1.95446	39992.7	-2.07957	-2.01993	-2.01685	-1.95446	0.1
1.09004707874	1.046593	1.04454	1.088539	-1.90182	39992.61	-1.89921	39992.61	-1.84235	39992.51	-1.95633	-1.90182	-1.89921	-1.84235	0.1
1.00179284916	0.964137	0.962477	1.000577	-1.79386	39992.42	-1.79162	39992.42	-1.73949	39992.33	-1.84395	-1.79386	-1.79162	-1.73949	0.1
0.92543037301	0.892579	0.891224	0.92444	-1.6946	39992.25	-1.69266	39992.25	-1.64462	39992.16	-1.74087	-1.6946	-1.69266	-1.64462	0.1
0.85890372459	0.830071	0.828956	0.85809	-1.60287	39992.08	-1.60119	39992.08	-1.5567	39992	-1.64582	-1.60287	-1.60119	-1.5567	0.1
0.8005907804	0.775148	0.774223	0.799918	-1.51771	39991.93	-1.51624	39991.93	-1.47485	39991.85	-1.55774	-1.51771	-1.51624	-1.47485	0.1
0.74919687037	0.726636	0.725865	0.748636	-1.43831	39991.78	-1.43701	39991.78	-1.39834	39991.71	-1.47577	-1.43831	-1.43701	-1.39834	0.1
0.70367684974	0.683584	0.682937	0.703207	-1.36397	39991.64	-1.36282	39991.64	-1.32657	39991.57	-1.39916	-1.36397	-1.36282	-1.32657	0.1
0.66318066645	0.645215	0.644669	0.662785	-1.29413	39991.51	-1.29311	39991.51	-1.259	39991.44	-1.32729	-1.29413	-1.29311	-1.259	0.1
0.62700936603	0.610888	0.610426	0.626674	-1.22829	39991.38	-1.22738	39991.38	-1.19517	39991.32	-1.25964	-1.22829	-1.22738	-1.19517	0.1
0.59458443127	0.580072	0.579679	0.5943	-1.16602	39991.26	-1.16521	39991.26	-1.13471	39991.2	-1.19575	-1.16602	-1.16521	-1.13471	0.1
0.56542342912	0.552321	0.551986	0.565181	-1.10695	39991.15	-1.10622	39991.15	-1.07726	39991.09	-1.13522	-1.10695	-1.10622	-1.07726	0.1
0.53912138373	0.527262	0.526975	0.538914	-1.05077	39991.04	-1.05011	39991.04	-1.02252	39990.99	-1.07772	-1.05077	-1.05011	-1.02252	0.1
0.51533626762	0.504577	0.504331	0.515158	-0.99718	39990.94	-0.99658	39990.94	-0.97025	39990.89	-1.02295	-0.99718	-0.99658	-0.97025	0.1
0.49377759616	0.483997	0.483785	0.493625	-0.94594	39990.84	-0.9454	39990.84	-0.9202	39990.79	-0.97063	-0.94594	-0.9454	-0.9202	0.1
0.47419738525	0.46529	0.465109	0.474066	-0.89683	39990.75	-0.89634	39990.75	-0.87216	39990.7	-0.92054	-0.89683	-0.89634	-0.87216	0.1
0.4563829258	0.448259	0.448103	0.456269	-0.84966	39990.66	-0.84921	39990.66	-0.82597	39990.62	-0.87248	-0.84966	-0.84921	-0.82597	0.1
0.44015096767	0.432733	0.432598	0.440053	-0.80425	39990.58	-0.80384	39990.58	-0.78144	39990.54	-0.82625	-0.80425	-0.80384	-0.78144	0.1
0.42534300618	0.418563	0.418447	0.425259	-0.76044	39990.5	-0.76007	39990.5	-0.73845	39990.46	-0.78171	-0.76044	-0.76007	-0.73845	0.1
0.4118214379	0.40562	0.40552	0.411749	-0.71809	39990.43	-0.71776	39990.43	-0.69684	39990.39	-0.73868	-0.71809	-0.71776	-0.69684	0.1
0.39946640676	0.393792	0.393706	0.399404	-0.67708	39990.36	-0.67678	39990.36	-0.65651	39990.32	-0.69706	-0.67708	-0.67678	-0.65651	0.1
0.38817320239	0.382981	0.382907	0.388119	-0.6373	39990.29	-0.63702	39990.29	-0.61734	39990.26	-0.65671	-0.6373	-0.63702	-0.61734	0.1
0.37785010289	0.3731	0.373037	0.377804	-0.59863	39990.23	-0.59837	39990.23	-0.57923	39990.2	-0.61752	-0.59863	-0.59837	-0.57923	0.1
0.36841657769	0.364074	0.364019	0.368377	-0.56097	39990.17	-0.56074	39990.17	-0.54209	39990.14	-0.57939	-0.56097	-0.56074	-0.54209	0.1
0.35980178371	0.355835	0.355789	0.359768	-0.52425	39990.12	-0.52404	39990.12	-0.50584	39990.09	-0.54224	-0.52425	-0.52404	-0.50584	0.1
0.35194330208	0.348326	0.348286	0.351914	-0.48838	39990.07	-0.48819	39990.07	-0.4704	39990.04	-0.50598	-0.48838	-0.48819	-0.4704	0.1

