N75 20380

EFFECT OF INITIAL CONDITIONS ON DEDUCED ATMOSPHERE FOR URANUS AND JUPITER ENTRIES

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MR. KIRK: I want to discuss atmosphere reconstruction and what I mean by that is the determination of the density, the pressure and the temperature as functions of altitude. I want to discuss how this determination is affected by errors in the initial conditions.

The initial conditions I am talking about are the entry velocity and the entry flight path angle. There are two distinctly different kind of errors that I want to distinguish between before proceeding. One is the navigation kind of error where you try to enter at a flight path angle of minus 30 degrees and because of various tipoff errors and so forth, you can only guarantee that you will enter minus 30 plus or minus 10 degrees. And this is an important kind of error in designing the actual probe, because it affects the peak heating and peak deceleration. But it doesn't affect the atmosphere reconstruction at all.

The error that affects the atmosphere reconstruction is that you really enter at 32 degrees flight path angle and you are told that you entered at 30 degrees. This 2 degree error does have a significant impact on the determination of the atmosphere structure.

Table 5-3 is a summary of the cases that I am going to talk about this morning. The Saturn mission is also included here to give kind of a complete idea about the outer planets.

What we have here, let us just go down the column. Under Jupiter, this is a reasonable entry velocity. Entry flight path angle of -9.5° indicates a very shallow entry to cut down on the peak heating. And let me point out that these numbers are all relative, relative to the atmosphere. They are not inertial numbers.

		Jupiter	Saturn	Uranus	(PAET) Earth
V_E	km/sec	47.4	28.9	24.8	6.6
γ_E	deg	-9.5	-39.5	-40	-40.9
$z = 0$		p = 1 atmosphere		→	→
z (1g)	km	244	358	341	76
z (peak g's)	km	102	148	139	35
peak g's		328	360	255	76
z (M~2)	km	60	99	87	26

V-11

results using "Nominal" atmospheres

Table 5-3

For all the cases, the zero altitude is where the pressure is one atmosphere, just arbitrarily. And I have listed here where the probe first experiences one G deceleration where it reaches peak G's, what the peak G's are and where it reaches a Mach number of two; and for the high speed part of the entry, all you are relying on is an accelerometer to determine the structure of the atmosphere. And this is where the errors in the initial conditions come into play quite strongly.

You will notice for Saturn, the altitude range is roughly the same. For Uranus, the altitude range is roughly the same. We are talking about roughly 300 kilometers down to 100 kilometers for each of the three planets.

All of these results are using the nominal atmosphere, but we did do cases with the extreme atmosphere and it does not affect what I am going to say.

I included, here, the PAET flight from three years ago into the Earth's atmosphere where we demonstrated this concept of high speed determination of the atmosphere. The peak deceleration was only 76 G's and the altitude range was from 76 kilometers down to 26 kilometers. Over that range, we feel that we determined the density profile well within ten percent of its true value, and that would be a reasonable goal that we would like to achieve for the outer planets if at all possible.

On Figure 5-3 I have the Jupiter entry with the flight path angle of nine and a half degrees. What is shown here is the percent error in density as a function of altitude, and this altitude is from the pressure equals one atmosphere level. Shown here are two curves, one for an error in the flight path angle of plus about a quarter of a degree and one for minus of about a quarter of a degree. Notice that this error is about two and a half percent of the initial flight path angle. It is not a very sizeable error, and is the one sigma, not three sigma, error from navigation that is assumed right now.

