N92-11111

QUICK TRIPS TO MARS

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and Electronics

We started out with a point design. We used the chemical propulsion weight statement for option five that Boeing Huntsville had been using, which totaled out to 731 tons. We took a shot at applying nuclear thermal propulsion to this, but not to exceed their weight estimates (see Figure 1).

We put together a vehicle essentially of two components that would have to be launched by two very heavy lift launch vehicles.

In what I call the second stage, which provides the Delta V to Mars, there is one group of tanks and then the upper part which has the habitat module and some storable propellant for MEV, which is in the second upper part of this vehicle (see Figure 2).

Once the vehicle is assembled in low Earth orbit, you have three NERVA boosters with a fourth in the center that acts as a dual mode system. The fourth generates electrical power while in route, but it also helped lift the vehicle out of lower Earth orbit.

I thought it was a good idea at the time to have three NERVAs here basically because of shielding. At that point in time I thought it would reduce the shielding. But based upon advice I have had from some of the shielding experts, most of the gamma is gained or emitted during the time you are firing, and so getting rid of those boosters before you head for Mars doesn't help your shielding problem that much. I would suspect in the future when the vehicle is optimized you would probably end up with maybe one NERVA in the middle and it will also be in dual mode.

The major portion of gammas are produced when you are firing. They are still there after firing but not as serious as they were: that's what the shielding people told me. I thought it would be a good idea to get rid of those boosters before you left for Mars, but it is not that beneficial.

You first fire all four of these engines for about 40 minutes, each one using about 100 tons of hydrogen. If you recall in a previous table there were 435 tons of hydrogen on the chemical vehicle. So you fire of those 40 minutes and get a Delta V for about 70 kilometers per second.

As you are firing, the center dual mode system continues firing longer than the three outside ones and eventually fly away from them. I show a very strong hard back through the core, up to the Apollo module, where there is another tank. It is designed such that when you are flying away from it there is an incline ramp that pitches your three other boosters off so they separate, and you continue on towards Mars. You have this strong back and when it gets through firing, the final three tanks come off. These three tanks hold what only one of the first three provide.

To give you some idea of scale, the first three tanks on the cylindrical part are each 100 feet long. They are 26 feet in diameter. The other tanks are also 26 feet in diameter. So each one of these stages holds about 100 tons of hydrogen, for a total of about 400 tons.

After they separate, then you go into a dual mode operation. I have not applied any nuclear electric propulsion in this mission. This particular electric power generation capability has been sized to generate 2.5 megawatts of electricity.

Now, I have said it is housekeeping power. But something I would like to evaluate in the future is what could you do with that 2.5 megawatts in the way of course corrections through electrical propulsion. The RCS's and ACS's generally use some kind of mono or bi-propellant and I would like to look into that. I think there is enough power there to do something beneficial for those subsystems, at a lot higher specific impulse.

There has been some discussion of dual mode here at this workshop and so I would like to present our case for that later. You are on your way to Mars and you have this electric power available for housekeeping and propulsion.

On the forward end of this vehicle we have a Mars Ascent Vehicle (MAV) and a Mars transfer vehicle stage. Mars Exursion Vehicle (MEV) is on the front also. They both have heat shield designs on them. The data from the Boeing workshop on aerobraking has a number of different concepts for aerobraking, heat shield and so forth. My thought is that this could be either a deep dish type, conical, or spherical, but the main feature this one would have, that the ones in those workshops didn't have is a way of deploying extra fins to increase cross-sectional area to at least the diameter of the aero shield they talked about. The reason I do that is to keep this vehicle here a total diameter of 56 feet. That's the outside diameter of the vehicle. But when it deploys, you are up close to 100 feet, like a 30 meter aerobrake.

This diameter would require a very heavy lift launch vehicle. It doesn't exist. I don't know if you know what the ALS of Boeing looks like, but they have a module that is recoverable on a tank that's expendable. I would see a number of those stacked around a central core tank like an ET, only maybe even larger than an ET. They think they could do a 56 foot diameter. In other missions, missions they called hybrid, you use the liquid oxygen to burn the solid so you can control them. They haven't drawn up any concepts yet. I hope by the first part of September they will have and I can make a configuration out of that. But that's why the 56 foot is about as large as I thought it could go based on what they told me about those potential boosters that they could put together.

I would like to discuss the unfolding of the heat shield. These fins can be either deployed thermally in a passive mode or electrical thermally in an active mode. You can't see it on these small drawings (see Figure 2), but there is something I would call flecture backing on the fins that are made out of this memory metal. When it gets up to its transition temperature it goes from Martensite to Austenite and then returns to its original shape. When it is in the Martensite structure and you bend them down to start, so that when you go through the yield region you don't yield beyond an eight to ten percent, you bring them back down and clasp the whole thing with a circumferential strap. When you get near Mars you pop the strap off, using what we call Nitinol actuators that they have been building at Boeing for other programs (so we know they work).

