COFFMAN

Coffman (Rocketdyne)

__________to maintain the supply in space environment. So we simply varied the helium tank, and the small tank you saw earlier is now buried in this larger tank. That was the major figuration that we changed. One of the other things that we came up against was the fact that as a part of this adding this skin system, We found it to be balanced, the energy balance was not proper between the oxidation and fuel table pump. We suffered some difficulties in getting the engine started as a result of that, so we added this system, which we call the oxidation activity and bypass system. It has a valve in it that is in one position for start and helps you spin it easier and another position for________ as part of the instrument calibration system. We built engines then. These are the early R&D changes before we ever produced an engine for the customers. We built engines in roughly in four blocks as we went down through our production level. The first ode _______ 2001 to 2011 for what we called our ground testing. They were simply to demonstrate the feasibility. They were not designed for flight. They had many deficiencies that would not have been allowable for such flight engines. They had many problems that you might anticipate in early engine _________. They produced relatively _________ in the scheme of things and they were very limited number of R&D engines that had been previously run. So they were in a beck almost R&D engines although they were produced and limited to the customer for demonstration purposes. 2012 was the real first production type engine.

It had several changes from prior engines. We bleed the J-2 engine, the propellants are bled into an overvoid situation that doesn't show here very nicely, but both the Lox and fuel go through bleed valves back into the stage and then recirculated and dumped overboard, depending on your desires. The bleed system, as you know the warming system, we increased it to 1.5-inch diameter. The gas generater, which is kind of hard to see, is this plot down in here, had been a bolt-on that had been flanged connection to the table pump, fuel table pump in the early prior engines. It became a well known, it was an intigral part of the manifold. We made some changes in timing the artical control assembly, which controls vertially all of the engine pumps, the signal and stop signals, everything else is pretty much automatic, so it contains in ________ logic and timers, etc., and we changed some of those. The pressurematic system, which has its helium bottle within this tank and a regulator over in here which uses the gas from the helium bottle. We added a redundant feature to it. We utilized one of these hands on an instrumentation can over here to become an accumulator, thereby if something happened over there that caused the helium to cease to flow to flow to the engine while it was in stage and operating. It has an accumulator __________ that it will continue to operate off of and provide gas to the system throughout the remainder of the flight, thereby preventing a premature shut-down, so this feature was added at the 2012 point. At 2020, we made a real significant production change point be varying to be a derivative engine that has gone to this point and was 2020 in and subsequently the demand rated flight type engines. Several things we done—we added and we have found that, the uninsulated star tank was not satisfactory so we added insulation to the star tank. We improved the performance of the engine by adding a different thrust chamber injector—the injector is a bolt-in, and we changed that configuration slightly to improve the performance. We made some changes in the electrical control assembly in the interest of realiability. We went from gold-plated circuit boards to solid-plated boards. One of the things that come out of many space studies was that there was a potential temperature environment study, so we painted the thrust chamber white. We subsequently found out that that was all wrong, so we took the white paint off at 2438, but at the time we thought that was the right way to go. Since 20 inch and 2020 are subsequently tested on various stages around the country we added only 12-stage static instrumentation. A number of instrumentation lines which came from thrushing so that the engine, additional flight measurements were desired, of course, of program test in various stages. One of the safety features of the engine is that it looks at itself early during the mainstage period and determines whether or not it should continue to run, monitoring in question. We had mainstage O.K. pressure switch in the earlier designs as one more package. We added a redundant pressure switch which now became a two-pressure-switch system, thereby caused the ---------- to be more reliable. Just the failure of a single switch would not terminate it. Finally, at the 2020 point, we went from relatively good, but not tarribly detected, electrical harnesses not shown here but a number of electrical Cables come from here and virtually all over the engine from this electrical Control Assembly. We went to what we call the ___________ harnesses at that point. These are harnesses that can withstand elevated temperatures for a significant period of time—1500°F for 30 seconds; it is pretty much within their capability and still not degrade the reliability. O.K., we went along, that was until we reached 2060, and 2060 was the earliest point in time we could implement what we call the 230K. The initial engines had been calibrated to run at 225 000 pounds, and vehicle definition had requested an increase in thrust of 5000 pounds to support the payloads as we got going. In order to uprate the engine reliably and make it a man-rated engine at 230 000 pounds, we did several things, basically in the turbomachinery area. The rest of the engine design was relatively agreeable to man, just up until a slight increase in pressures. But the turpopumps did require some realatively major work—beefing up the turbine