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COMMUNICATIONS CONSTRAINTS ON A JUPITER PROBE MISSION

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MR. HINRICHS: My question was fairly simple compared to some of the questions we have heard today. That question was, "Can we take the Saturn-Uranus design that we performed for Ames previously, communications data handling system design, and fly it on a Jupiter mission?" So that is what we intend to address for a few minutes.

Our point of departure here (Figure 3-58) is Byron Swenson's trajectory to Jupiter. In relay communications terms, this is the arrival date, which means the angle from the roll axis of the spacecraft to the Earth and the excess velocity which describes the trajectories.

Very briefly, without going through them, this is what the trajectory looks like. As he has pointed out, we will deorbit something like 50 days out with about 66 meters per second Delta V. The probe will descend, as we pointed out before, the spacecraft pushed out into a flyby. We have the possibility of a correction maneuver about 26 days out which I will discuss a little bit later on, and go into the planet. So this is a general introduction to the problem we are going to try to attach.

The first thing that we start out with is, of course, the geometry. Tom Hendricks had a slightly different definition of some of the geometric characteristics. So. returning a little bit earlier to the geometry that Byron Swenson was talking about, the spacecraft aspect angles here (Figure 3-59) are the angle from the spacecraft roll axis to the probe, and this is the negative roll axis, if you will, that portion of the roll axis away from the Earth. Of course, the probe aspect angle is the same.

We investigated approximately twenty-one different trajectories, i.e., relative trajectories of the probe and the spacecraft, on our 6600 computer. We varied the spacecraft periapsis from 1.7 RJ to 2.2 RJ, but since the higher RJ data fell off of the interesting side of the chart, for clarity I didn't show it. The other parameter