I mentioned passive and active operation. In order to make this passively stable, I have put this skirt so the center of gravity is up as far to the nose as possible. When you do hit an atmosphere with it and it starts heating, say it starts heating on this side, when it reaches 350 degrees Fahrenheit, this material will transition and straighten out a fin. Then you start braking more. If it starts flipping over, the other side would heat more and it would start deploying and if you weren't happy with that you could thermally deploy these before you hit the atmosphere or deploy the whole thing or parts of it by heating that metal electrically. Since I have 2.5 megawatts available, I can do a lot of heating; this metal will transition as fast as you can heat it.

The MEV goes down to Mars on its own. The skirt of the heat shield becomes its landing gear and it stays behind when the subsequent stage goes away. When the subsequent stage goes away, the middle part of that heat shield comes back up with it. I was told that this adds an extra penalty or scar weight on the propulsion system. Now, at this point in time I haven't tried to change any of the weights of the MEV other than what was on that table for the chemical. I just used their weight statement. I realize there might be scars there that hurt the system.

The rest of this vehicle did propulsion brake with a storable propellant. If we had hydrogen I would be working with 900 seconds for Isp. The propellant we used through the reactor is a much heavier molecule and I am guessing its weight density is about 45 to 50 pounds a cubic foot.

Its Isp will only be about 480 seconds and that's the reason I said the quick trip thing is in quotes, that 480 Isp hurt us on the return.

We still burn that same propellant with the same reactor when we return to Earth. It goes back into the dual mode operation with the deployable radiator that recovers again. The Nitinol is also used again. It reminds me of those things you have at a New Year's Eve party that blow out and come back automatically.

I had originally thought it was a good idea to bring as much of this vehicle back as possible for refurbishment in the space station orbit. However, I have been told that it is not necessarily a good idea for NTR to bring a mass penalty back with us. That can be decided in the future.

When we separate again, part of the vehicle becomes the heat shield aerobrake. It might go into a long elliptical the first time around and brake, but I show it here once around. Then you drop off the Apollo type capsule and reenter back to Earth.

Figure 3 shows the typical orbit we would have: outbound and inbound with a potential Venus swing by.

Figure 4 has an error here. Line four in mass allocation should read "LH2 and storable propellant" and the number should be 557. There are about 438 tons of LH2 in the propellant budget.

The trip time outbound didn't come out as well as I thought. I had been doing some calculations and I thought it was going to come out closer to 154 days. It didn't when we ran it on the program. However, the person running the program didn't have time to do any optimization. He picked what he thought was the best trip start time. I noticed he picked February of 2016 which is the right year. But it looks like April would have been better.

The return trip is not good; it is 300 days. As I said before, the Isp killed me going back to 480 from the 900. However, I don't have to carry liquid hydrogen all the way through this trip. I think that might be a problem. I am not convinced you can store liquid hydrogen that long without a considerable loss.

I would like to speak a little bit about the dual mode. The center part of this vehicle, the central core reactor, would be a system that's laid out in Figure 5. This was actually laid out for a LTV that was stowed in the shuttle. When we got to sizing it, we found it didn't leave much room for payload.

You see in Figure 5 the hydrogen source. We have done some trades for other gases. Hydrogen, Helium, Xenon and so forth. However, during the closed mode you have a valve that has to close; that's one of the technology problems. There are concerns over the valve being in the line of a direct nuclear propulsion system. We think this configuration can be designed based on some technology that exists for the Pegasus engine used in the Harrier aircraft. They have some ducting that controls the thrust vector on their jet engine. They think they can do that same type of technology for a little bit higher temperature. We are in dual mode. We are up to 700 degrees coming out of reactor, so we think that valve can be developed without a lot of risk.

The generators sit around the end of the design unit (it is a Brayton and closed cycle incidentally). They are being driven by a turbine. This system was originally designed to have some burst power. Figure 6 shows a schematic of that system and it shows you the burst power capability.

Figure 7 shows the variables we keep track of when we are doing the evaluation on this.

In Figure 8 we see the results for a hydrogen working fluid. It wasn't laced with anything. With a radiator sink temperature 0 degrees Fahrenheit, you can see this was done by the mechanical engineer based on the units (BTU's per second). Efficiency came out 29 percent. Specific weight is 5.4 kilograms. Notice on Figure 8 the system weight, and radiator area. That's why I used the size for the one I used on the Mars mission.

The radiator is 58,000 square feet. Keep 50,000 in your mind. Based on what fluids you use, it is around that. It is a low temperature radiator.

We are only coming out of the reactor at 1,700 degrees Fahrenheit. It is more efficient with the regenerator. Like I mentioned before there is a valve; a technology area. This radiator is something we needed. I think I can develop the concept for that, but we need to do something to test that in conjunction with Battelle looking at fabric radiators. If I take the regenerator and I put the radiator in, the efficiency drops way down.