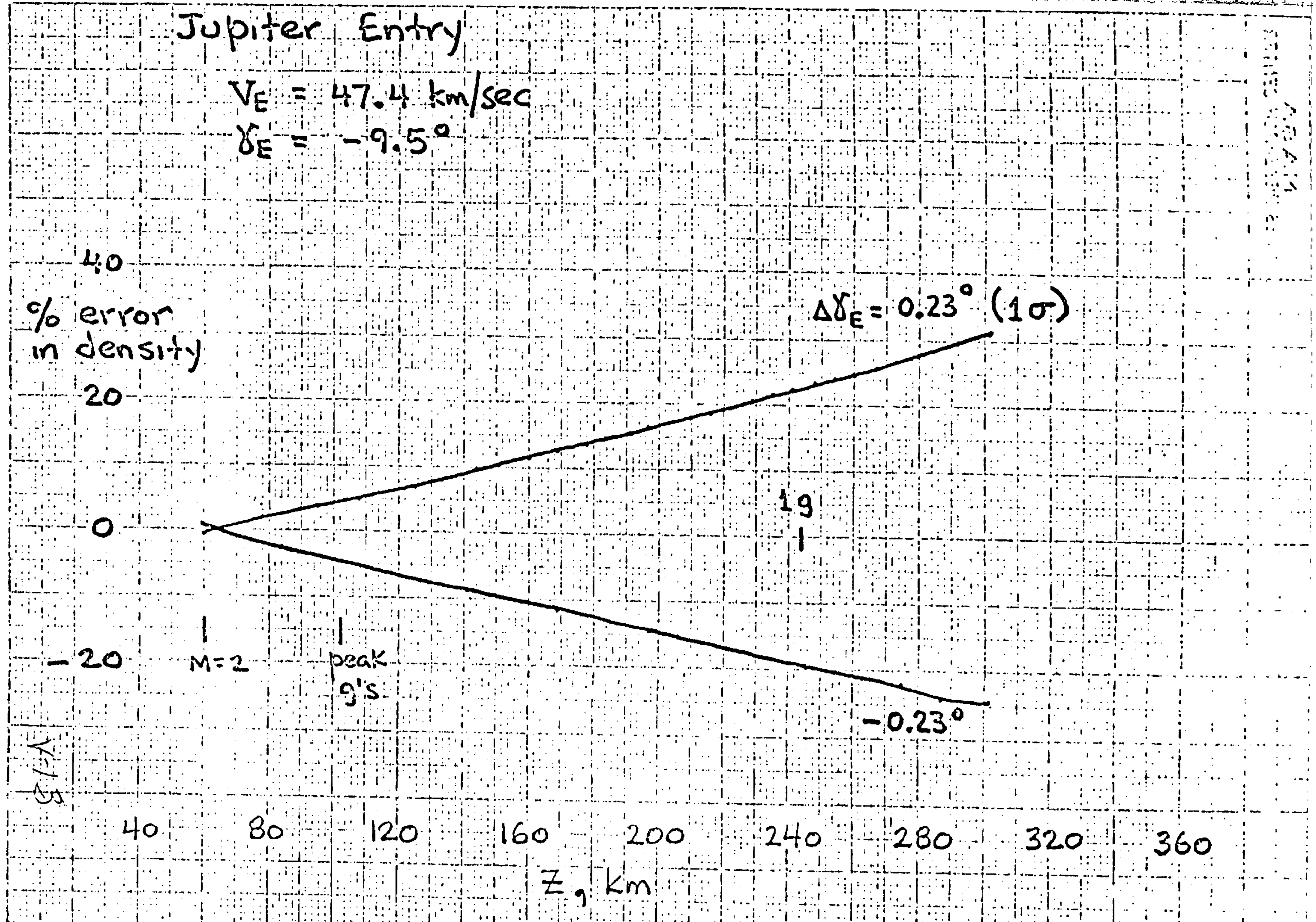
Jupiter Entry
V_E = 47.4 km/sec
γ_E = −9.5°
40
% error in density
20
0
−20
M=2
peak g's
1g
$\Delta\gamma_E$ = 0.23° (1σ)
−0.23°
40
80
120
160
200
240
280
320
360
Z, km

Figure 5-3

After the fact, we should be able to do better in knowing the entry flight path angle. How much better, nobody seems to know. But you will notice that for this kind of error, you are talking about errors in the density of 30 or 40 percent at the altitude where the probe is experiencing more than one G deceleration and where you had hoped to have a very good handle on the atmosphere. And this error is only due to this initial condition error. Everything else is completely exact.