primarily-so they could withstand high speeds, etc. So both the turbopumps had relatively significant detailed improvements for the 2060 and subsequent engines. In addition, some of our early flights experience had convinced us that ground test simulation of the engine star transient was not entirely sufficient to understand how the engine was going to start it out. We had some near misses. We never caused one to fail to start at altitudes, but we scared ourselves pretty good on some of the early flights. As a consequence, we improved the pushing of the pneumatic, hydraulic (hydraulic in this respect) being oxidized, control features in the early engines, the main oxidizer valve located here came out of the oxidizer pump and into the main oxidizer valve. Its a butterfly type valve, ordinarily valve. The entire engine is pneumatic controlled. Its a pneumatic controlled valve. In order for the engine to start properly, it is necessary that it ramp rather slowly from an intermediate position of about 13 degrees open until its full-open position. When I say slowly, I mean almost 2 seconds. Getting a valve that is pneumatically controlled to do that, well if you are familiar with the butterfly valves, flow forces on them tend to close them at immediate positions, variably up to about half open, and we were controlling the valve pneumatically by venting of the actuator rather than by trying to pressurize them. We jammed the pressure to the opening side and controlled the opening of the valve by venting the closing side of the actuator. So it is highly sensitive to the temperature of the gas and the temperature of the valve that was being vented, and the space environment was causing us to see colder timperatures than we had anticipated. The net result was a closed-loop system that was not particularly beneficial with the engine—the problem being that as you try to vent down the valve. If you didn't vent it down fast enough, you would build up flow forces, and as you build up flow forces you would make the situation worse because you would be increasing pressure between the table pump and this valve, which in turn fed the gas-generator and it would be the gas generator ever higher pressure liquid oxygen would tend to drive the gas generator to higher levels in both temperature and pressure which would in turn tend to produce more liquid oxygen head pressure which would tend to jam ________________. With all the valves available, why did you stick to the butterfly? Was it because this was the normal operation or this was more desirable? Yeah, it was a simple reliable valve derivative of our prior programs with no problems. We only got into a problem, I think, because of the necessity for building the engine up relatively slow. The solution implemented was not entirely a new type valve although we did ___________. We evolved a something called a static controlled orifice of the valve. You can devise and we have flying an orifice situation which is insensitive to temperature. This is a series of pimples that are temperature sensitive which move within orifices. The sense the temperature and immediately regulate the flow of the gas out of the valve to be insensitice to this temperature condition, thereby allowing us to start the engine very nicely. It was a very small change to a part demonstrated through the reliability and mainstage, etc. were these valves fairly new hardware items? Did you do all of them? Were they on-the-shelf hardware? No, we had to do all of the thermostatic work ourselves. Our control people developed, and we tested it at the Arnold Development Center, Tullahoma, where they are extensively as well as unsealable are our facilities. We did incorporate it into the 2060 engines and will back incorporate it back into the 200 series flights that have engines prior to the 2060 on them, I believe 206 and 7. In any event, it was an enevitably successful fix to the problem. It got us out of any detailed control system _____ or valve ________ at a point in time when that would have been very difficult implementing ________. O. K., those were the changes at the 2060 point. At the 2140 we began to eliminate some of the excessive instrumentation___________________ that we no longer require, and that was essentially the major changes thwt we saw in the latter part of production in the program which run up to 2152. During the scope of the program we did retrofit some of the engines, because of engine stage problems, the S-II oxidizer system, as you are aware the S-II does not have recircular pumps in the oxidizer side. These are thermal cycle systems that was necessary to insulate the oxidizer, number of the oxidizer components bleed lines and so forth on the engine and earlier promote adequate cooling. We have added insulation to the __________ can be come of the flight applications and we have insulated the fuel bleed lines on the S-II and S-IVBto allow them better efficiency on their research. Those are the kind of major changes that we see. If you like, these just go through the chronology. Is there any questions that I can attemp to answer? Who has control of the research system, you or contractor? Contractor has control of the research system. He has the _________ pumps. We simply supply an interface point at our fluid customer _________, where we send back to him the fluid that has been pumped through the engine. In the case of the oxidizer system, the bleed point is very close to the main oxidizer valve. This here is the bleed valve. It also goes over and supplies the oxidizer. It is tapped of right there. This goes back to a customer connect fluid point over here, as the vehicle picks up these customer connect points and goes with them as they wish. For example, if you wish to just dump them overboard you could: of course the propellent management both for the S-II and S-IVB have returned to the main tank in case there is a research pump located in the tank. Actually, the way they do this is they close the main propellant valve in the