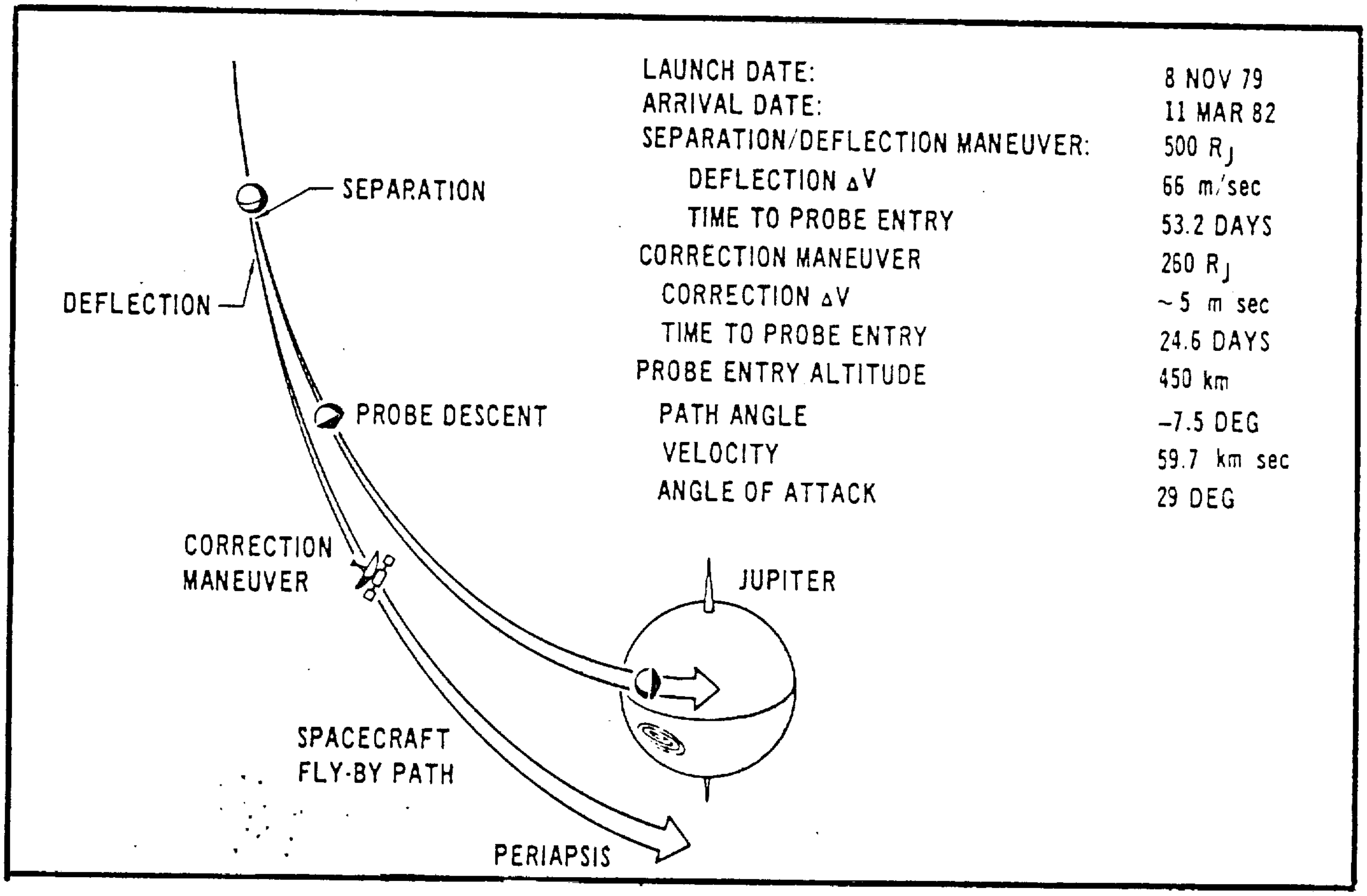

FIGURE 3-58. Jupiter Mission Parameters

in the spacecraft trajectory, besides periapsis, is spacecraft phasing. Now what we mean by spacecraft phasing here is the time from probe entry to the spacecraft at probe zenith. We ran actually .2, .26, .3, .4, and .5 hours phasing.

For the application of the Jovian entry to the Saturn-Uranus design we would like to see the probe view angles below 33 degrees, and the spacecraft angles between 40 and 90 degrees. This is because the spacecraft, as we recall from the Saturn-Uranus design, was Pioneer with a squinted pattern. Finally, we have the communications range we sometimes like to draw maximum ranges like 100,000 kilometers or so, but that fell off the top of this chart. This presents, then, the geometric parameters that we have run through.

Now this geometry is only a portion of the problem, however. Associated with this is the accuracy that we believe that we can meet.