Figure 5-4 is the same kind of plot for entry at Saturn. Again, this is the one sigma error that is assumed right now as far as navigation is concerned. They claim that they can enter at thirty-nine and a half degrees plus or minus three degrees one sigma. So, again you see that through a large part of the altitude range, you are talking about sizeable errors that could be introduced by an error in the initial flight path angle.

Figure 5-5 shows the same thing for Uranus. And here I don't know what the one sigma or three sigma errors in navigation are, but shown is the result if there is an error of one degree. It is similar to the previous plots, a ten or twenty percent error in the density is introduced by this one factor.

I want to point out one thing: to get the pressure in this high altitude region, you essentially integrate the density so the same kind of error that you get in the density shows up in the pressure. What this leads to is a surprising thing, that the temperature that you get by just dividing the two comes out quite good. For this particular case, the temperature error over that entire altitude range was less than five degrees kelvin. So you can get sizeable errors in density, sizeable errors in pressure, but small errors in the temperature.

Everything I have done so far has been for errors in the flight path angle. Figure 5-6 shows the effect of errors in the initial entry velocity, and this is for the Saturn entry. You remember

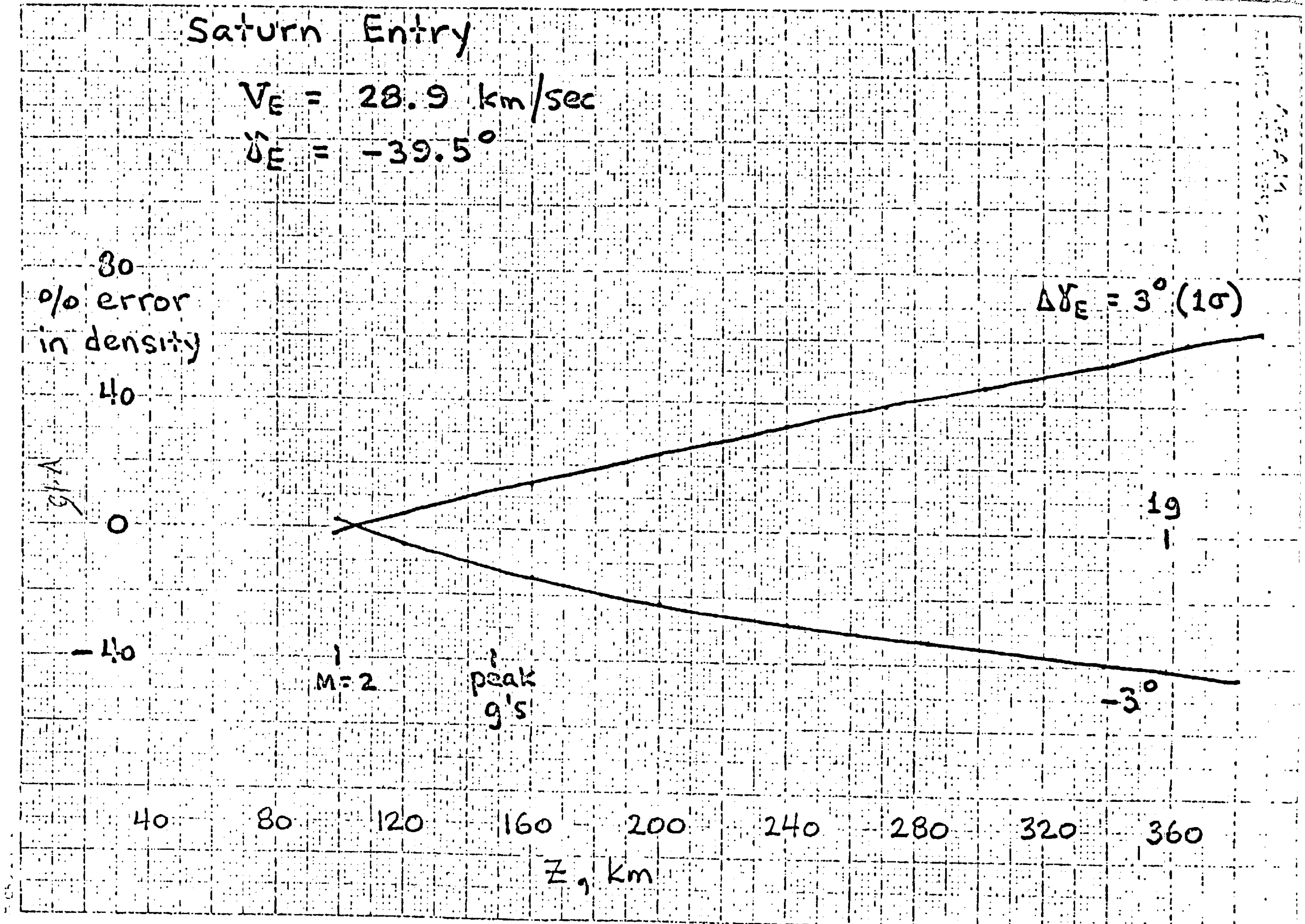
Saturn Entry
V_E = 28.9 km/sec
$\hat{\gamma}_E$ = -39.5°
80
% error in density
40
0
-40
M=2
peak g's
$\Delta\gamma_E = 3°$ (1σ)
1g
-3°
40
80
120
160
200
240
280
320
360
Z, km