In Figure 9 we use a helium xenon working fluid. The turbine people like a heavier molecule, but when you optimize the whole system, the previous one with hydrogen was better. You see the efficiency dropped a little bit. I think this is a little lower, the mass is a little lower.

When we were working this, turbine people wanted to spin faster and so forth to get their system smaller. If you put multiple turbines in, you don't really have to worry about the size so much. The generator people don't like to spin so fast.

The hydrogen system provides slightly more efficiency on the overall system, but it's heavier. It depends which way you want to go with the system.

Figure 10 is one without the regenerator; the efficiency went way down and you also are heavier.

The next step here is (and we have talked about this at JPL) you have to find out what kind of power you need. Power conditioning here needs to be married into this. If you are going to use NEP you need those thrusters and so you need the propulsion people and the power conditioning people to get together. That's a big headache.

With the turbines and the generators that you see in Figure 5, you might be able to give the thrusters the kind of power they want directly without much power conditioning. This is a closed Brayton cycle. In the burst power it is open Brayton. If you want a lot of electrical power in the burst mode you are dumping the hydrogen into space.

When you are talking about storing hydrogen for a long time it is a scar weight or you have a refrigerator to carry along with you: refrigerator plus electric power requirement to run them, especially if you are going to use them there for a long time.

Boeing has looked at a couple of areas. That tank I showed on this system at the beginning is about a 12 thousand cubic foot tank. Boeing has designed a tank a long time ago about that size that they thought would lose about seven pounds of hydrogen a day in space. I figured out the numbers once and even with that tank, they put a lot of MLI on it and it is not a dewar. I have a feeling if you are going to carry hydrogen around until you leave Mars, you need a dewar. I don't know what the weight penalty is on that, so I can't say.

A VOICE: It you went with lighter weight tanks and compensated the light weight tanks and a little higher thermal input with electric powered coolers, you could meet the same requirements.

MR. HORNUNG: Do you know what they weigh?

A VOICE: That's just it, I don't think anybody ever looked at that.

MR. HORNUNG: That's the question. We were working on one where you pump hydrogen gas through a membrane and you can get very deep cooling; down below the typical minus 423 degrees Fahrenheit. That looked good but those things start stacking up and if you want any large quantity it becomes a horrendous weight. Somebody has got to look at that part if you want to carry a tank along.

A VOICE: You have a thing here that's talking about radiation sink temperatures of zero degrees F. Don't you think that's bit conservative?

MR. HORNUNG: Yeah, the guy that did this is conservative. He has been around Boeing some 35 years and he has been burned a few times, he was a little reluctant to do this analysis because he didn't know all about the application and so he was conservative and we only had 10-K. So I didn't have money to go back and have him do it again. At the time I forgot to tell him what I thought the space temperature might be and thus it is conservative system, overdesigned in a sense.

A VOICE: I noticed the vehicle swings into Venus orbit and I would think that that might be optimistic. You are saying you can orient the radiator?

MR. HORNUNG: I was hoping during most of the orbit the sun would be over in the right spot so the radiation would be looking at the radiator on edge but I don't know that to be true. This incidentally is a double sided radiator.

A VOICE: You are not thrusting, so unless there is a crew requirement or a heating requirement on the tanks, it doesn't matter.

MR. HORNUNG: Even if I put in NEP in a certain region of the mission for course correction, I can vary those as long as you put it out near the CG somewhere.

A VOICE: I guess the other thing is that the radiator is just a figurative depiction there?

MR. HORNUNG: Well, I took a little bit of artistic leeway.

A VOICE: I am worried about when it is deployed. I am not sure you have a two part shield on your reactor.

MR. HORNUNG: I am not worried about radiation on the fabric of the radiator.

