

## INTELSAT-V: NICKEL-HYDROGEN BATTERY

G. Van Ommering  
Ford

I would like to talk a little bit about the nickel-hydrogen program we are doing for Intelsat V. I guess I said a few words about that on Tuesday, but I will just go through this thing as planned.

First, I will give you a little bit of background on the program.

We will have the first slide, and then immediately after that, the second slide.

(Figure 6-22)

The program we are doing for Intelsat is divided into three basic parts: Phase I is the design study that was completed in about February 1979, and that primarily involved doing some basic studies as to what was involved in incorporating the nickel-hydrogen battery into a spacecraft which was originally designed to incorporate a nickel-cadmium battery.

Some additions and minor changes to the spacecraft were required and were resolved in that period. Also, the basic design of the battery was defined at that time.

Right now we are going through a development phase, that is our Phase II. We are making pretty good progress in that.

Under that phase we are procuring battery cells. We started out with two vendors, and eventually selected Eagle Picher as our battery cell vendor. We have been testing these battery cells, and we built an engineering model battery that we just completed about a week and a half ago which is currently in test.

The remainder of Phase II will involve the fabrication of five more batteries, two for qualification purposes and three for integration purposes. In addition, the engineering model battery will be refurbished to serve as integration battery.

We also are doing battery life testing. We have started the life test on the engineering model cells. That is currently going on. We will also be doing life test on the qualification batteries, and COMSAT laboratories will be doing life testing on one of the control batteries.

On the basis of the results of this Phase II, and in particular the cycling results, we expect that Intelsat will award Phase III, probably in March 1980, which is currently an Intelsat option and which will involve the fabrication of batteries for the Intelsat F5 through F7 spacecraft. There has been a recent addition of the possibility of pressure that will circumvent spacecraft for which nickel hydrogen will also be used. That's the basic structure of the program.

(Figure 6-23)

In this next slide, I would like to briefly revisit some of the reasons why we think, at this point, nickel hydrogen is a good technology to develop into actual spacecraft application and use.

I will just highlight a few of these items. The negative electrode, obviously, is a bit less of a problem than the cadmium electrode NiCads. We had no cadmium migration; no recrystallization problems. The electrode is purely catalytic and because of that does not significantly change over thousands of cycles. It is something we simply do not have to worry about very much.

The separator does not degrade with time as nylon does. Asbestos is much more stable and also is much more wettable in the long run than nylon is, particularly in competition with nickel electrode.

We have a bit more electrolyte in these cells per ampere-hour than we have in typical NiCad cells which also have several benefits as listed on the slide.

Another significant benefit is state-of-charge indication that we get by simple pressure measurement, which will permit us to minimize overcharge. Conceivably this might eventually get developed into automatic charge maintenance of nickel-hydrogen batteries.

Lastly, we are introducing the electrochemically impregnated nickel electrode into actual spacecraft use through this nickel-hydrogen battery. There is a lot of experience on that; several papers have been presented in the past at this workshop.

We expect, in addition to all these advantages, nickel hydrogen will add a 10-year life on the synchronous spacecraft, and possibly longer. And that is our main reason for this strong interest in applying it at this point.

The weight advantage, which was a bit over sold early in the nickel-hydrogen development, isn't really that significant. We are saving weight on the design of our battery, as I will show you, but it is nothing to write home about. It is not spectacular. We can use that weight, it is great, but it is not our main reason for doing this.

(Figure 6-24)

On our next slide I would just like to complete this nickel hydrogen versus nickel cadmium background picture a bit. I would like to show some data taken at Ford on the nickel-hydrogen battery that we have on loan from Intelsat.

This is a prototype NTS-2 battery. We are cycling that right alongside Intelsat-V nickel-cadmium battery. They have essentially the same actual capacity, 38-ampere hours approximately, and we are cycling them under the exact same regime. And typically this is the kind of performance that we get through an eclipse season showing the end-of-discharge voltage there as a function of eclipse data.

You can see we are getting about 20 millivolts, maybe 30 millivolts, better performance with nickel hydrogen, which was expected simply on the basis of the equilibrium voltage at the couple. We are getting that consistently. Essentially, the nickel-hydrogen battery, I guess, is about three years old; stored in all sorts of ways, generally at room temperature. It has not really been treated particularly friendly. It is holding up quite well.

Now we will get into the real Intelsat-V battery in the next slides.

(Figure 6-25)

I have shown the general characteristics that are more appropriate with the ground rules we are working under for this nickel-hydrogen battery.