Figure 5-4

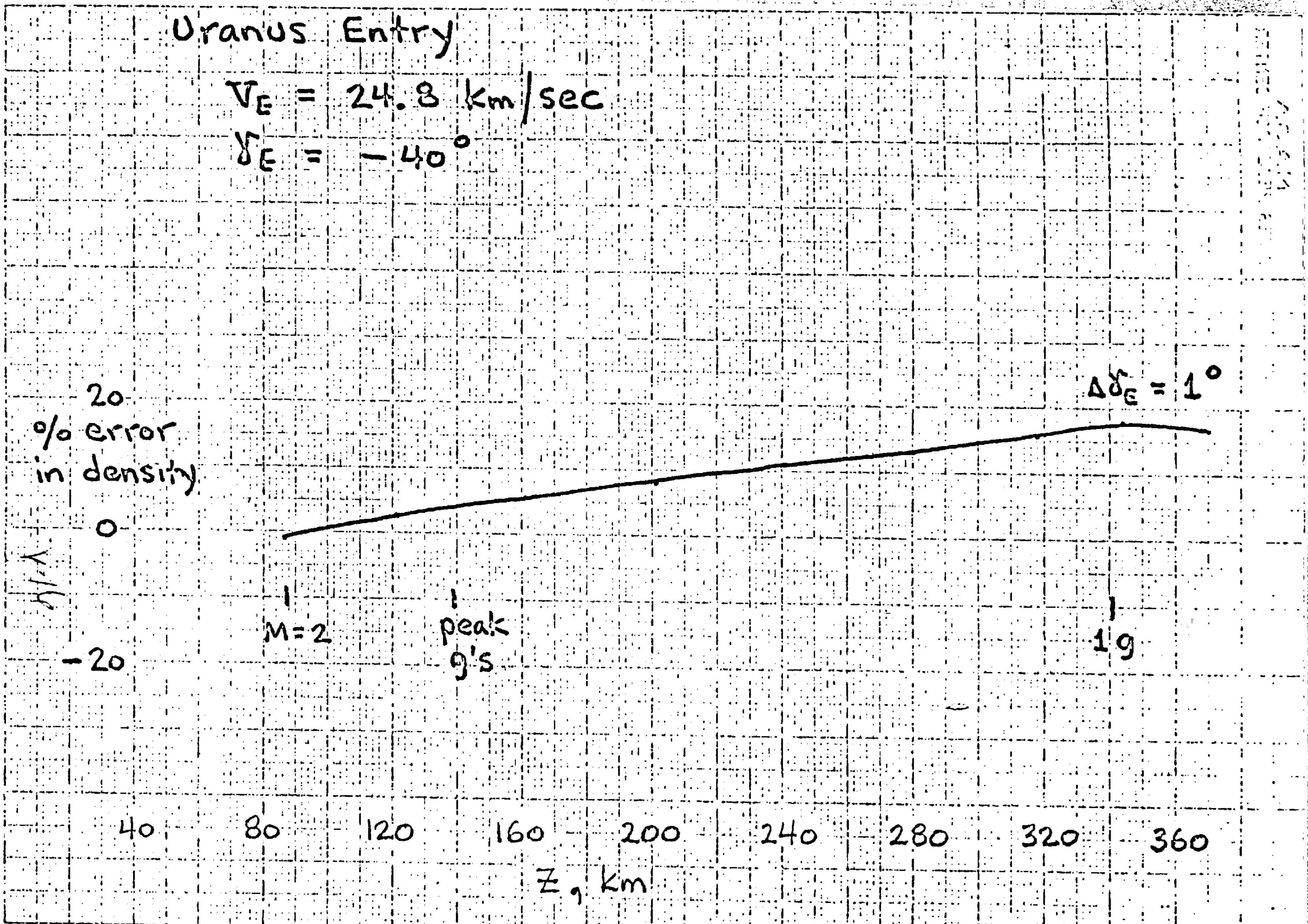
Uranus Entry
V_E = 24.8 km/sec
γ_E = −40°
20
% error in density
0
−20
M=2
peak g's
1g
$\Delta\gamma_E = 1°$
40
80
120
160
200
240
280
320
360
Z, km