tank, it get closed and the recircular will bypass around it, since the ________ oxidizer pump up to the duct here ________. The fuel bleed valve is located here, so you see it does not show this last little bit down to the thrust chamber which remains relatively normal temperature. It likewise feeds through the bleed valve to the gas generater and the bleed valve has an outlet line, not on this model, that goes into the fluid ________. In the case of both the S-II and S-IVB intake around the main propellant valve, research systems are provided with pumps. Do you tell all of these people how to go about this, or is this their problem? There is an interface document that degines the requirements of the engine and stage in respect to each other and later on in the program that was defined as to what the flow will be and at chilling intervals and so forth, through inter_____, this has become a relative esy situation. Do either of these ______ do you deliver these to the government, do you _______ and let the government hassle or does Noth American do this? No, these were a number of significant hassles on aerospace down through the years, but in general the government was basically to provide their good offices to let the contractors solve the problems. If we follow the F-1 ________. I think it is pretty much true with the J-2. If we have a problem with the S-IVB stage the it is pretty much up to us the the government looks to resolve. Its been expecially in the S-II stage where indeed the two boarding parties were part of the same company. The government is the very people to take a position. Hey, would you guys with your silly company please get everything under control? In the program ______________________________ were being hessed out. There were several meetings set up by NASA where all the contractors ________________different interfaces would get together for large meetings __________________________________. Needless to say,______ without all the details an this thing. There were several areas of cocern to' stact interfacing ___________ of the stage. You also have to concern yourself wit with all the ground equipment interfaces, electrical interfaces, guidance and control systems, things of that nature, so all of the _______ got together. In the case of the F-1 program, we used the pattern somewhere in the neighborhood of 12 or so. We probably had in the neighborhood of 12 or 15 formal meetings to establish all these interface requirements. Then in between these meetings we would have also smaller discussions and samller meetings and things of that nature. So at this point in the program where most of these problems are resolved, only minor changes would come up nowadays. Now we generally handle them as they come up. At that time these were formal meetings and what was interfacing requirements. _________________________between the contractors to get these interfacings? Yes, for instance, we are only on contract with NASA. We are not subordinate contractor to the stage manufacturers. So, consequencly, being on contract strictly with NASA, thats our prime responsibility. So we deal through the NASA people _________________. It might have been better the program management from Marshall's point of view and D.r Rudolph had the responsibility for all Saturns but he didn't have the engines so he __________ the engines, and so he could do the whole stage and worked back through you people to find out what was going on with the engines. Within the NASA organization. I don't know, it may or it may not. I can see within NASA why they had to split it up also. Consequently, they have interface among themselves, and its still like that. All of the engines programs are handled by one program management organization within NASA—Marshall and the stage offices, and consequently they have interface amongst themselves also. Did the organization face any problems? As I understand they didn't even know that the engine office would be giving corrections for Rocketdyne, and Rocketdyne would send back and say here are the drawings. I wonder, I suspect the early days were the worst. They were defining engines and defining stages and its certainly turn my case and turn ________ that we were not strongly involved in decision-making process at that point in time, we were both doing basically engineering work. Some of the folks that were _______ mentioned earlier. __________ would be an excellent one to talk to on that in respect to the J-2. Some of the early F-1 people that were in the program management. That would less an engineering problem than would be a program management problem. The engineer would just get furstrated. The program manager is the one thats got to resolve. At that point in time I was basically connected with the thrust chamber assembler, so I didn't feel these frustrations particularly. I think these probably a lot of frustrations. Whether these was a better way, whether there was a way would be obvious to a

___________ or really well known, and I don't know. There was a lot of fault, needless to say, and lot of ___________ and working relationships and what have you to iron these things out. I think that everybody connected on it, including the NASA people, and with time, they just work these things out, establish working arrangements and working agreements on who is responsible for what and ___________ interface with who. Just establish a procedure and requirements for differenct contractors for different documents, say an engineering change proposal to make a design change and to have any impact on the interface for the operation of the engine, say it was a stage contractor. We have made arrangement through NASA and they have agreed that we would get a copy of these documents and we would have to review them and formally send back an answer to NASA indicating whether that has an impact on the engine, if it does what is the impact or what suggestions do we have. Similarly, they do the same thing within the ________. We have to send a copy of every