The major ground rules are that we should have complete spacecraft interchangeability between nickel hydrogen and nickel cadmium. The way the implementation of nickel hydrogen will be handled is that the decision between building or using the nickel cadmium or the nickel hydrogen in say, the F5 spacecraft, will be made rather late – very shortly before the launch of the spacecraft – and we are actually building the NiCad batteries right alongside the nickel-hydrogen batteries for the spacecraft just to give us maximum insurance because it is a program that involves a bit of technical risk.

The spacecraft impact has to be minimal. All the things that plug into the battery have to be identical. We have achieved that without any great difficulty.

The second item there shows that we have two 27-cell assemblies as opposed to the 28-cell assemblies that we had for nickel cadmium. The reason for that is that we have a slightly higher charge rate also for nickel hydrogen. We simply eliminated one cell to make sure the charging system could handle the battery.

That had the advantage of making available an additional telemetry channel which we are using to transmit a strain-gauge signal from one of the cells so that we will have some information as to what the pressure, and consequently the state of charge is at the battery.

We are using Intelsat cell design which has been proven on NTS-2 and was very successful, and is still very successful there.

There are a few very, very minor changes which were considered to be improvements, but they do not affect the basic design of the cell.

Intelsat gave us a maximum DOD guideline of 70 percent based on a lot of cycling data that existed. We are actually using more in the range of 58 to 65 percent, so we have a little margin there.

We control the temperature so that it does not go below 0°C, heaters automatically switch on at 1°C, and switch off slightly higher than that.

We have the same wide range of charge currents that John Armantrout discussed yesterday for the nickel-cadmium battery, and we have reconditioning capability since it is built into the spacecraft. We may or may not need that.

(Figure 6-26)

On this slide there are a few more characteristics. I am not sure I am going to develop them.

The spacecraft mode is slightly higher than is shown here, 930 watts, now, 465 per battery constant power. The current load uses about 61-percent DOD in the worst-case voltage situation. Normal beginning-of-life expectation is about 58 percent. Actually through all these various conditions, it runs about 10 percent higher than nickel-cadmium battery, generally.

Let's see, what else is worth highlighting here. The heat dissipation is somewhat different from the nickel-cadmium battery. We have slightly higher dissipation on discharge, but then during charge we have more endothermic period than the NiCad has. And during most of the charge the nickel hydrogen puts out a bit less heat than the NiCad.

The total heat dissipation over a full cycle is expected to be equal to or possibly slightly less than the nickel cadmium shows. With the increased heat capacity, which we have due to the added electrolyte, the actual range of temperatures that are predicted for the nickel-hydrogen battery is about the same as for the NiCad. We are looking at approximately predicted actual values of 1°C to 23°C.

(Figure 6-27)

This slide summarizes the telemetry we have on the battery. Twenty-seven battery cell voltages are available. Battery pressure is on the 28th voltage channel. We have thermistors on the battery to permit measurement of the temperature and compensation of the strain gauge signal, because we need to compensate for the effect of temperature on the pressure of the battery.

(Figure 6-28)

This slide shows the basic layout we are dealing with on the spacecraft panel. The array of little circles is the outline of the nickel-hydrogen battery that really is a nice, tight fit.

The dotted line superimposed on the nickel-hydrogen battery indicates the location of the nickel-cadmium battery.

As it looks here, the nickel-hydrogen battery isn't really that much larger than the nickel-cadmium battery. Probably a bit misleading because some of the lines on the outside of the nickel-cadmium profile are really a little thermal shield which we really don't consider part of the battery.

But you can see that we really didn't have to move much equipment to put that battery in. There is one little box in the south panel that was moved over a little bit, and that was really all that was necessary.

The battery was also higher than the nickel-cadmium battery. There was sufficient clearance to handle that, so mechanically there was really no difficulty in getting that battery on the spacecraft.

(Figure 6-29)

If this conference would have been a week later, I would have had a photograph here, but this is basically what that nickel-hydrogen battery looks like.

I will just highlight a few of the features. Electrically, we are trying to keep the thing fairly clean by running all the sense wires through the bottom of the battery. It is a fairly clean package when it is together. There are a lot of wires there, but it goes together fairly easily.

We have, of course, redundant power wire, also a diode bypass potential, and that is mounted right inside the little aluminum sleeves that contain each of the cells. That makes for a reasonably compact structure. The top surface of the cells are insulated with polyurethane to prevent any accidental grounding.