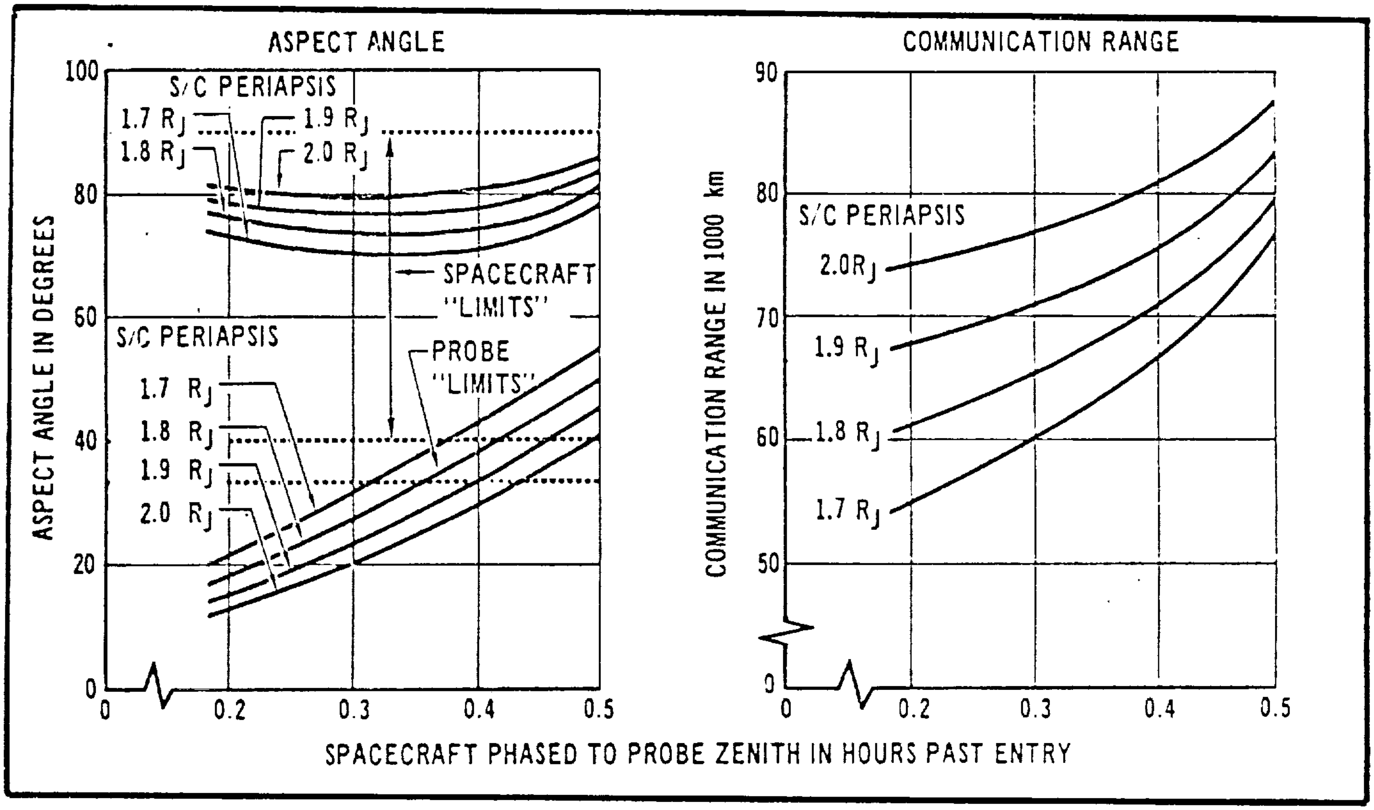

FIGURE 3-59. Parametric Study in Phasing Relationships

For one of these trajectories, (cf. Figure 3-60) the 1.8 RJ periapsis, 0.4 of an hour phasing time trajectory, (they are all very similar). I have illustrated the nominal view angles and ranges together with two sets of three sigma tolerances. The set represented by the solid line are those if we made a single maneuver, i.e., the deorbit maneuver. The set represented by the dashed line is those if we made a second maneuver approximately 26 days prior to entry to correct for the errors in the deorbit Delta V. This second maneuver would be of the order of five meters per second. Recall that the initial Delta V maneuver was of the order of 66 meters per second. We see very quickly, from this type of chart, that as far as the probe is concerned, if we did not make such a maneuver, the adverse tolerance line for a great amount of the trajectory, both in early phases and late phases, would be exceeding the beam width of the design probe antenna.