change to NASA and then if it impact the stage they send that to stage contractor. So these kind of agreements have to be established and they were. It took some time to work these things out. Their subsystem pretty well now. ___________ just to keep everybody informed. Needless to say, the more people involved, the more complicated it gets, that there is a lot of companies involved , a lot of people, a lot of NASA organizations within their own structure. Then you have the responsibility for all of the equipment devoted to the thrust chambers, the S-II, and S-IVB also ________________ equipment. As you see it here, we have the responsibility for that. ____________ actually we stage equipment and we don't have any responsibility for that. The oscillator terminal point down here at the bottom has an access part to hydraulic pump at the stage gear. We don't have any responsibility for that. __________ instrumentation is supplied by us to ______. ______ Packages on the engine, and we _______ required and send them to our electrical interface to the stage whether modulator transmitted. The stage doesn't hang too much stuff on us. The insulation that is on an engine is Rocketdyne's responsibility. Thats about the size of it I guess. They don't hang an awful lot of stuff on this. Special measurements were made to the interface point and allowed us to do something here to a _______________, but that relatively rare. _________________________ temperature and heat radiation that is on the engine and the only requirement that we had there was to provide a half-competent transducer, and the lead wire _________ worked out, and thus interface requirements. On the _______________ they also provide _________ actuation system. We provide a __________ of high pressure ducts which they tap of high pressure fuel to operate the cable system width; and a similar _____ to have a boss on the turn system to become absolutely fluid flow from the cable system. So we are providing the fluid power but they provide the mechanical system to do the job. So you get into those kind of interfaces. Those points are always _____ as to who makes the gimbal system and who makes the hydraulic pumps and so forth. Rocketdyne was ____________ contracted to demonstrate the engines so we had our gimbal system and demonstrated _________ engines

that the engines withstand the forces and to keep them operating that its probably just as effective and just as neat to have the stage responsible for that too, so with guidance as gonna be theirs and there is a logic that is suggested that everything involved in quidance should be ones person or another. I think its strainght with NASA's ________________ gonna provide what equipment we initially, in the F-1 tempted to sell them both the ________________ which has to flex one of the engine ripples as well as the gimbal system, but they elected in both cases to provide their stage contractor with the responsibility rather than Rocketdyne. One of the more interesting questions of whose responsibility is it has made it a ________ situation that occurred on both the S-IC and the S-II. In both cases we are talking about engines stage feed systems coupled instabilities wich could not ________ single member of the loop ________ find loop that could affect solutions. In both cases, the solution were kinda hybrid. ________ how many the problem by changing the system gain and therefore ________________. How did ________________________.
There is a big case for where NASA recommends the problem and establish a photo working group previously, actually, as a result of the S-IC program to be under pretty much ________ assistance. A photo working group worked with a number of contracting agencies________________ Rocketdyne, ________________ ________________, engine gains, and ________ assistance, as well as ________ contributed to the ________ ________________ ________ which involved not only flexible ________ ________ ________, but a ________________ ________________. The space division folks were dominant

in supplying information to define the stage _______, for instance. The government engaged Bellcomm and the Boeing Company to help them in the analysis which would be performed by both Rocketdyne and _________. Rocketdyne developed its own model of the whole thing, ____________ developed its model of the whole thing. As for as an analytical model is concerned, Boeing and Bellcom would likewise, and the photo working group in Huntsville did likewise. In that result. __________ they were able to define the problem to each others satisfaction although __________ model was a little bit different. The accumulator looked like and attractive solution to the problem. The accumulator was actually about the third solution to the problem. The first solution has been that its not a problem and we noted it, and we don't think it will ever divert. Then the ___________ on successful flights and the concern so we shelved the center off early, because the amplitude seemed to be largest toward the end of burning. On the ____________ flight the amplitudes got very large and they ________ very rapidly and it was the engine pressure switches which are engine during the run-through on the engine conficuration that shut the engine down and saved the stage, because the next cycle would very likely destroy the stage. The engine was ________ to the high level of oscillation and ceased engine operation on No. 5. The accummular was a solution which had been previously developed by space division, and was there on the shelf waiting for you to go. So he got what he asked. On the center engine these ducts do not exist, since the center engine is not a gimbal borne engine, these ducts are removed and the stage ducting comes straight in. Its a relatively short gain _______ as far as physically, since the bottom of the S-II sits right above the engine. Its come out straight into the oxygen pump. It was a good case and the point of the government acting both actively and passively setting up the