Figure 5-5

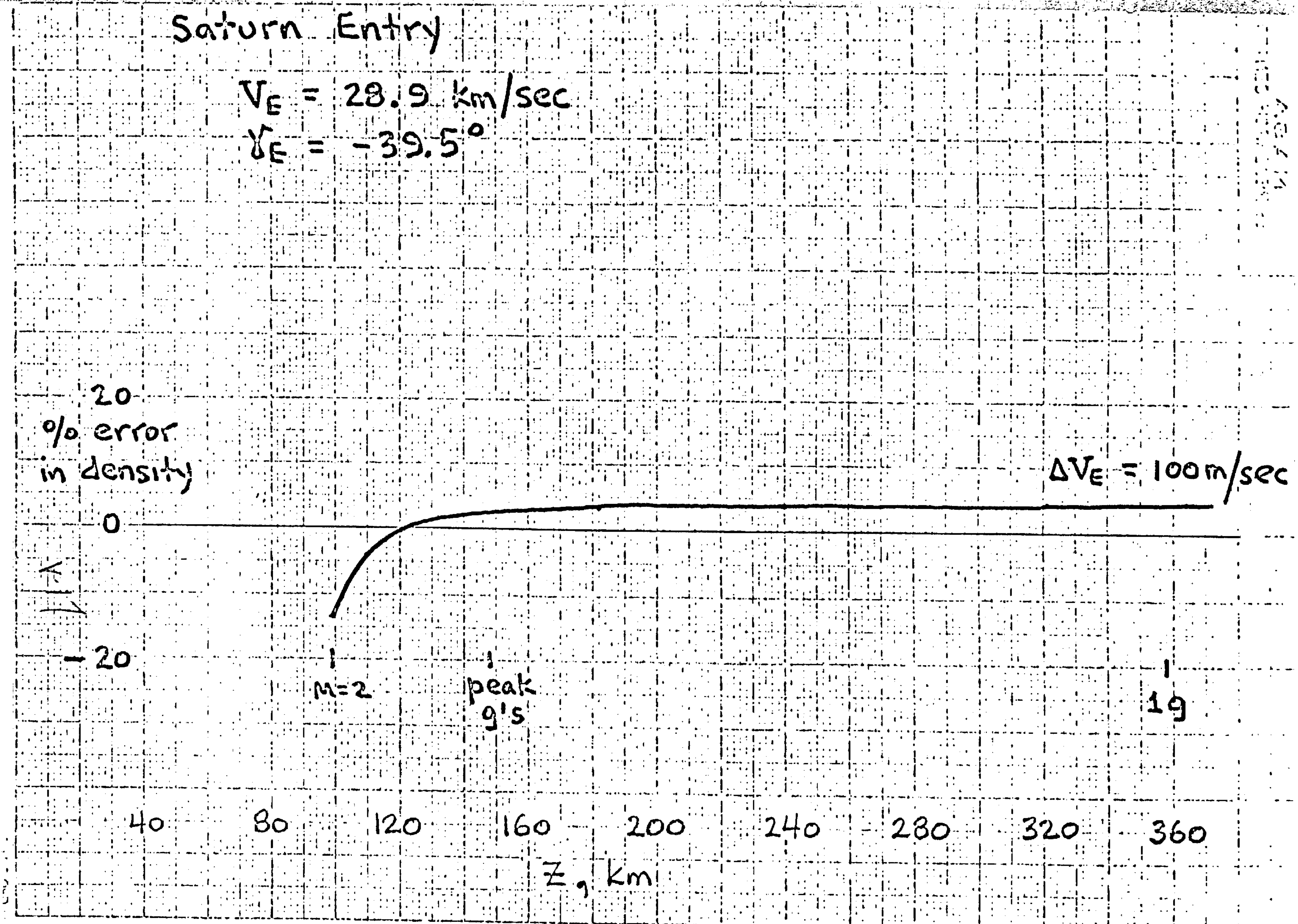
Saturn Entry
V_E = 28.9 km/sec
γ_E = -39.5°
20
% error
in density
0
-20
ΔV_E = 100 m/sec
M=2
peak
g's
1g
40
80
120
160
200
240
280
320
360
Z, km