Assume model as External Flow over Sphere

$$Nu = 2 + (.4\,Re_D^{1/2} + .06\,Re_D^{2/3})\,Pr^{.4}\left(\frac{\mu}{\mu_s}\right)^{1/4}$$

valid for $.71 < Pr < 380$

$3.5 < Re_D < 7.6 \times 10^4$

$1.0 < (\mu/\mu_s) < 3.2$

$Re_D = \frac{VD}{\nu} \Rightarrow \frac{V D \rho}{\mu}$

$\nu = \frac{\mu}{\rho}$

$\bar{h} = \bar{Nu}\,\frac{k}{D}$

$V = 3.9$ m/s

$D = 4$ m

$\rho = 1.3257$ kg/m^3

$\mu = 3.03 \times 10^{-5}$ N s/m^2

$Re_D = 682538.6$

$Pr = .737$

$\mu/\mu_s = .9$

$Nu = 687.859$

$k = 25.8 \times 10^{-3}$ w/m K

$\bar{h} = 4.4$

$Nu = 2 + (330.46 + 465.12)(.8851)(.974) = 687.859$

Appendix R

PHASE TRANSITIONS

Clausius - Clapeyron Equation (2 point form)

$$\log (P_2 / P_1) = (\Delta H_{vap} / 2.303\ R)\ [(1/T_1)-(1/T_2)]$$

This equation relates temperature and pressure with the heat of vaporization. We can use values of pressure and temperature off the Van't Hoff plot for a specific chemical. Units of ΔH_{vap} --> kJ / mol
The heat needed for the vaporization of a liquid is called the heat of vaporization (or enthalpy of vaporization)

HEAT CAPACITY

Heat Capacity, C, is the quantity of heat needed to raise the temperature of the sample of the substance one degree C.

$$q = C * \Delta T$$

where $T = T_f - T_i$ and the units of C are Joule/^oC

SPECIFIC HEAT

The specific heat of a substance is the quantity of heat required to raise the temperature of one gram of that substance by one degree C.

$$q = sp.ht. * mass * \Delta T$$

where $T = T_f - T_i$ and the units of sp.ht. are Joule/ gram ^oC

CRITICAL TEMPERATURE AND PRESSURE

The temperature above which the liquid state of a substance no longer exists is called the critical temperature. The vapor pressure at the critical temperature is called the critical pressure. It is the minimum pressure that must be applied to a gas at the critical temperature to liquefy it

APPENDIX S

Properties of Methylene Chloride (CH_2Cl_2)

Taken from: CRC Handbook of Chemistry and Physics 67th Edition

Pg C349 No. 9060
Molecular weight 84.93
Boiling Point 40 °C
Melting Point -95.1 °C
Density 1.3266

Pg C671 Heat of Vaporization ΔHv = 7572.3 gram calories/gram mole (To convert to Joule/gram mole, multiply listed by 4.184)

Pg C716 Limits of Superheat of pure liquids
P = 0.101 MPa
T = 394.8 K

Pg E4 Thermal Conductivity k = 0.0002908
[t(°C) = 0, t(°F) = 32]

Pg F63 Critical Temperatures and Pressures
Critical Temperature Tc (°C) 273
Critical Pressure Pc (atm) 60