There was a little episode with NTS-2 that we would rather forget.

Mechanically, the cells are held in aluminum sleeves which fit fairly tightly around them. There is a thin layer, approximately 15 mils of silicon rubber between and that serves to both electrically isolate the cell from the mounting structure, and to take up some of the expansion of the pressure vessel that occurs on charging.

The sleeves are all mounted together in various ways. There are top attachments between these mounting sleeves; there are bottom attachments to make it a fairly rigid package. Every sleeve has a foot that overlaps the mounting foot of the other sleeve, so it minimizes the total mounting points of this battery. Nonetheless, we still have 34 inserts that we have to add into the spacecraft panel to handle this thing.

The baseplate is attached to all these sleeves. The baseplate is riveted to a ring at the bottom of those sleeves, and that provides for adequate thermal contact. In addition, that baseplate is optimized to provide the right kind of thermal gradient along the battery.

We had a bit of difficulty with the radiator which we are using for the battery, since it is physically sized for the nickel-cadmium battery and has to remain compatible with that. So the baseplate had sort of a graduated conductivity over its area to handle that and to conduct heat from cells that are on the perimeter of the battery toward the center of the battery. This is simply done by things like lightening holes, etc.

We have a basic conduction path through the sleeve, through the baseplate, through the spacecraft panel to the OSR radiator, and up through space. We have heaters, one of which is shown on the batteries. It is a thin filament heater that is glued to the sleeve.

On top of the battery we have a thermal cover to isolate it from the rest of the spacecraft, and a thermal skirt around the outside for the same purpose.

There is a little box behind one of the front connectors there (strain gauge electronics). It is an integral part of the battery. It is a very lightweight electronics package, about 100 grams, and provides power for the strain-gauge bridge on a lot of the cells. It takes it directly off the battery terminals, conditions it, supplies it to the strain-gauge bridge, takes the signal from the strain-gauge bridge, and converts that into a voltage that is somewhat similar to a cell voltage and then feeds it into that 28th channel.

So, as far as the spacecraft telemetry system is concerned, it thinks it is just looking at battery cell voltage, and that signal has to be further conditioned on the ground to convert it to the pressure for a capacity.

(Figure 6-30)

This slide summarizes a few of the physical properties, length, width, height, and weight. That's a lot there. Weight is actually a slightly bit higher now that we have our engineered models. One reason is the condition of that thermal cover that I mentioned. We are about 30.1 kilograms right now. The nickel-cadmium battery weighs about 32.5 kilograms, as Armantrout showed yesterday, so we are saving about five kilograms per spacecraft. So you can see it is not spectacular, but it is significant.

In the next slide, I have summarized some of the weight data.

(Figure 6-31)

It still shows 30.01 kilograms total. The cell breakdown is typical of the Intelsat design. I won't go into that too much. The total weight is about 890 grams. We are doing slightly better there in terms of energy per unit weight than we did for the NTS-2 design.

The battery assembly adds approximately six kilograms to that cell weight, and that's considerably more than you will typically find on your nickel-cadmium battery.

These little aluminum sleeves, while they are lightweight, there are 27 of them and that will raise something. So we are really paying a bit of a penalty here for the packaging inefficiency of the nickel-hydrogen cell. In spite of that though, we are still saving some weight.

(Figure 6-32)

This slide shows the Intelsat cell design that has been talked about here several times. What I need to highlight here is its simple design. It has been built successfully by Eagle Picher. It goes together without any great difficulties. It is pretty much foolproof. We haven't really had any major problems with getting the thing assembled so far.

It is a new thing to do this assembly on a flight program. We are doing a lot more control on all the components and on all the processes than we did on NTS-2. In most areas we have had some iterations and some difficulties. It has been very successful.

The engineering model cells that we are testing right now have shown performance generally better than what we were used to with NTS-2.

(Figure 6-33)

This slide summarizes some data on that. When we get these cells at Ford, we do some validation testing involving capacity measurements at 0°C, 10°C, and 20°C. Charging at 0°C is done at 1.5 amperes. Discharges are at 15 amperes. At 10 to 20 degrees, the charging is done at three amperes and discharge at 15 amperes.

The results you see here are interesting. The capacity is better at 0°C than at 10, there it's better than 20. On NTS-2 the capacity at zero and 10 were about identical. I guess it might have been slightly less at zero.

This performance is just excellent. The distribution is fairly tight. The charge voltages are, as we expected, a bit higher than what we see on the nickel cadmium. With the 27-cell package, we stay well within the system capability.