organization, the organization staying on top of the problem and that results the design verification board being in Washington shortly before the flight __________ the accumulator was a reasonable solution to the problem. The data of flight would indicate all the analysis that was done. It was far and away the smoothest flight from the standpoint of the ____________ pogo. We were still talking about the oscillation characteristics. Could you give me oscillation characteristics when you fire the _________ engines the first time. It didn't have a lot of significance but there was a lot of concern about it. There was concern as to the normal level acoustic modeling on a similar apparatus determining the sewing ________. All the predictions turned out to be on the high side and the actual noise level was not greater than the similar engine. The same was true on the ______________________ never become a problem acoustically. There was some radiant problem with radiation on back having an average affect on some of the electrical interface. Is that why you _________ later on? No, the was on the amature harnesses ____________. In some locations, the harness connects on the connector itself, have a little rubber boot around them. We found the black rubber boots didn't make it but the _________ rubber boots did. They had just that much difference in the _________. We put the black rubber boots on we found that we started __________, so the first stage static test was a completely wrapped with aluminum. That was quite sufficient for _________, not a flight problem on we really didn't grade anything that was principally caused. The ___________ is associated with the early stage testing and MTF, which were very significant and those were all very complex operations, difficult to implement and we were indeed having trouble making propellant quality on the oxidation system, particularly because of the thermal cycle system thats only pact connection to all this, to everybodys satisfaction. By the time we got the launches, it was very little of this that caused __________. ______________________________ are basically the same on the F&T and they are primarily designed as a safety feature in any event there was a fire in the engine area that you could affect safe engine operation _____________ electrical system. Both engines, needless to say, rely on electrical power, shut them down. So its a very bad failure mode as you burn harness to the ______________ in order for the engine that can't stop it. The only way you can stop it is let the tank run out of propellent. So thats primarily why the narnesses were harbored the way they are, to provide high temperature relatively short time in the neighborhood of 5 or 10 minutes operation of 2000 degrees without burning through the harness, which is sufficient to allow the engine to withstand for the severe fire and still be able to shut the thing down safely. Thats primarily what _________________________. There ware a lot of changes and a lot of initial design features that were the results of _____ as far as man rated safety is concerned. It had to say how many of those would have caused various ____________ current design practices opposed to the __________ harnesses. Its not obvious, but you will never know. Certainly there have been several significant failures to the J-2, like the situation these being several significant failures, the first being the problems that occurred on 502, when the 152 engine shut down subsequencly because of the stage having the problem where two engines shut down. There was one that had a real engine problem, and later on in the same flight we were able to restart the S-IVB engine. The detective work that went into that was pretty significant. Have you seen that progress report ________? Yeah I looked at it. Do you want to talk about it in any way? There was an-instance of_____________ as you are aware, which had different characteristics on the S-2 engine and there on the S-IVB engine. Technically, it was very hard to relate the two together until studies actually confirmed the whole thing. We did with another instance when both Marshall and Rocketdyne collaborated to good end results. We ran tests here, they ran tests there. It was interesting. The test came to _________ within a day or two. We ran the S-IVB test case at _________ and completely demonstrated the mechanishm with a fairly elaborate test rate to everybody's satisfaction. In about a day later they ran bobtail spin with the assembly trimmed differently to reflect the differences in S-II configuration. Those were principally differences in oxidizer orificing of the _____________ unit that caused the situation to be different. Their failure made demostrated that its so completely. Not only did they show all the operational characteristics of the igniter of the ejector, tossed it into the nozzle and suffered exactly the same misalignment in the same quadrant as the __________jump. A little more than just misfortune. It that result was that by working very hard by both ends of the country we were able to solve the failure, to reconstruct from the flight data what had happened to be beyond a reasonable doubt that anybody with technical credentials that we knew what had happened. Then taking that data and going to the laboratory we were able to shove into the laboratory the mechanism for failure. The __________ failure in a vacuum environment. We get down into its component parts as far as what was the vacuum contributions and what was the flow contributions and so forth. We understand why ____________ occurred in flight. Implement changes to the design and qualify those changes in time to fly again without any significant delay in schedule. So ultimately costly, but kinda madantory in my mind to keep it going, to keep the flight to the moon push on or perhaps the country would have lost it completely at that point. Your saying was the __________ coming out of your hide in cost-plus incentive or? I don't think so, I think it was