Pg D59 Selected Values of Chemical Thermodynamic Properties

	0 K		298.15 K	25°C		
State	Δ Hf	Δ Hf	Δ Gf	H_{298}-H_0	S	Cp
Liquid	--------	-29.03	-16.09	------	42.5	23.9
Gas	-20.462	-22.10	-15.75	2.830	64.56	12.18
	Kcal/mol		Kcal/mol		cal/deg m	

APPENDIX T

The Energy Needed to heat the liquid

E = ΔT (heat capacity)

ΔT = 33 degrees (this is modified from the original calculations)

heat capacity = 99997.6 J / deg

E = 3299920.8 J

To change from liquid to a gas.

E = (heat of vaporization)(number of moles)
= (31682.5 J/mol) (200 mol)
= 6336500 J

Total Energy Needed 9636420.8 J

Heat recieved

Conduction	201.5 W
Radiation	56.3 W
Convection	1080.85 W
Total	1338.65 W

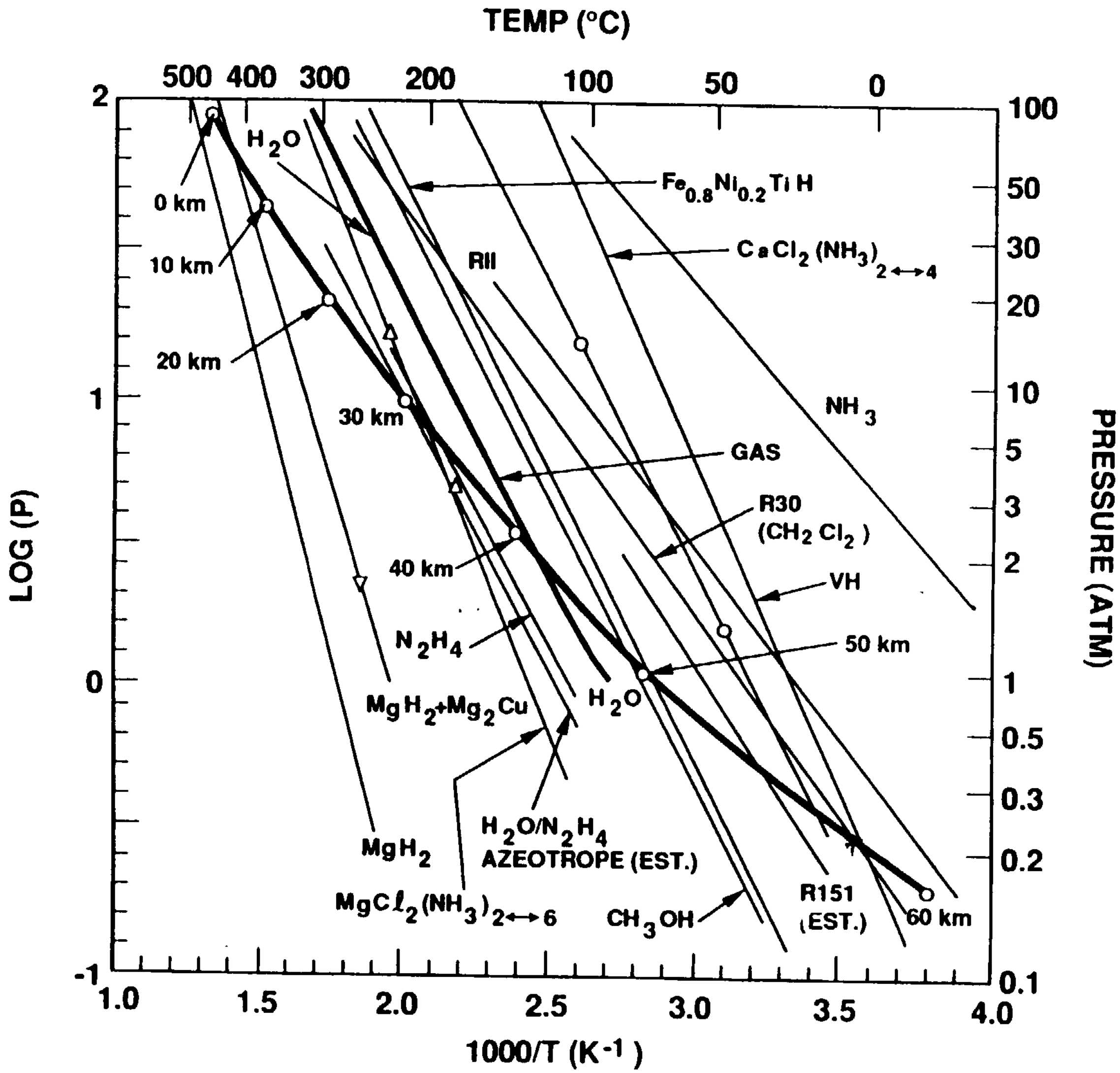
=> 1338.65 J/s

The time required to provide the needed energy is

$$\frac{9636420.8}{1338.65} = 7198.65\ s \rightarrow 1.9996\ hrs.$$

Appendix U

VAN'T HOFF PLOTS FOR REVERSIBLE FLUIDS



Appendix V

Volume Required

We have 200 moles of Methylene Chloride
1 mole = 84.93 g → 200 mole = 16.986 kg
We know the specific gravity is 1.3266

$$SG = \frac{\rho_{Meth\,Chl}}{\rho_{water}} \rightarrow \rho_{Meth\,Chl} = 13.014\ kN/m^3$$

$$Volume = \frac{mass \cdot gravity}{density} = \frac{(16.986\ kg)(9.81\ m/s^2)}{13014\ N/m^3} = .0128\ m^3$$

This is the Volume of the Methylene Chloride in liquid form. When we heat the liquid, the gas will expand requiring a larger volume.

$Volume = \pi r^2 h$ (Conversion $1 in^3 = 1.639 \times 10^{-5} m^3$)

radius (in)	3	4	4.5
length (in)	27.6	15.54	12.27
volume (in^3)	780.37	781.13	780.58

We see that a 4.5 in radius is short enough to fit inside of the entry vehicle (length of 13.78 in)