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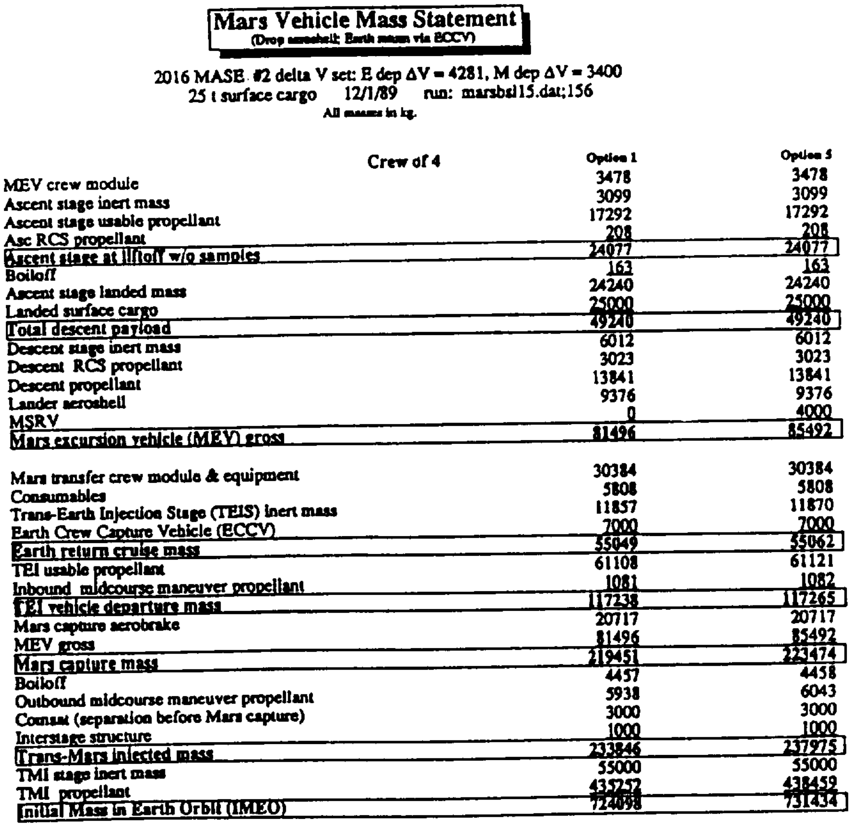

Mars Vehicle Mass Statement

(Drop aeroshell; Earth return via ECCV)

2016 MASE #2 delta V set: E dep ΔV = 4281, M dep ΔV = 3400
25 t surface cargo 12/1/89 run: marsbsl15.dat;156
All masses in kg.

Crew of 4	Option 1	Option 5
MEV crew module	3478	3478
Ascent stage inert mass	3099	3099
Ascent stage usable propellant	17292	17292
Asc RCS propellant	208	208
Ascent stage at liftoff w/o samples	24077	24077
Boiloff	163	163
Ascent stage landed mass	24240	24240
Landed surface cargo	25000	25000
Total descent payload	49240	49240
Descent stage inert mass	6012	6012
Descent RCS propellant	3023	3023
Descent propellant	13841	13841
Lander aeroshell	9376	9376
MSRV	0	4000
Mars excursion vehicle (MEV) gross	81496	85492
Mars transfer crew module & equipment	30384	30384
Consumables	5808	5808
Trans-Earth Injection Stage (TEIS) inert mass	11857	11870
Earth Crew Capture Vehicle (ECCV)	7000	7000
Earth return cruise mass	55049	55062
TEI usable propellant	61108	61121
Inbound midcourse maneuver propellant	1081	1082
TEI vehicle departure mass	117238	117265
Mars capture aerobrake	20717	20717
MEV gross	81496	85492
Mars capture mass	219451	223474
Boiloff	4457	4458
Outbound midcourse maneuver propellant	5938	6043
Comsat (separation before Mars capture)	3000	3000
Interstage structure	1000	1000
Trans-Mars injected mass	233846	237975
TMI stage inert mass	55000	55000
TMI propellant	435252	438459
Initial Mass in Earth Orbit (IMEO)	724098	731434