Another very interesting point is the cell discharge. We do a cell discharge test where we charge the cells up with three amperes for 16 hours, let it sit on open circuit for 72 hours, and do a capacity measurement. Typically in the past in nickel hydrogen you would expect to see about 70-percent capacity at that point.

We have consistently been measuring about 80 percent on these Eagle Picher engineering model cells of that original capacity. I am not totally sure why, we were very pleased with it, they were very tightly built, and I think things like cleanliness or just keeping plates clean during assembly, avoiding any possibility for getting minute metallic particles in there, whatever. That is all considerably better now than it has ever been. I think that is something that contributes to this good performance.

We will continue to work on the five additional batteries. Next year there ought to be a presentation on the results of that effort, and I hope some test data on it for flight batteries that will have been built by that time.

## DISCUSSION

THIERFELDER: You only have one strain gauge on 27 cells. Does your data show that your pressures are that uniform and a sample of one is enough?

VAN OMMERING: The pressures are not as uniform as you would like them to be.

There are some minor variations between cells, primarily due to capacity variations. When you make a stack you will find, as I show, a standard deviation of maybe an ampere-hour between cells. That capacity variation will translate into some pressure variations.

So all we are really doing here is getting an idea where the battery is at and what the state of charge is at of one cell. Now, we know what cell that is and we have a pretty good idea of what the state of charge is over the entire battery.

But it continues to be an estimate. It is not an exact indication for the whole battery.

THIERFELDER: If you lose that telemetry point, you don't feel that is critical?

VAN OMMERING: We are using that in this program purely for information. We are not using it for charge control. But we might. We have that extra channel available, so we put it on, but we don't need it for our control purposes.

The baseline approach for the nickel-hydrogen battery charge control is the same that we are using for nickel cadmium. While the baseline is the same, we don't know for sure what that baseline is.

ROGERS: On the strain gauge, our experience has been that we get a slow continual upward drift in absolute pressure as a function of time and cycling.

I am wondering whether you have noticed that, and whether your state of charge indication – or if you can use it for control – can take that into account?

VAN OMMERING: At COMSAT Labs, there has been quite a bit of testing done on these strain gauges, and I think occasionally we did see some.

Joe Stockwell would probably be the one to comment on that, since I suspect he's got that at his fingertips. But right now, our current cells, we have strain gauges installed, we are looking at them on these engineered models but, we have not been testing them long enough to draw any conclusions from this particular pressure cell.

ROGERS: It is not the strain gauge that drifts, it is the cell?

VAN OMMERING: Yes. I know what you mean.



STOCKWELL: Howard, yes, indeed. I think I showed some of that data from the NTS-2 here last year, where we do see an upward increase in pressure in the cell with time. It does show up with the strain gauge.

MAURER: You are saying that you are saving five kilograms going with nickel hydrogen, compared with nickel cadmium.

I assume that is based on the engineering model weights? And if so, are you assuming the same watt-hours delivered in both cases at the design maximum?

VAN OMMERING: Yes, that's correct. We have the same watt-hours delivered.

The weights are based on the engineering model.

The power that needs to be delivered is controlled by the spacecraft. The reason we are doing a bit better here is that we are going to deeper DOD, and that is where most of the gain comes from, deeper than we go on the NiCad. The NiCad limit is 55, and nickel hydrogen limit is 70. We have a little bit of margin built into both of them. Nickel hydrogen always runs about 10 percent deeper.

I would like to add something to that. The design we are dealing with now, diameterwise the cell is 3.5 inches, which is a pretty traditional thing. And that's really a design that's optimized for 50- to 70-ampere hour size. The 35-ampere-hour, 30-ampere hour battery cells would be much better off weightwise if you went to something like a 2.5- or 3-inch diameter. The weight savings involved in that are significant. But at this point we wanted to get this technology on the spacecraft, we don't want to fool around with trying to make new pressure vessels. That is a whole new ball game that would take several days to develop.

So we stuck with what was available, and we are paying a little bit of a penalty, but we would like to prove the technology in a real environment. That is what we are interested in now. We will handle weight improvements in the next generation.

DUNLOP: One thing that is interesting about the data that Van Ommering showed is capacity as a function of temperature. You will notice for the nickel-hydrogen batteries, you are actually drawing from about 32 or 33 ampere-hours, I think, at 22°C; after about 35 ampere-hours at 0°C, and about 34 ampere-hours at 10°C.