Figure 5-6

how all the flight path angle errors were relatively linear and came down to a value that was very small. This shows that at high altitudes, a 100-meter per second error, that is one hundred of 28,900, introduces about a four percent error in the deduced density. This four percent stays constant through most of the altitude range, and then switches sign near the end of the high speed experiment. At this point, you are going to deploy a temperature sensor, and from then on you are going to actually measure the temperature, measure the pressure. So, from then on, the atmosphere reconstruction is extremely accurate.

The funny thing here is that if you corrected this value of density to the value you get from a low speed experiment, in other words, push the entire curve up, what you would be doing is throwing the rest of the atmosphere up to about a ten percent error.

I want to conclude by saying that my feeling is that it is a shame to introduce sizeable errors like this in the atmosphere reconstruction. What I hope is that people who are knowledgeable in tracking can come up with ways to get errors in the initial velocity and initial flight path angle down to an abosolute minimum.

MR. FRIEDMAN: That was error that was associated with the a posteriori effect.

MR. KIRK: Yes, that is correct

MR. FRIEDMAN: That is a knowledge error that you can obtain through solving.

MR. KIRK: We don't care anything about real time, necessarily. Two weeks after the fact, what is the best estimate that people can come up with?

MR. RON TOMS: I am not sure I quite understood how many readings you need in order to get those kinds of accuracies that you are showing. I have heard people say that the Uranus descent may be competent of reading all the way down to the surface.

MR. KIRK: No, you have to get a number of readings during the high altitude part and these readings would be put into a storage during the entry and then played back during the low speed descent.

MR. TOMS: So the errors you are showing had nothing to do with the number of readings that are taken.

MR. KIRK: I have assumed exact acceleration readings throughout the entry. Only the initial conditions have affected the accuracy of the atmosphere reconstruction. When I ran the case with no errors in the initial conditions, I deduced the atmosphere within a tenth of a percent through the whole altitude range.

UNIDENTIFIED SPEAKER: Just a comment. I think your Jupiter numbers probably more than any others look very optimistic. You are hoping for a lot to get a determination that good. The other numbers, I think may be somewhat more reachable.