Figure 1

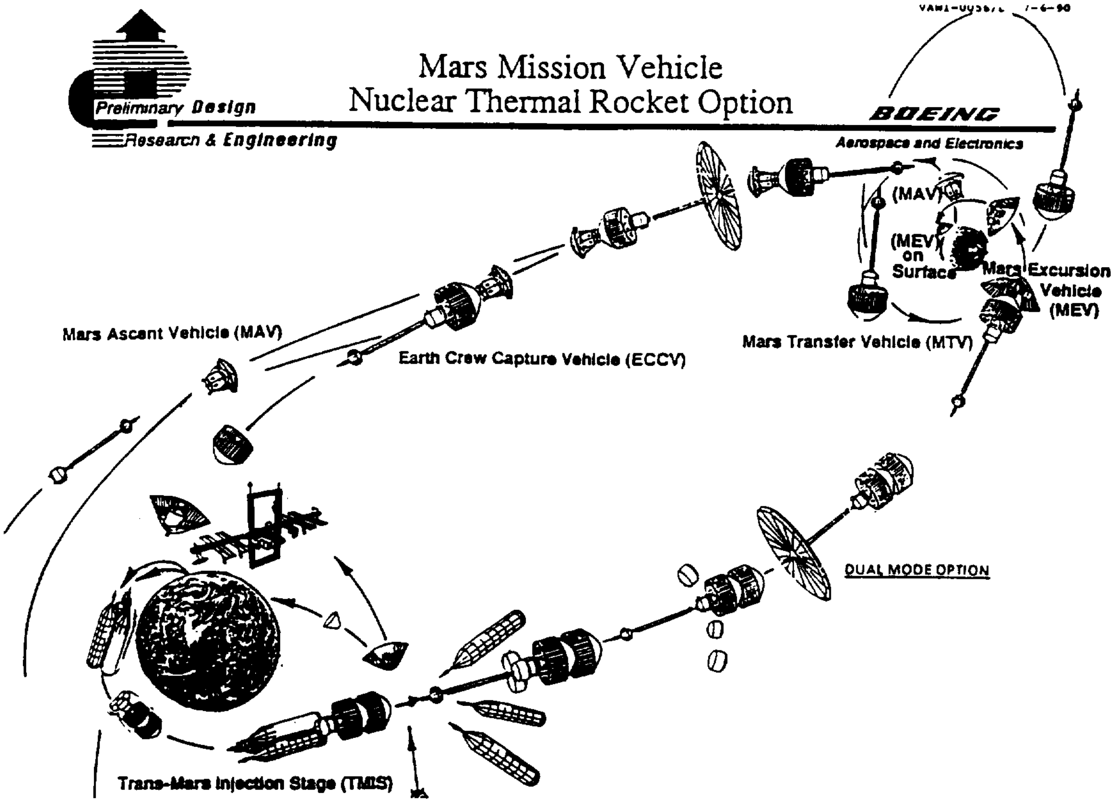

Figure 2

Aerospace
Systems
Technologies

NTR MARS MISSION

Boeing Aerospace & Electronics

Interplanetary Mission Legs

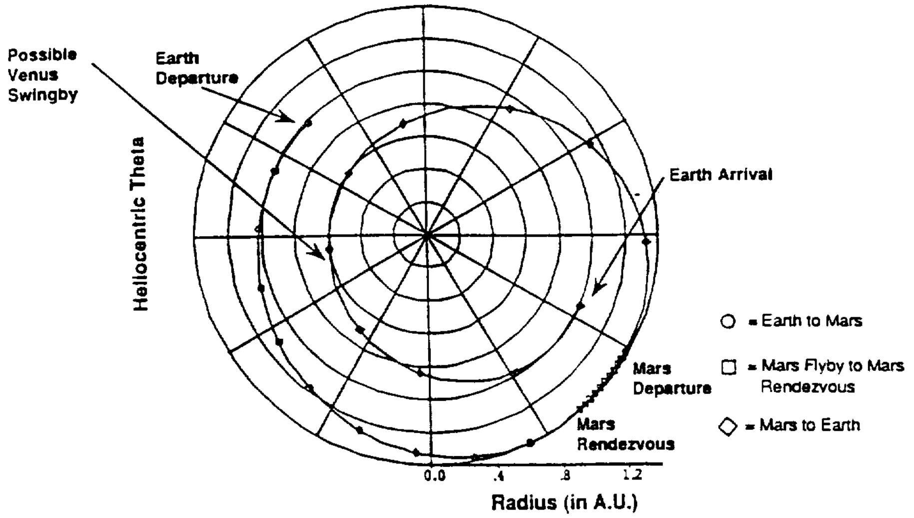

Figure 3

Aerospace
Systems
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NTR MARS MISSION SUMMARY

Boeing Aerospace & Electronics

Mission Parameters

Specific Impulse-NTR 900 sec

Lunar and Planetary flybys are being investigated for possible performance gains. At present, the vehicle must fly by the Moon in order to receive a gravity boost, enabling a quicker transfer time to Mars. A quicker Earth-Mars transfer reduces subsequent delta vee requirements and provides the opportunity for a Venus flyby.

Mass Allocation

IMLEO (SSF orbit)	732 MT	
Payload Outbound	84 MT	
Payload Inbound	40 MT	
LH2 Propellant	577 MT	** Preliminary data
Stage Mass	55 MT	
Vehicle Dry Weight (after staging)	16 MT	

Mission Summary

Outbound Trip Time (Including Earth escape)	200 days
Inbound Trip Time	300 days
Stay Time	30 days
Departure Date	February, 2016

WGV7/09/90
Disk 1

Figure 4

SPACE SYSTEMS
PRELIMINARY
DESIGN

High Performance Propulsion with Multimegawatt Power (Dual Mode Capability)