If you look at the nickel-cadmium battery, you get the opposite effect. You have got about 35, 36, 37 ampere-hours at 20°C, and you drop down to about 32 ampere-hours at 0°C.

So, when you talk about DOD, one of the things you run into is DOD at what temperature?

It turns out this particular spacecraft is operating at somewhere between zero and 10 degrees when they finally figure out where it is going to be during discharge. It might just be that it is not exactly easy to prepare DOD. The way the capacity as a function of temperature is turning out, it may be that there isn't much difference.

MUELLER: On your last vugraph, you had a column that was labeled range. Is that the spread in voltage among the cells when you have applied an average voltage shown in the first column? Is that what that entry means?

VAN OMMERING: I didn't really elaborate on that, what that whole charge of all this data means.

For one thing, it is a peak charge voltage of battery cells. The charge will roll over in a voltage cell. It is the peak voltage we are concerned with. The system has to be able to handle it, so that is one thing it shows, peak voltage.

The range shows the total variation in these charge voltages within a lot of cells, so I show 15 millivolts, for example, at 0°C. That means the difference in the charge voltage at that peak from cell to cell was 15 millivolts.

Now, when we take those cells and select out of that a set of cells to build a battery with, we have got material for the matching of that voltage to about six millivolts. So we take 40 cells, take 27 out of them; in that group of 27 the maximum is about 6.

MUELLER: 50 millivolts is for a lot, rather than for a battery complement of 27 cells.

VAN OMMERING: That's right.

FORD: You are carrying nickel cads along in parallel with nickel hydrogen.

The question I have is what criteria, or what had to come about before the final decision is made as to which way you go? And how long before the launch data of that satellite does that decision have to be made?

VAN OMMERING: No question about it, but I can't speak for Intelsat and COMSAT. Of course, we may run into surprises with nickel hydrogen, but what we have seen so far has been good. It will be a decision, I imagine, the recommendation by Ford to Intelsat, and it will have to be seriously considered by Intelsat.

If they go along with it, we will fly nickel hydrogen. But we plan to make that decision shortly before the first launch, and we are going to look very hard at the life-test data in particular, compare that with the data that we have on the Intelsat-V NiCad batteries. And we are going to do a very thorough analysis because we do always have to look at minimizing risk.

There certainly is a risk involved. We don't have seven years of testing on these batteries.

FORD: A followup question is, how many equivalent years? If you are doing accelerated tests, how many equivalent cycles do you expect to have when you make that decision?

VAN OMMERING: There are three life tests we are doing: One is done on engineered model cells and that is designed to give us a total capacity turnover on these battery cells. Equivalent to 10 years initially, it is going to be about 12 or 13 years at the provided time that we might launch that F5 spacecraft.

We are doing life test and accelerated life test or semiaccelerated life test I should call it, on one of the 12 batteries. That one is going to go on eclipse cycling, but we will accelerate it, if that is the right word, the solstice seasons. In other words, we are going to shorten them to something like 14 days.

That is probably a fair test because we have not really found a purely time-dependent or strong time-dependent degradation for the nickel hydrogen yet. By the time we launch the first spacecraft, I suspect we will have something like probably five or six full eclipse seasons completed on that.

In addition, we would like to have a full year of real-time testing on the other qual battery at COMSAT:

LEAR: Gert, that one slide you just showed up there when you compared the nickel hydrogen to the nickel-cadmium system, that was for the first season. How many seasons have you completed so far, and have you seen those curves drawing in?

VAN OMMERING: That is a real-time test, so that data isn't coming out very fast. I think we are about to start the second season of eclipse cycle.

LEAR: How does the data compare with the first season?

VAN OMMERING: Maybe John can answer that.

ARMANTROUT: That was just completed in the last week here. We haven't totally reduced it, John, but there is no trend that indicates anything is any different, just looking at it on a daily basis.

LEAR: One final question. What are you using for charge determination control?

VAN OMMERING: On the tests that we are doing, we are simply doing it on a time basis. On the spacecraft, I think there is still a final decision to be made on exactly what will be done in terms of charge control.

Ford's baseline is to use the bisequence charging scheme; five minutes on, five minutes off, and base the charge cutoff period on time. This isn't really based on what we would like to do for nickel cadmium. As I said with nickel hydrogen, we really don't have more information to try to decide on, as to when to terminate charge.

If that strain gauge business works out real well, I think we can minimize the charge and use that consistently.

BETZ: Gert, on the life test are you charging with the bisequence charge?