worth performed, and we were compensated for it. Now I don't know how it affected our peace structure that was involved in __________. I labored ______ ____________ for a couple of months there trying to duplicate the S-IVB failure and convince our management that I wasn't crazy. The test, I've never been so happy to see a winged plane in my whole life. I've seen a lot of __________ __________ into the ground but that was one I wanted to get. I'll admit its ________ __________ was indeed _______. Its copper, its principally a copper assembly, and when I saw the green fine at the area here I was delighted. the results, in terms of the physical hardware, that came out that was pretty impressive that the engine would even attempt to run would not be blown to bits, and any subsequent attempt to start it was kinda beyond logical comprehension. The final three pogo which was the precurses of the 508 program caused us to run the engine in shorter durations was a pretty significant point. The 504 third burn experiment was one of the more significant of _______ the flight of the J-2 engine. For that particular instance, we wererunning what we hoped to be a verification of a flight mission role which had been in effect for a significant period of time. The mission role dealt with contemancies involved in a failure recently propellants or S-IVB restart andit caused certain actions to take place. Not everybody was convinced that those actions were proper and we had propellant and so forth, so prior funding caused us to put it in 504 where after the crew was off and everything was done. The engine started and about 40 or 50 second in, I recall vividly I was in the Ci effort. At the Cape at the time, we needed numbers back over the phone at people back here. Just in a relatively void voice, all of a sudden, I remember dropping and it didn't make any sense. But, indeed, what apparently had happened was that we had gone into full load combination and stability in J-2 during transit, during start transit. In that full result in that prolonged instability was not as you would predict for _______________ rocket engine system ever made. It goes into larger instability and destorys itself in a very short period of time. Its not true in the J-2. We knew part of it in flight would run 4 or 5 seconds before it unstabled, without apparent engine damage. Subsequent to the flight we go into another test program that caused us to drive the assembly unstable, drive the engine unstable and transition and sit and watch for some 100 plus seconds, duplicated the essence in all the flight situations. The decay and performance was due to loss of pneumatic pressure and attending valve position and so forth. There again, although there were no accelerometers on that flight, used to prove to people that we had actually seen full instability. We were able to reconstruct from the flight data hypothesizing the instability and demonstrated beyond a reasonable show of a doubt that this is what occurred on the third burn. Subsequently the flight mission rules were changed anc considerably different pattern which will prevent the engine from ever going into an unstable region, as a result of excessively cold temperatures' that the flight mission rules situation opposed. Its enough about it that flight mission rules now would probably affect a safe start even without recirculation. Then the final significant flight problem that the J-2 has gone through is the 508 shutdown problem that we got back into the pogo business again. These areas are the known problem areas that we did not have a design factors enough to stay out of it. Are there many other problems that we would have gotten into if we hadn't implemented things like ____________ harnesses, redundant accumulatory and humidity accumulator and so forth thats an improbable? When you were talking before I just wanted to, I think minor things that occurred to me, at one point you said you went from a gold solder to a lead solder? Yeah. Were some of these assemblies? Why do that? I guess I have to beg off on the detail technical answer except these were some problems with the gold printed circuit boards, PC boards, that had been utilized in the original design, at that point to the gold who you would think dominatly think would be a less satisfactory material. But apparently, as a result, utilizing other design techniques, and the solder approach. It was an improved design. That was part of my game at the time. So I can't really get prejudice ___________ as to shy. In something I remember from the film that we sae component. Maybe it was the electrical control assembly, but there was something in the film that we saw earlier that said this is a real advance in the state of the art. It seems to me that it was some kind of print circuit board. If that what we're talking about here, the electrical control assembly? Yeah. What made that such an advance in the stab of the art? Why was it so much different than anything you've done before? Got a whole sheet on that. Actually, with the _______ of the technology, sort of breaks away from the configuration a little bit. As I got the charter from Bob Fontain day before yesterday, what things would you do with the conception of the design? If you look at any brand new design, __________ that something we've always done, and that's something we've always done, and thats something that brand new, we've never done that before. We've only done that one experimental models and so forth. That kind of a technology item. Seems to me that technology items on the J-2 fell principally into several areas, ____________turbomachinery thrust chamber assembly, and the electrical area. I asked the appropriate members of supervisors on those three areas to put together a little