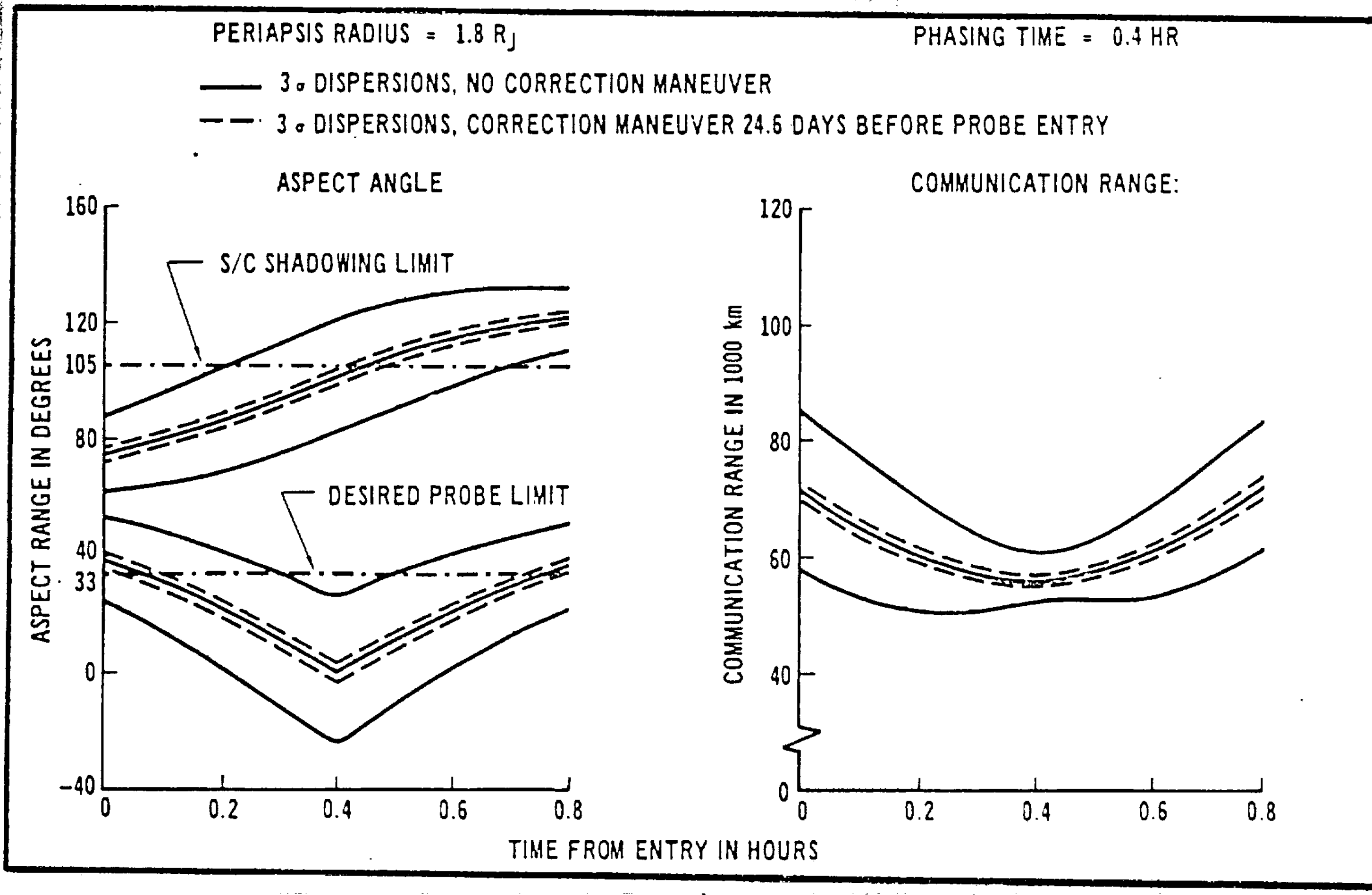

FIGURE 3-60. Trajectory Dispersions

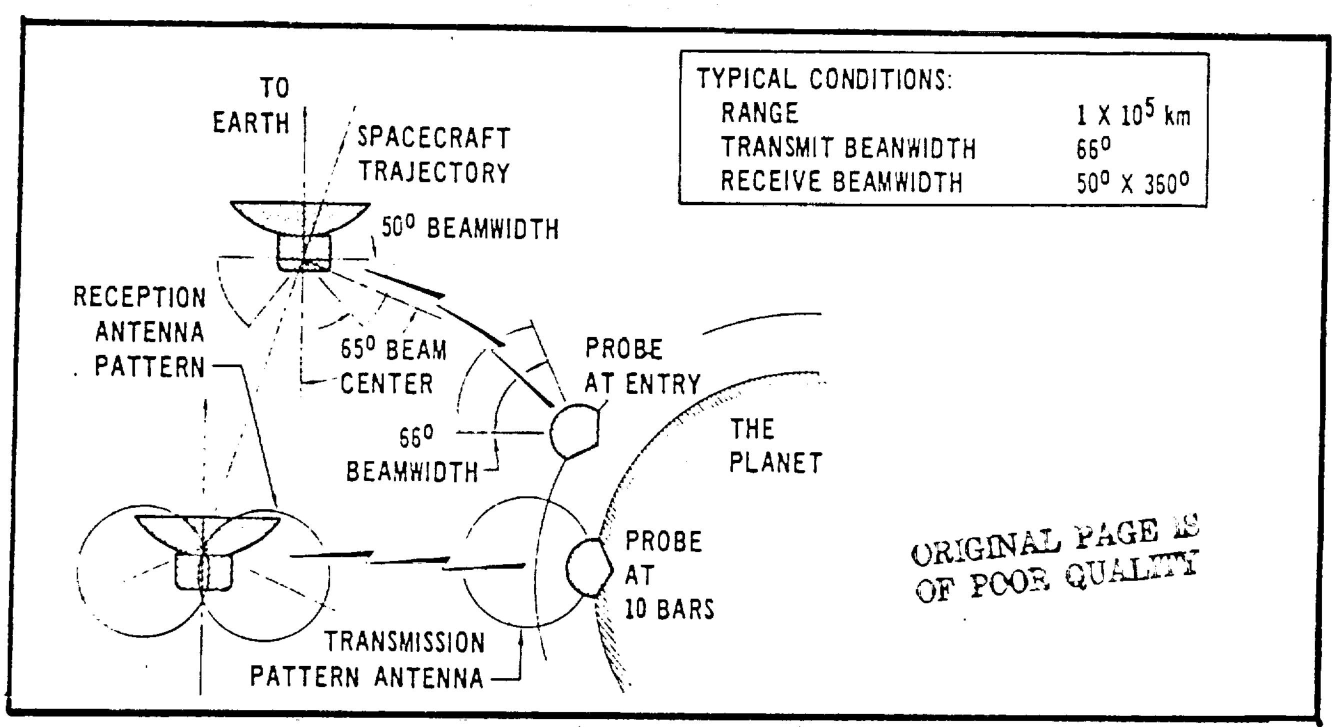

FIGURE 3-61. Communications Relay Geometry

Similarly, we see that we have a shadowing limit imposed on us by the spacecraft. You will recall from the previous chart, we wanted to try to keep the spacecraft aspect angles between 40 and 90 degrees in order to stay inside the beam width. However, if the aspect angle goes beyond approximately 105 degrees, the spacecraft antenna that is receiving the probe data, will be blocked by the large spacecraft dish, which is pointing at the Earth.

In our previous study, we have taken this as being 105 degrees. We will see in some succeeding charts that this begins to impose quite a constraint on us for the nominal mission, at least at time of entry, which this data is showing here. For the nominal mission, we could go out around approximately 0.4 of an hour phasing time and not be shadowed. However, if we wound up with an adverse tolerance with no Delta V correction, this could drop down to slightly below 0.2 of an hour.

And so, phasing will be a significant factor here. The previous small set of charts were strictly the trajectory geometry. On top of this, we have to impose the electrical geometry as shown in Figure 3-61. By this I mean the effects of antenna patterns. (I apologize for the artist here; he insists on flying a spacecraft in a straight line rather than a hyperbola.)

The typical probe pattern in the previous study, as I believe I have mentioned before, was a 66-degree beam width antenna whose maximum is on the roll axis of the probe. And on the spacecraft we have a loop vee antenna that Bill Dixon referred to earlier. This has approximately a 50° beamwidth. The center of the beamwidth is 65° off the roll axis. You will recall now, as I said before, at about 105° - the cartoon, of course, isn't to scale - we will start seeing some abrupt shadowing. I might also point out that the link that we will be talking about here is the Saturn-Uranus link which is specifically one which starts out with a 44-bit data stream. This is transmitted over a 40-watt, 400-Megahertz antenna. This is the basic link that we are talking about, and we really haven't perturbed it yet.