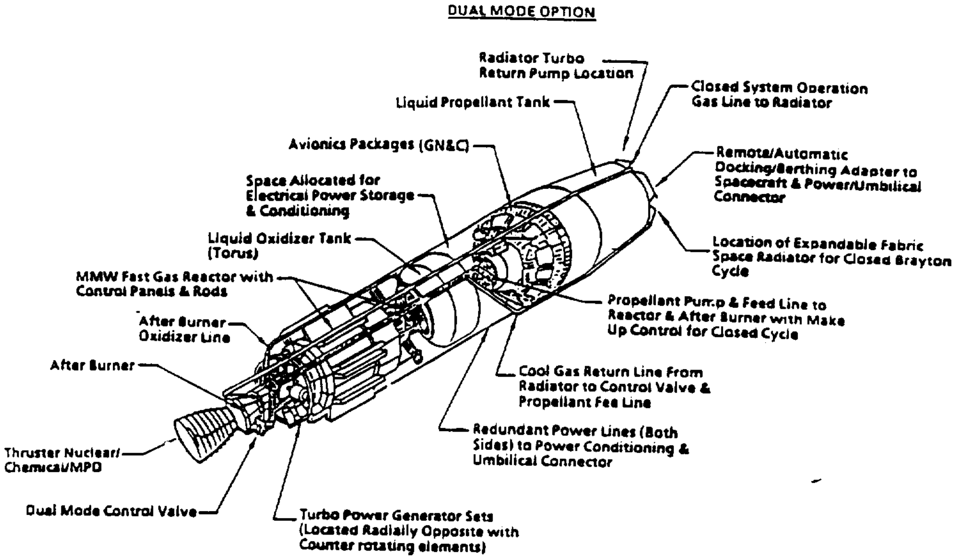


Figure 5

Preliminary Design
Research & Engineering

Preliminary System Schematic

BOEING
Aerospace and Electronics

- 20 MW Burst Power