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bit of a list for me on that where existing technology is being utilized on the J-2 engine system design. Joe has a controllably a much better list with respect to t the F-190 the J-2. We'll get straightened out on that a little bit earlier and ____________________________ be able to put more manpower on it in the ________ period of time. The technology sheet, which I'll give you a copy of, talked about connectors as well as ECA's and so on. We can all look at it for the first time together. I haven't really gone through this. Its all on one gape and it really all comes to the fact that we had no previous rocket engine experience along this line. What we were doing was reducing electronic industries state of the art and incorporating it into a rocket engine. The corket engine is kinda unique in many respects, especially in amplitude type rocket engine, where your talking vacuum conditions, and relatively large temperature extremes as well as the high vibration, the potentially high vibration environment. Those th three things tend to take a component that might be totally acceptable, in a tape recorder that sits on a desk that gets bumped around in your briefcase. We do something thats nonusable relatively quickly. It was kind of a leap into toe next century as for as the rocket engines are concerned, with respect to the electrical control assembly. The control assembly have any similar type control apparatus on it. Most rocket engines to this point has accepted control signals from the stage principally. The J-2 was a little bit ____ in that respect. You folks don't have any real strong electrical control, so everything is hydraulic ________. ____ and we did have

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_______________ transducer that was _______________ in the environment in case of the ________. The engine vibration on the Saturn was probably the vibration on the S was probably worse on any other engine around and quite literally shakes everything apart. It took quite a bit of development and redesign attempts on transducers to get a tramsducer that would stand up to that vibration environment. It was primarily a vibration problem like so much temperature change; for instance the flight transducer was a self-contained u unit and solid-state amplifier built right in it, and its mounted right on the engine and the whole package is only slightly larger than the microphone assembly____. To package the amplifier pressure sensitive device in an _______________ approximately that size to withstand the engine environment was a real challenge. So it took several cuts at the designs to come up with a transducer to do that well. That is the only solid-state electronic device we have mounted on the engine. I think your transducers, our transducers, RECA both are __________ harnesses, and the connectors that we used, in effect, took state of the art electronic and metalurgical items and reduced them to __________ for the first time. _____ ____________. Why did you do to the turbopumps that you got so much extra power. Say you went from a 225 to a 230 K, just ______ by juggling around on the turbopumps. Actually, as you might imagine, the power requirements are not particulary significant. The problems we faced were to be able to reliably accommodate the speed change sencerity to produce the higher pressures. So we, in effect, beefed up the turbine wheels and the drive mechanisms ________ bearings and seals and so forth, which then allowed us to operate the speed of the table pump. This is getting into metallurgy then? Yeah, a little bit. It was the sort of thing that the initial designs _______ oxidator __________________ _________, and a redesogm was 1rpbably in order. Even the lower levels were retrofitted many of the 225K engines with 230K oxidizer _________, because we felt it was much better, the out gas sealing characteristics and so forth, fuel turbopump had given a lot of problems. So these were redesigned along with the heavier __________ and so on. You specified three things—the turbomachenery the electronics, and thrust chamber— as J-2. Have you really talked about the throust chamber? The thrust chamber is unique in many respects for Rocketdyne. Probably ____ ____________________. I do have an 11 o'clock meeting so, incidental, that will kill it. ____. Lets try to get down to this list on the thrust chamber. First thing is, is that its the major application of hydrogen asopposed to the thrust chamber of high pressure applications. That doesn't sound like it necessarily, doens't mean much but the fact of the matter is that NBS has not yet beef-lined all the heat transfer characteristics of __________ hydrogen, so I'm in the dark a little bit. Whether the physical properties of the ___________ point. There was a lot of data out on our ________ hydrogen and ________ hydrogen, which stood still and easier to analyze, but their hydrogen was pretty tough to analyze. We had long since passed the point of no return and NBS finally for around to producing data and we were pretty convinced by then that it would work because it ______. What do you mean by __________ hydrogen? Atomically, there are three forms, there are two forms of hydrogen, respect to molecular construction __________ to form to which gasious hydrogen will revent __________ another form. Thats the form to which gets produced by liquid hydrogen plants. Normal in the normal balance between the two, which is 80 percent--or 20 percent ________ as I recall. They have different heat transfer characteristics ____________________ coefficients and so forth. They are different from the one to the other. At the time we invite the designers, the thrust chamber was knowing where ________________ was. It made it kind of an exciting game. The F-1 and the J-2 were large, relatively large. ____________ assemblies that had ever been built fro this country. All the thrust chambers _________________ and stuff until that point in time. So fabrication technology item with respect to the thrust chamber, obviously the F-1 created a greater problem that the J-2 fit-up in combustion on this final shell was a pretty tough problem in replacing and getting a reasonably decent bond was quite a