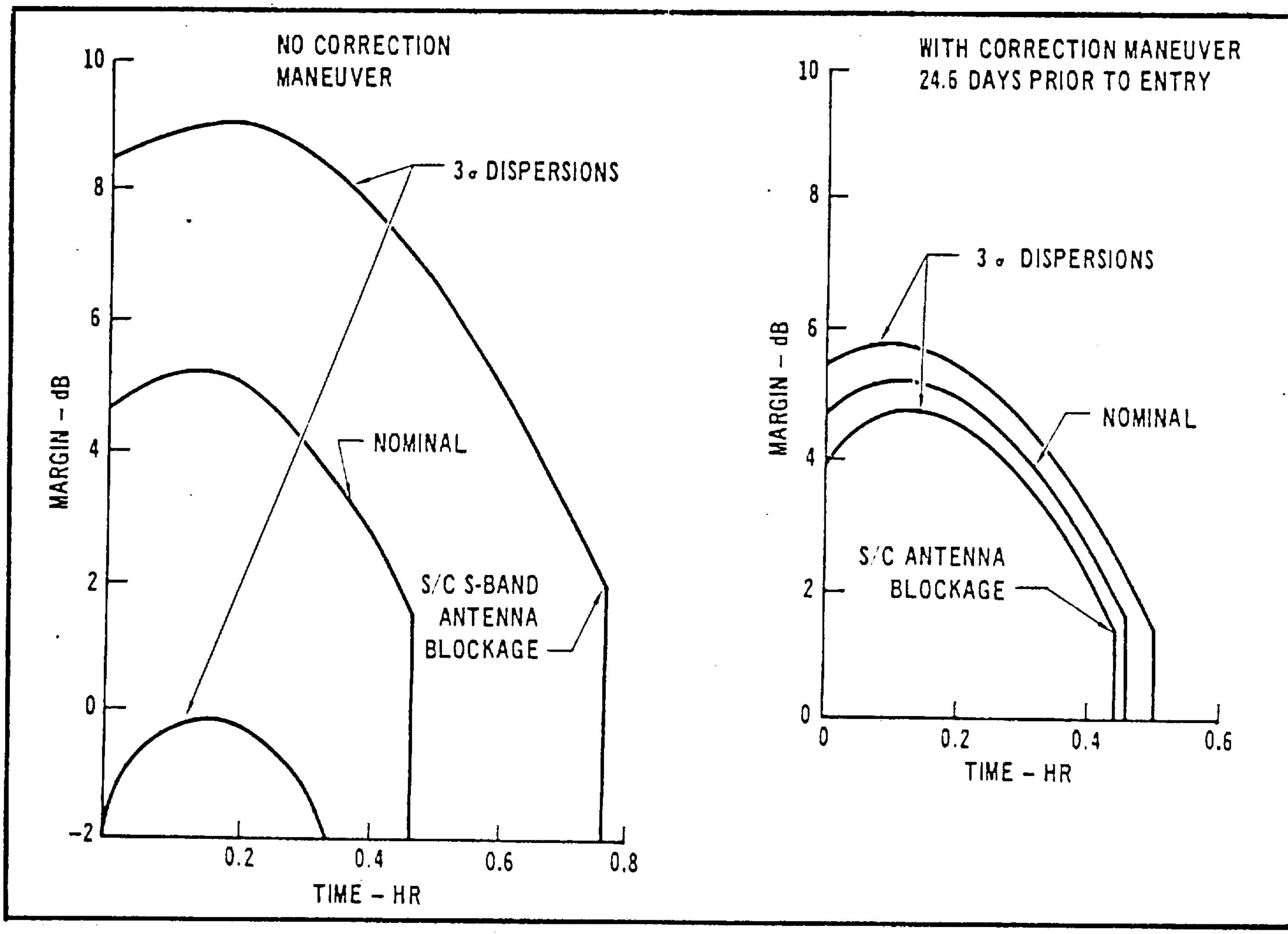

FIGURE 3-62. Effects of Trajectory Dispersions on Link Margin

With the electrical geometry coupled together with the trajectory geometry, we can establish a margin history. (Figure 3-62). The martin of the communications link is a function of the entry time and, if we have no Delta V correction, that is no second maneuver correction, those large antenna look-angle variances reflect in an extremely broad spread in the margin. By margin we mean, in this case, the true margin. At zero db margin we have a fifty percent chance of the link operating. At some value not indicated right now, typically about five db is the adverse tolernace limit. Above that point we will say that we have a one hundred percent probability of communications.