- 2 MW Continuous Closed Cycle System

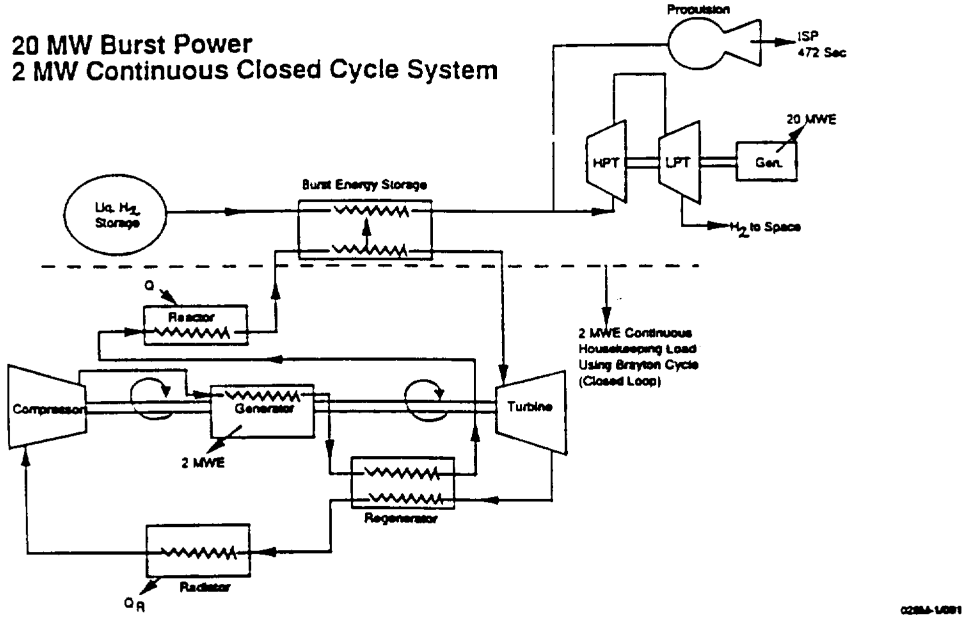


Figure 6

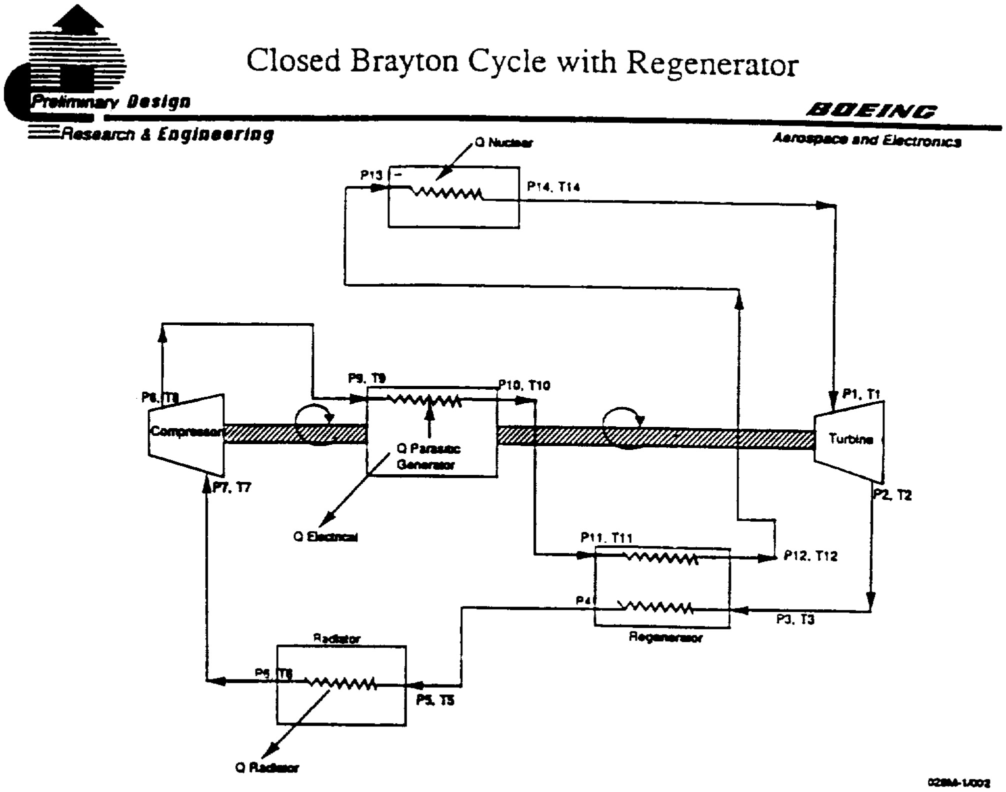
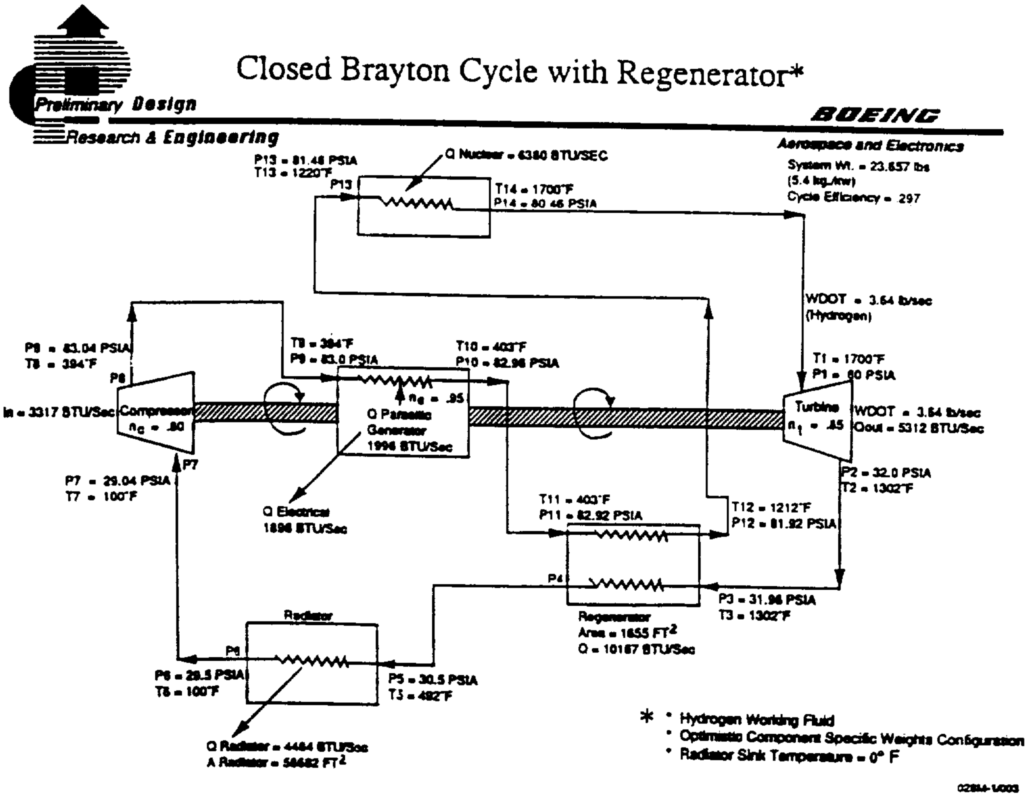
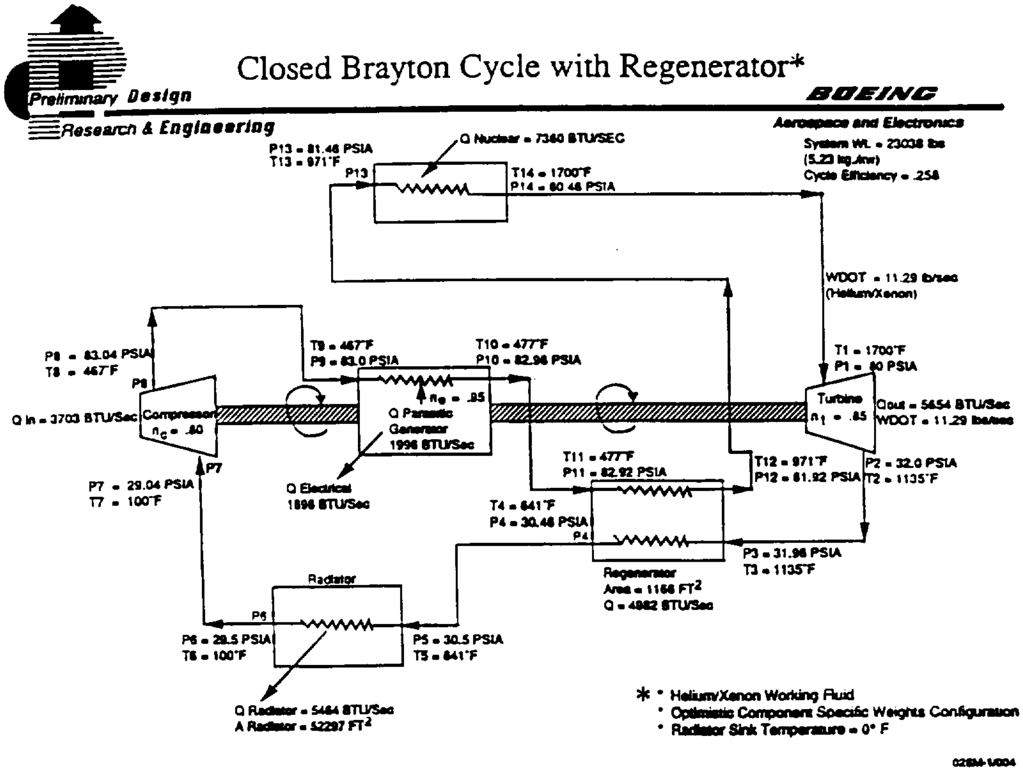