Next to calculate the Stresses and thickness of the walls.

Dimensions
radius = .1143 m Area = $2\pi r h$ = .2239 m^2
length = .3117 m Volume = $\pi r^2 h$ = .0128 m^3

Appendix W

Stresses

hoop stress $\sigma_1 = \frac{pr}{t}$

longitudinal $\sigma_2 = \frac{pr}{2t}$

Shear $\tau_{max} = \sigma_2$

where p denotes the gage pressure of the fluid, ie the excess of the inside pressure over the outside atmospheric pressure.
r is the radius
t is the thickness

We are looking at aluminum with a yield stress of 416 MPa.

The hoop stress is critical.
The pressure at 48 km = 1.3 atm = 131690 N/m^2
If all the liquid becomes vapor we can use the ideal gas law $pV = nRT$ (pressure · volume = no. moles · gas const · temperature)

$$p = \frac{nRT}{V} = \frac{(200 \text{ moles})(8.314 \text{ m}^3 \text{ Pa/K mole})(373 \text{ K})}{(.0128 \text{ m}^3)}$$

$$= 48455031.25 \text{ Pa}$$

The gage pressure is 48323341.25 Pa
Now optimize the thickness and the stress.

DON'T USUALLY OPTIMIZE THE STRESS!

σ_1	200×10^6	300×10^6	400×10^6
t(m)	.0276	.0184	.0138
t(in)	1	.72	.543

WHAT ABOUT THERMAL STRESS & STRAIN?

IT SHOULD BE INCLUDED, & WILL COUPLE WITH PRESSURE STRESSES.

ORIGINAL PAGE IS OF POOR QUALITY

Appendix X

Weight of Heat Exchanger

Surface Area = $2\pi r h$
Volume of material = $2\pi r h t$
Weight = (Volume) (Density)
= $2\pi r h t \rho$

r = radius = .1143 m
h = length = .3117 m
t = thickness = .0138 m
ρ = density of aluminum
= 2770 kg/m^3

For these conditions, the weight is 8.5 kg

If the thickness is changed to 0.0184 m
then the new weight would be 11.409 kg

Why was aluminum picked?

Your material choice was never justified!