VAN OMMERING: On our accelerated life test we do not. That's the only one we have done so far. On that other life test, yes, we are using that, the one I showed the voltage data on.

BETZ: Are you reconditioning your nickel-hydrogen batteries between seasons on your life test?

VAN OMMERING: Yes. I think we take that right along with the nickel-cadmium battery. We are treating them exactly the same. I don't think it is benefiting us a great deal on that NTS-2 prototype, but we are doing it.

This is the first time anybody is going to have decent comparative data between NiCad, nickel hydrogen, same capacity, same operation.

BETZ: What is the thickness of your aluminum sleeves on the Ford battery?

VAN OMMERING: It is optimized to give us proper thermal control and sufficient mechanical strength. We are running typically 40 mils on that.

BETZ: The NTS-2 nickel-hydrogen batteries in orbit right now have a total voltage range of about 21 millivolts over 14 cells after 2 1/2 years in two of the assemblies on opposite sides of the satellite, so there are some temperature differences.

I still think our voltage range hasn't changed but about 7 millivolts since launch.

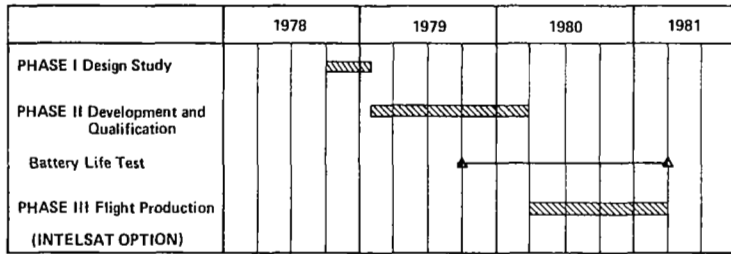
MAURER: This question is to any of the nickel-hydrogen types in the audience. Is there any data on nickel-hydrogen cells at elevated temperatures? In other words, life data?

VAN OMMERING: No.

Maybe Hughes has some, but as far as I know COMSAT, Intelsat really haven't done any long-term life tests above 20°C. I think there have been some life tests run on boilerplate cells just sitting in a room. The summers in the Washington are can be hot, the energy problems, the air conditioning isn't doing all that well. So I think 25 degrees for half of the year is probably the worst we have ever seen.

LEAR: I don't speak for Hughes, but they do have tests for high temperatures. But, Howard left to get an airplane.

## NICKEL-HYDROGEN BATTERY SCHEDULE



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Figure 6-22

## NICKEL-HYDROGEN DESIGN ADVANTAGES

### NEGATIVE ELECTRODE NOT SOLUBLE IN ELECTROLYTE

- IMPROVED LIFETIME STABILITY
- NO MIGRATION
- NO RECRYSTALLIZATION
- RELATIVELY INSENSITIVE TO DOD (CATALYTIC SURFACE) - HIGHER USABLE ENERGY DENSITY

### SEPARATOR (ASBESTOS)

- CHEMICALLY STABLE
- INHERENTLY WETTABLE

### ELECTROLYTE SURPLUS

- NO DANGER OF OVERPRESSURE
- NO DANGER OF DRYOUT AT CHARGE RATES EXPERIENCED ON SYNCHRONOUS ORBIT
- HIGHER ELECTROLYTE INVENTORY-MORE HYDROPHYLIC SEPARATOR

### START-OF-CHARGE INDICATION

- PRESSURE DIRECTLY PROPORTIONAL TO SOC CAN BE MEASURED BY STRAIN GAGE

### POSITIVE ELECTRODE

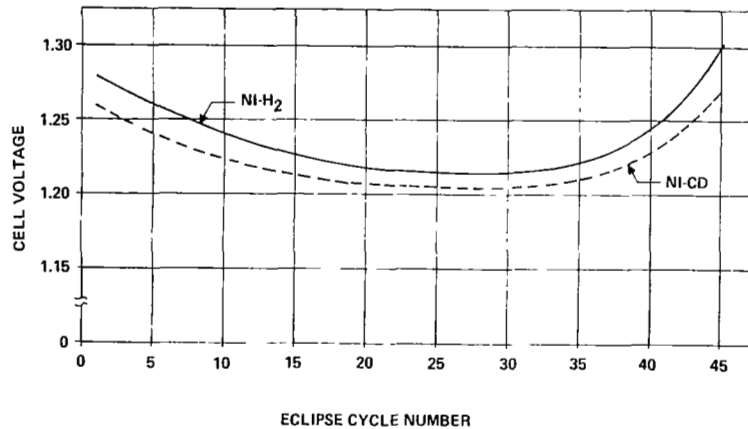
- ELECTROCHEMICALLY IMPREGNATED-INCREASED UTILIZATION REDUCES ELECTRODE EXPANSION