As we move to the chart on the right side for the same trajectory, we can see that if we make a second Delta V correction to take out that error, (the five meter per second maneuver) these tolerances come way down; within about three quarters of a db. So, we can

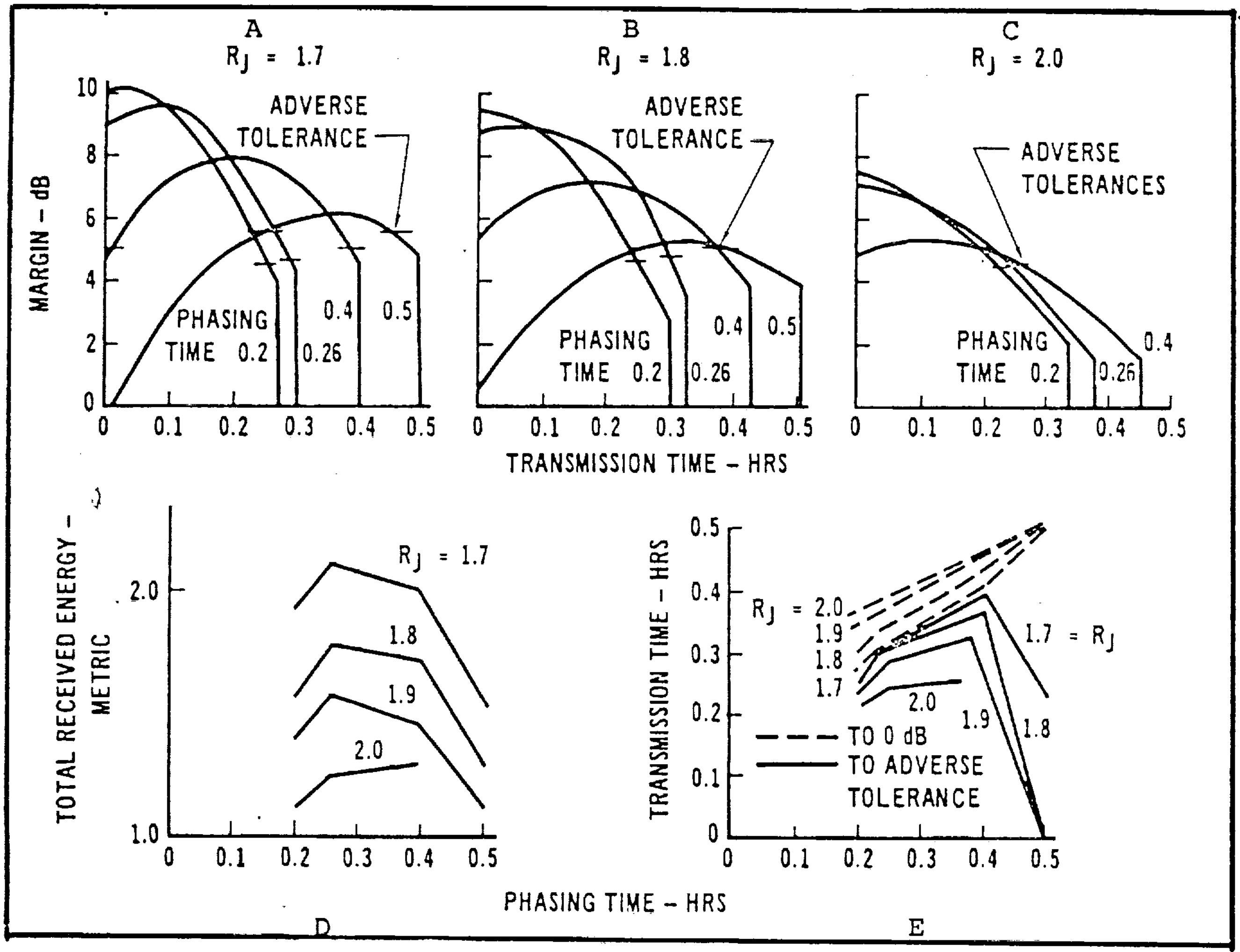

FIGURE 3-63. Link Margin and Communications Time Parametrics

have a greater assurance of the quality of the link simply be reducing those angles. This leads us very quickly to the conclusion for the Jupiter mission that a second burn to reduce the Delta V would be a very advantageous thing from the communications viewpoint.

Given that we have decided to go along with a second burn to eliminate the Delta V errors, we can generate a large, confusing family of margin histories (Figure 3-63). Again, this is the amount of signal strength we have (over and above what the link table would tell us we require) for a number of different trajectories. In this case, we run another computer program for the electrical geometry and the link table, utilizing the trajectory geometry as inputs. On each of these margin charts, I have tick marks to indicate the adverse tolerances. They are slightly different for each trajectory because of the difference in the synchrotron noise (being closer or farther from the planet; and depending on how we integrate to get the amount of noise.)

They also are somewhat different in that we have assumed in the adverse tolerances a five-degree uncertainty in the pointing angle of the probe at time of entry to account for "wobble."

Taking a typical mission, again our friendly 1.8 RJ, four tenths of an hour phasing time, we can see that the margin starts almost at the adverse tolerance point, increases as time goes on, (to about two tenths of an hour,) then begins to decrease until about .35 hours where we drop below the one hundred percent probability of communications. Then at some point the margin abruptly drops to zero where we have hit the shadowing limit of the big dish.

As I said before, these are pretty confusing charts to look at. If you do stare at them for a week or two, you begin to make some sense out of them. One of the ways of making sense out of them is to try to pick a trajectory, let's say that maximizes the total amount of energy at the spacecraft receiver. This is simply the integral of the margin history and we can take this as a metric then to find the "goodness" of a particular trajectory, in relay communications terms.