Appendix Y

CONDUCTION

$$q_r = -k A \frac{dT}{dr}$$

L = Length of tube

r_1 = radius of hole

r_2 = radius to outer surface

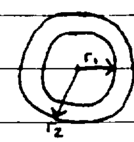
T_{s1} = Surface Temp @ inner surface

T_{s2} = Surface Temp @ outer surface

k = Thermal Conductivity

$$\frac{dT}{dr} = \frac{T_{s1} - T_{s2}}{\ln(r_2/r_1)}$$

$$q_r = \frac{2\pi L k (T_{s1} - T_{s2})}{\ln(r_2/r_1)}$$



→ NOT A VERY GOOD DESIGN AT ALL!

$q_r = 201.5$ W

$L = .3117$ m

$r_1 = .1143$ m

$r_2 = .6573$ m

$T_{s1} = 337$ K

$T_{s2} = 338$ K

$k = 177$ W/m K

WHAT?

WHY DON'T YOU USE A FINNED TUBE? MUCH BETTER HEAT TRANSFER CAPABILITIES.

YOU HAVEN'T PICKED A MATERIAL, HOW CAN YOU HAVE A K VALUE?

Appendix Z

RADIATION

$q = A(\alpha_s G_s + \alpha_{sky} G_{sky} - E)$

$q = A(\alpha_s G_s + \varepsilon \sigma T_{sky}^4 - \varepsilon \sigma T_s^4)$

$\alpha_s G_s = 18.48 \ W/m^2$

$\varepsilon \sigma (T_{sky}^4 - T_s^4) = 233.02 \ W/m^2$

$q = 56.3 \ W$

α = Solar absorptivity
ε = emissivity
A = Area
G_s = Solar flux
σ = Stefan-Boltzmann Constant
T_s = Temp of surface
T_{sky} = Temp of atmosphere

Material: Aluminum (anodized)

$\alpha = .14$
$\varepsilon = .84$
$T_{sky} = 93°C \rightarrow 366 \ K$
$T_s = 65°C \rightarrow 338 \ K$
$\sigma = 5.67 \times 10^{-8} \ W/m^2 K^4$
$A = .2239 \ m^2$
$G_s = 132 \ W/m^2$

Solar flux at Venus 2600 W/m^2 ← GOOD!
Absorbed Solar flux 132 W/m^2

Appendix AA

Forced Convection

Modeled as a cylinder in cross flow

$$Re_D = \frac{V D}{\nu}$$

$$Nu = C \, Re^m \, Pr^{1/3}$$

$$h = \frac{Nu \, k}{D}$$

$$q = hA(T_\infty - T_s)$$

V = Velocity of Wind
D = Diameter of tube
ν = viscosity, Kinematic
Re_D = Reynolds number
Nu = Nusselt number
Pr = Prandtl number
h = convective heat transfer coefficient
K = thermal conductivity
A = Area
T_∞ = Temperature of Atmosphere
T_s = Temperature of Surface
C, m = Constants

$V = 50 \ m/s$
$\nu = 14.3 \times 10^{-6} \ m^2/s$
$D = .2286 \ m$
$Re_D = 799300.7$
$C = .027$
$m = .805$
$Pr = .737$
$Nu = 1376.8$
K = [redacted] W/m^2 24.3×10^{-3}
h = [redacted] $W/m^2 K$ 146.35
$A = .2238 \ m^2$
$T_\infty = 366 \ K$
$T_s = 338 \ K$