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Figure 6-23

## ECLIPSE DISCHARGE VOLTAGE

BATTERY ECLIPSE SEASON ONE



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Figure 6-24

## GENERAL CHARACTERISTICS OF NICKEL-HYDROGEN

- SPACECRAFT INTERCHANGEABILITY OF NICKEL-HYDROGEN AND NICKEL-CADMIUM BATTERIES
- TWO 30 Ah, 27 CELL ASSEMBLIES
- STRAIN GAGE CELL PRESSURE MONITORING (ON ONE CELL)
- INTELSAT CELL DESIGN
- 70 PERCENT DEPTH OF DISCHARGE MAXIMUM LIMIT
- AUTOMATIC LOW TEMPERATURE HEATER CONTROL
- MULTIPLE CHARGE RATE CONTROL SYSTEM
- BATTERY RECONDITIONING CAPABILITY

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Figure 6-25

## NICKEL-HYDROGEN BATTERY ASSEMBLY PERFORMANCE CHARACTERISTICS

CHARACTERISTIC	VALUE
TOTAL ELECTRICAL BUS LOAD	911.5 W
MAXIMUM DEPTH OF DISCHARGE (% OF ACTUAL CELL CAPACITY AT 1.18 V AVERAGE)	59.0% DURING ECLIPSE OPERATION
ACTUAL CELL CAPACITY	30.0 Ah
NOMINAL DISCHARGE CURRENT	14.3 A
MAXIMUM DISCHARGE TIME	1.2 HOURS
FULL CHARGE CURRENT (EOL, EQUINOX)	2.39 A
TRICKLE CHARGE CURRENT (EOL, SOLSTICE)	0.71 A
TOTAL CYCLES AND ECLIPSE (7 YEARS) (616 ECLIPSE CYCLES + 175 ETT FIRINGS)	791 CYCLES
ORBITAL LIFE	7 YEARS
BATTERY CONFIGURATION (2 BATTERIES PER SPACECRAFT)	27 CELL ASSEMBLIES
NOMINAL BATTERY HEAT OUTPUT DURING OVERCHARGE, AVERAGE	50 W (EQUIVALENT)
ALLOWABLE BATTERY TEMPERATURE RANGE DURING ORBITAL OPERATION (THERMISTOR MEASUREMENT)	+1.0° TO +25.0°C
MAXIMUM BATTERY CHARGE VOLTAGE	42.3 V
MINIMUM BATTERY DISCHARGE VOLTAGE (WITH ONE CELL FAILED)	29.7 V


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Figure 6-26

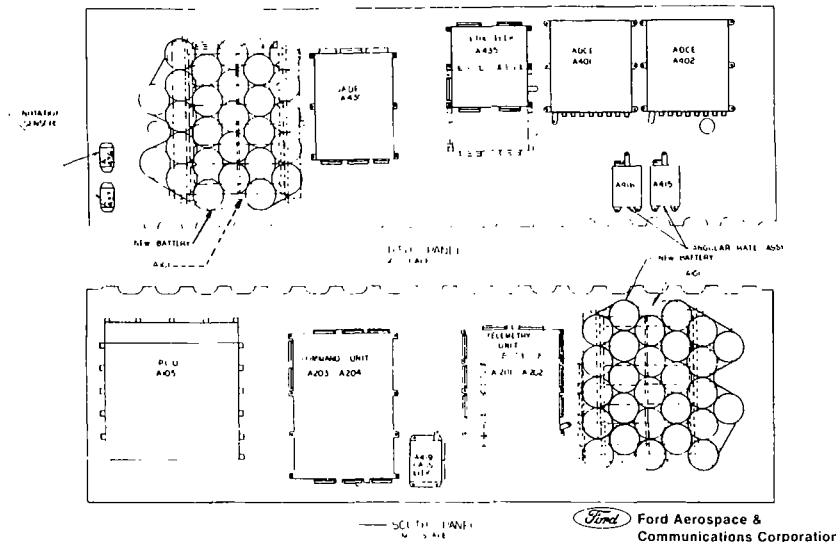
## BATTERY TELEMETRY

- 27 battery cell voltages
- Battery pressure - strain gage bridge (uses 28th voltage channel)
- Battery temperature - thermistor