So, I have plotted this "goodness" for these different trajectories here on Figure 3-63D. The larger the better. We can see that as the spacecraft periapsis moves in the apparent "goodness" is better. In other words, we have about fifty percent more energy for the 1.7 R_J .26 phasing mission than we have for, say, about the 1.9. This "goodness" criteria, however, does not take into account the amount of time that we have to transmit. If we look at just the time that we have to transmit we get somewhat of a different picture. (Figure 3-63E). Again, each point here indicated by a break in the curve represents a complete trajectory; that is a complete run through the communications and a complete run through the exoatmospheric trajectories. So, we can see as we plot, for example, the total transmission time to the adverse tolerance limit, that as the periapsis moves in we get more and more transmission time; things get better and better. This is, fairly obvious because we are moving in closer and we are getting more margin. Things are beginning to look better.

However, if we plot the total amount of time to zero db or in most cases, blockage - I don't believe I have an example up here where zero db does not occur at blockage - we see somewhat of a different trend. In the one case as we drop to periapsis we increase transmission time. For zero db, as we decrease periapsis we decrease the time. In this case, of course, as we are coming closer in we have less and less time to view. So, in the one case the adverse tolerance line moves up to a point where it is, let us say, caught by the zero db transmission time and then it is swept down. The obvious best point, then, is where these two parametrics cross. In this particular case, for this case of geometries, this is at 1.7 R_J and results in a maximum transmission time of about four tenths of an hour if we have a phasing of, also, about four tenths of an hour.

We currently have ignored our scientific friends in that we have only been talking about maximizing the margin and the communications time. We really haven't talked about science. Science, in our terms, is the data handling system. So, I'd like to just very briefly go through the data handling system and show why this communications time was so critical.

The upper diagram of Figure 3-64 is a block diagram of the data handling system of the Saturn-Uranus design. The first thing that happens in the design is that early in the game we would like to catch the earliest possible deceleration (which, by definition, is .0004 G's and is the least resolvable deceleration time,) so that we can monitor the deceleration all the way from that least possible deceleration through the absolute maximum down to the point where we deploy instruments.

So what we will do is early in the game (prior to that .0004G point) we will turn on the data handling system, we will start