Closed Brayton Cycle with Regenerator

Figure 7


Closed Brayton Cycle with Regenerator*

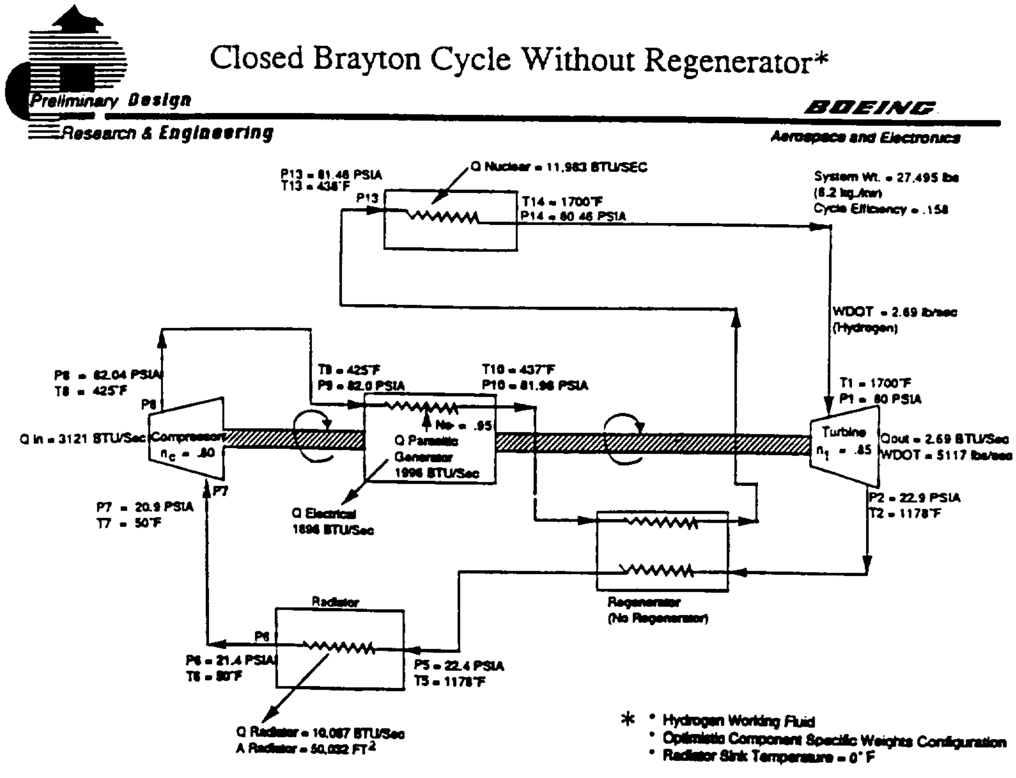
*
- Hydrogen Working Fluid
- Optimistic Component Specific Weights Configuration
- Radiator Sink Temperature = 0° F

Figure 8


Closed Brayton Cycle with Regenerator*

* • Helium/Xenon Working Fluid
- Optimistic Component Specific Weights Configuration
- Radiator Sink Temperature = 0° F

Figure 9


Closed Brayton Cycle Without Regenerator*

* • Hydrogen Working Fluid
- Optimistic Component Specific Weights Configuration
- Radiator Sink Temperature = 0° F

Figure 10