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Figure 6-27

## NICKEL-HYDROGEN BATTERY EQUIPMENT PLATFORMS




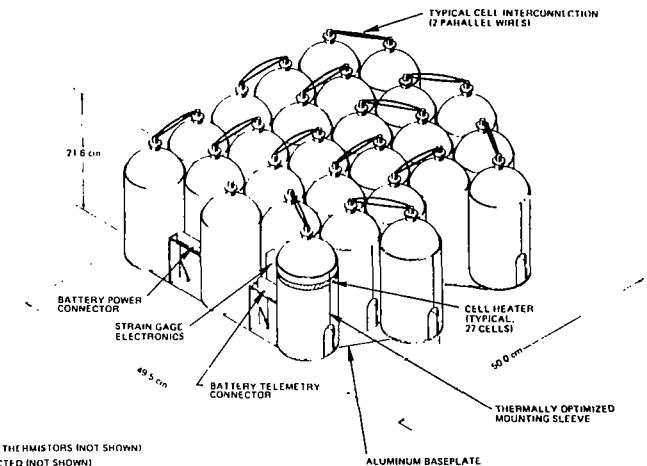
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Figure 6-28

## NICKEL-HYDROGEN BATTERY CONFIGURATION



\*4 TEMPERATURE SENSING THERMISTORS (NOT SHOWN)  
\*EACH CELL (FIGURE PROTECTED) (NOT SHOWN)  
\*PRESSURE SENSING STRAIN GAGES ON ONE CELL (NOT SHOWN)  
\*BATTERY WEIGHT - 30.0 kg (MAXIMUM)

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Figure 6-29

## NICKEL-HYDROGEN BATTERY PHYSICAL PROPERTIES

- Length 52.07 cm
- Width 51.82 cm
- Height 22.15 cm
- Weight 30.01 kg

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Figure 6-30

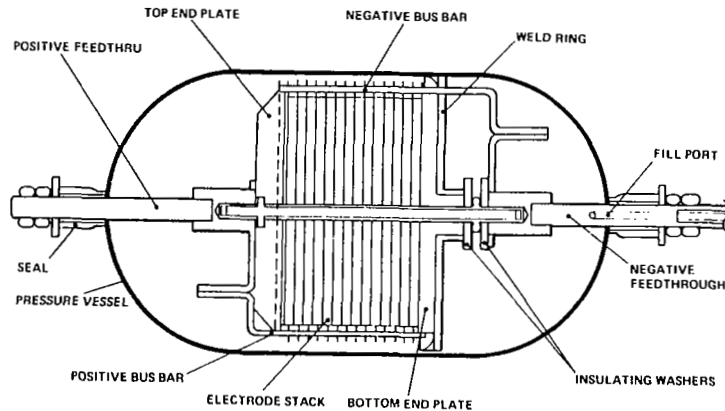
## NICKEL-HYDROGEN CELL AND BATTERY WEIGHTS (ESTIMATED)

	Quantity	Unit Weight (g)	Total Weight
<b>Battery Cell Assembly</b>			
Positive electrodes	24	12.3	295g
Negative electrodes	24	2.0	48
Separator	24	1.1	26.5
Seams	13	0.5	6.5
Electrolyte	A-R		50
Insulators	2	17	34
Pressure vessel	1	243	243
Mounting hardware	A-R		14.7
Total cell weight			590 g
<b>Battery Assembly</b>			
Battery cell assembly	27	950	24.03 kg
Fast mounting shells	27	125	3.38
Baseplate	1		0.65
Endcap assemblies	27		96
Mounting hardware	A-R		10
Connectors, heaters, thermistors, and strain gauges	A-R		0.23
Microtransmitters (status page output)	A-R		0.66
Battery assembly weight			30.01 kg

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Figure 6-31

## INTELSAT NICKEL-HYDROGEN CELL DESIGN



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Figure 6-32

## ENGINEERING MODEL CELL PERFORMANCE

TEST	TEMPERATURE (°C)	CAPACITY (Ah)		CHARGE VOLTAGE (V)	
		AVERAGE	STD DEV	AVERAGE	RANGE
CAPACITY	0	35.34	1.13	1.540	0.015
CAPACITY	10	34.80	1.04	1.524	0.018
CAPACITY	20	32.06	0.89	1.506	0.018
72-HOUR SELF DISCHARGE	10	28.52	0.52		

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Figure 6-33