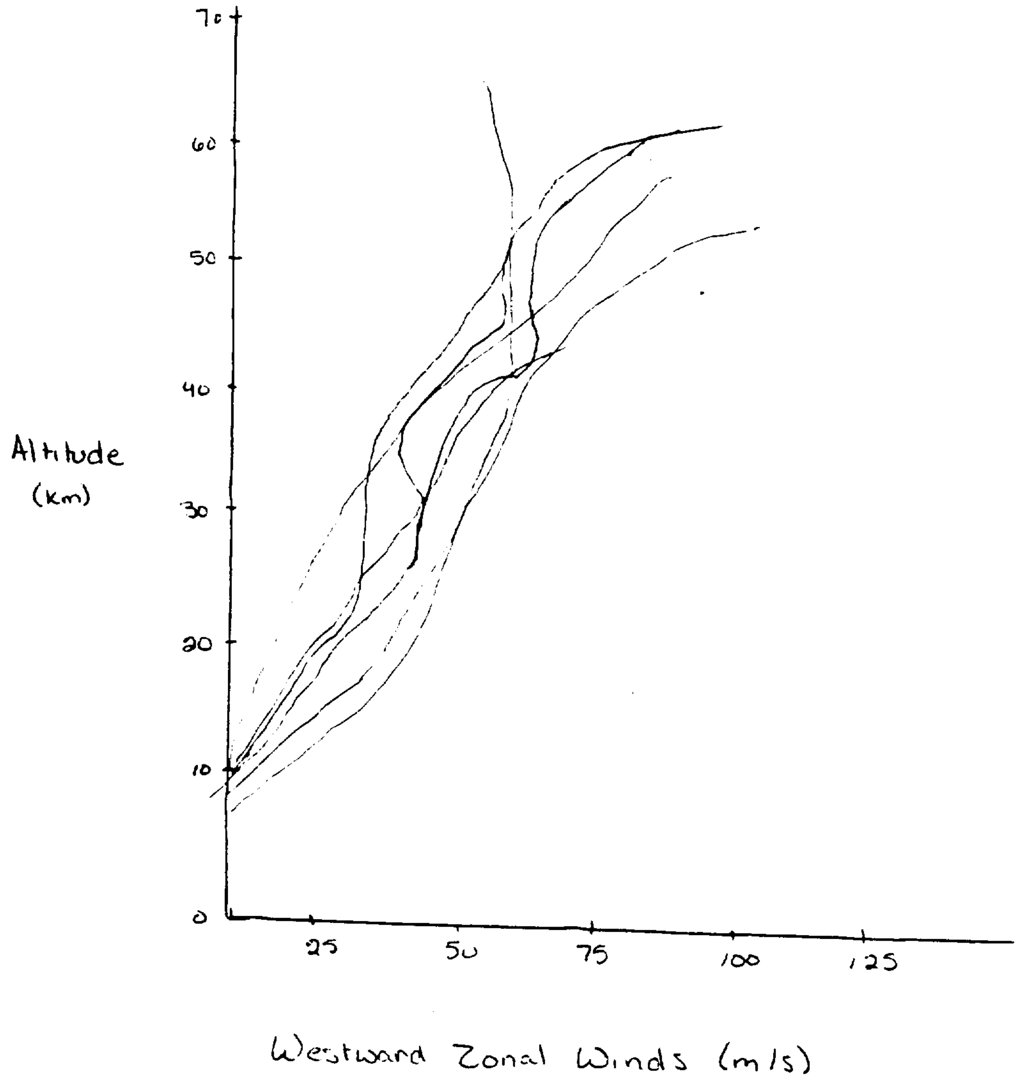
$q = 1080.85 \ W$

Constants

Re_D	C	m
.4-4	.989	.33
4-40	.911	.385
40-4000	.683	.466
4000-40000	.193	.618
40000-400000	.027	.805

Appendix AB

The Winds on VENUS
(HORIZONTAL)



Appendix AC

Free Convection

Inside of Heat Exchanger, modeled as isothermal vertical plate in laminar flow.

$$Gr = \frac{g\beta(T_s - T_\infty)L^3}{\nu^2}$$

$$\beta = \frac{1}{T}$$

$$Ra = Pr\,Gr$$

$$Nu = \frac{4}{3}\left(\frac{Gr}{4}\right)^{1/4} g(Pr)$$

$$g(Pr) = \frac{.75\,Pr^{1/2}}{(.609 + 1.221\,Pr^{1/2} + 1.238\,Pr)^{1/4}}$$

$\leftarrow$ NOT COMPLETED!

Gr = Grashof Number
β = Volumetric thermal expansion coefficient
T_s = Temperature at Surface
T_∞ = Temperature of gas
L = Length
ν = viscosity
Ra = Rayleigh Number
Pr = Prandtl Number
Nu = Nu

Difficulties in finding this because of two factors.
1) Lack of information about the properties of methylene chloride.
2) The methylene chloride will boil inside the heat Exchanger.

~~pool Boiling~~ $q'' = \mu_l h_{fg}\left[\frac{g(\rho_l - \rho_v)}{\sigma}\right]^{1/2}\left(\frac{C_{pl}\,\Delta T_e}{C_{s,f}\,h_{fg}\,Pr_l^n}\right)^3$

NOT USED!

Could not find information on saturated liquid and vapor states.