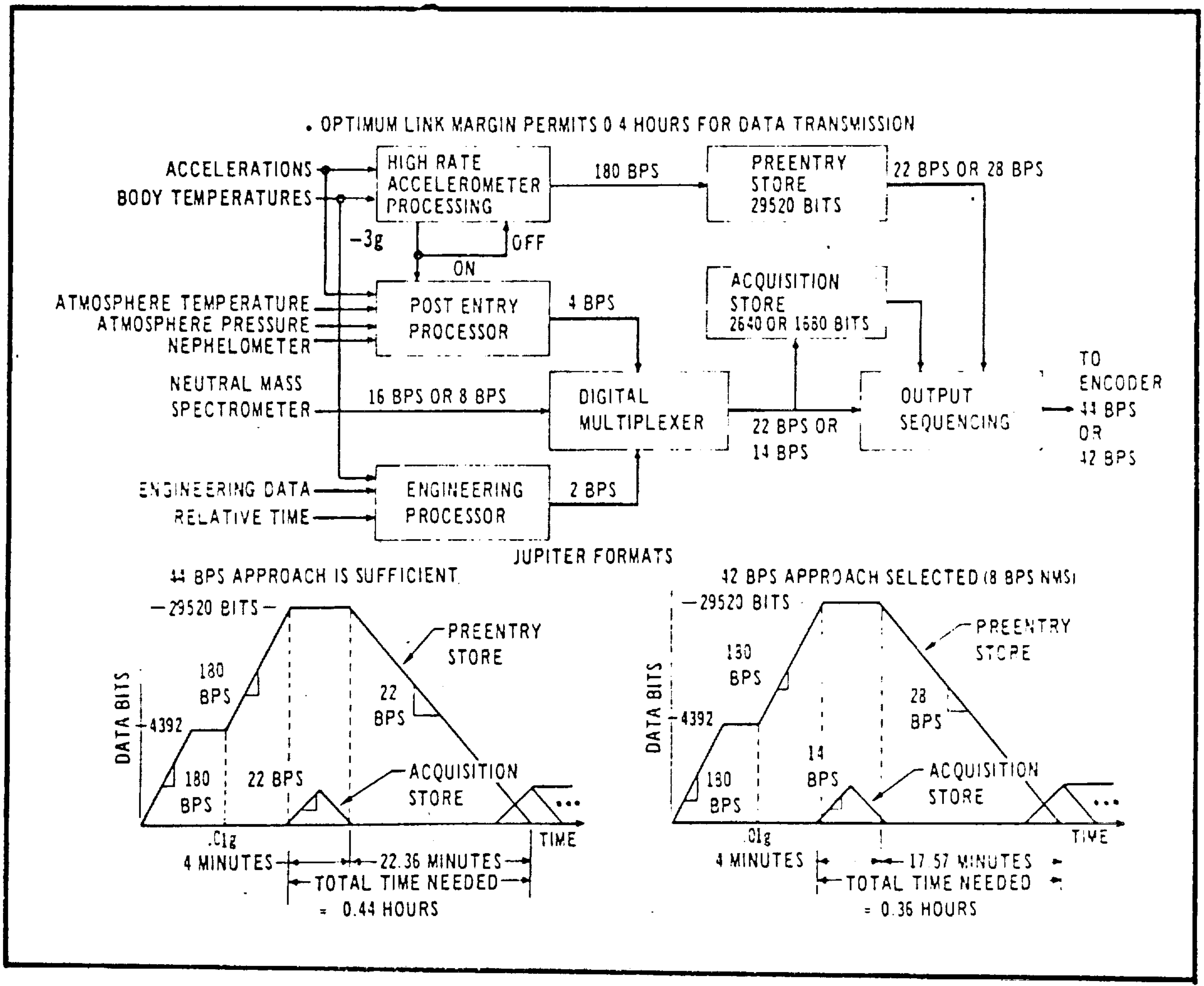

FIGURE 3-64. Data Handling Approach

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monitoring these decelerations and we will store them in a line. We will start filling up that line at 180 bits per second; and when that line is full, the first bit that went into the line falls off and we pump a new bit in. We hold the system at that condition until we see some very definable, highly reliable G level; in our case, arbitrarily, .01 G's. When we hit this level, we have trapped .0004G (that least resolvable G), and a very reliable G. At this point then, the high rate processor, having found the crossover point, ceases filling the first line and fills up another large line to the point where we are now ready to deploy instruments.

This is, typically, like three or six G's (it seems to vary from day to day and from planet to planet). I just ask the trajectory people what the number is currently and use it. At this point the high rate processor turns off. It has sensed the G levels and has decided that we have been through peak deceleration. Then we start our normal processing. This is the normal post-entry data from the nephelometer that we have heard to much about, the temperatures and pressures, the neutral mass spectrometer and other dull stuff that we think is required to help support the mission and define the quality of the data. This is all multiplexed together and sent out as real-time data.

While we are starting to send this data out, we will fill up a small store, the acquisition store on the figure. We fill up this small store and then immediately dump it. We call this an Acquisition Store because it serves as a time buffer for the spacecraft receiver and bit synchronizer to sweep to the appropriate center frequency, taking Doppler and Doppler rate and so forth into account; lock and acquire. Once this has happened, we can begin dumping the big store, (Pre-entry Store). We can dump this out interleaved with the real data out to the transmitter. Once this is dumped, then we can start utilizing the Acquisition Store, which now simply becomes a Redundancy Store.

This is exactly the same technique we used in the Saturn-Uranus design with the exception that we had a much longer time in which to perform this function and we could actually dump these stores redundantly. In the case of Jupiter we don't quite have this time and we can't do it redundantly; but if we dump them once, we can minimize that time. So, if we minimize this time, from the time that we start transmitting live data until we have got all of the deceleration data out, we can do it in .44 hours. (Lower left curve on the figure.) That is too bad because we only had four tenths of an hour to work with so we have lost .04 hours.

Another option, would be to leave the initial portion of the sequence the same up until the point that we begin dumping, but rather than dumping in a one-to-one sequence, 22 bits to 22 bits, if we could dump in a two-to-one sequence, that is 28 bits to 14 bits, we could dump the store quicker. We can actually dump, then in about seventeen and a half minutes compared to about twenty-two and a third minutes. This means, then, that we can acquire all of the data including all of the pre-entry data, and have a .36 hour mission. The trajectory phasing gives us a .4 hour mission and we can do the mission.

What did we pay for this? Obviously, if I have reduced the real time data rate from 22 bits to 14 bits per second, I had to pay something. We have arbitrarily, for purposes of this presentation, decided to pay it in the neutral mass spectrometer rate. In the Saturn-Uranus design, as Howard Myers told you this morning, we had a 16-bit per second data rate. That was nine sweeps out of the NMS: one sweep which was transmitted as raw data; the other eight sweeps were averaged and then sent out as a single stream. So we could delete one or the other of those two streams, for example, retaining the same sampling times, and cut the rate in half.

In conclusion, the question was a relatively simple one: can we use the Saturn-Uranus telemetry design for Jupiter entry? The answer is: not exactly. We have to make some qualifications in the data handling. The qualification is a single dump rather than a dual dump, and a reduction in the neutral mass spectrometer rate, and providing that we can make a second burn, a delta V correction.

SESSION IV - PROBE DESIGN AND SYSTEM INTEGRATION

T. N. Canning, Chairman
NASA Ames Research Center

MR. CANNING: Gentlemen, I am not going to make any introductory remarks and just simply start with the first speaker, Dick Ellis, of DYNATREND, who will summarize the content of the draft report which was provided to you: The Ten Bar Probe Technical Summary.