bit for the thrust chamber worlds efforts. Some of the early efforts came out with 13 percent bond and they are a little bit afraid to fire that one. Its just liable to go away. The effort was successful enough that a pretty good period of time we were getting 90 plus percent braze bond between the two on the outer shell for __________. There was a lot of metals application contribution and the certainly teamed on large lightweight structures was ____________ there had been no direct _______________ within documentary systems. One of the design criteria was to fabricate a nozzle contour would be relatively optimum in altitude and it would be difficult in testing sea level without significant performance losses. This had a lot of long-range ramifications. But basically, there had been no previous experience for concern. What eventually happened was that we ran into internal testing evolved within Rocketdyne at the time what we called the _________ pressure gradient nozzle. You only think of a nozzle as you go futher downstream the static wall pressure reduces. That not true with the J-2 nozzle. The lowest level is about here. It then hooks back pressure increases from here and the design factors that had been used caused us to believe that by hooking it back it would get a high enough _________ pressure that it would not seperate as judgment was not totally indicated because we did suffer early in the development programs. Seperation problems have considerable magnitude which ___________ bands down here. In fact __________________ _________ take it which just didn't make it. We eventually developed and _____ really what we call a diffuser. It classically is not a diffuser at all. We were going to put a diffuser on the J-2. The classic diffuser would have to be 1 1/2 diameter. It would have to be something in the neighbohood of 10 feet long. This one is 6 inches. It causes it to obtain full flow early and maintain full flow at levels much lower than would otherwise be allowable without diffuser. Its a bolt-on, something we put on for ground test and its water cooled. It has a water line coming down and pumps water. But we have _______ this thing and to allow engines testing to continue. As it was, without that diffuser, which entirely supplementary piece of gear we would never have understood what we was going to have to make. About when did that come along? 60, 61, or 62. In the years of the _______ program. Yeah. I was pretty strongly involved in that one and we went back out till we learned some models contour to the performance determination. We went back out to the model __________ and started in just cutting and trying. The first nozzle extension, this was a one-tenth scale model, so it was _________ inches in diameter. The first nozzle extension that we bolted on to that thing were made of _________ __________. The model was uncooled, so duration was not a problem and _____________________________________, and it sure is cheap. The model shop can build it in a heck of a hurry. We just started trying all kinds of crazy configurations until we finally found a few that worked, sort of backing up. Eventually, we got to the point _______________ tenth scale models. Something that is 6 inches long, isn't very big at all. By that point we were just chopping them out of flat plates steel. We finally became convinced that we had something. We went over, this chamber is like an early chamber in that is does not have a flange down here at the end. The actual J-2 chamber has a flange down at the end for bolt-on and fuse-on, stiffening rings and so forth to keep it from going out of round. We actually went out and welded on something that it looked about the shape that might work. We kinda hammered it and beat into it into a rough approximation after we made the weld close outs. On our thrust chamber stand ____________ and it worked. We went home that day feeling pretty good, came in the next day and it was gone, it disappeared over night. It was cut off by the engine people and was never welded on the engine thrust chamber next door. From that, then we logged in the water cool designs an ________ other simple bolt-on designs that is now capable of being installed in about an hour or two. It takes 80 bolts, just line them up and bang them on an take them up and you're on your way. Connect up a water source, relatively low pressure ________________ water type source. So that was the major, it were major, it was address grediant pressure nozzle concept, however, it was a major new concept that was put in an had never been implemented on any full size rocket engine previously. I've seen some of the installing, I've never seen it done, I've seen pictures of the installing the F-1 engine where you get that tone inside, installing it horizontal. You install this in the vertical position. Are you able to just sit that engine down on the pad? Supposedly. There is no problem it supporting its weight while sitting. There is diffusers bolted on and the diffusers are pretty clumsy. so just sit it down ______________________. It just light gauge sheet metal. So you have to take the diffusers off and sit it down ____________________. The engine weight is not ___________, it weighs 3500 pounds or so. Of course the thrust structure is of 2 bundles ____________ ___________. ______________________________ either with or without the nozzle. __________________ do you still ______________ the engines?

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As a matter of fact that's how we install it in a single engine stand. We have a piece of ground support equipment thats hydraulic lift table and just sit the engine right on this table and just _______ carry on. A couple of other things on the thrust chamber. This is what we call a pass and a half chamber and _________ for fuel actually goes in here and goes down one of every three tubes in this area, it turns and comes back and this is a three for two tube slots in here. The down two coming back. The slots were these go from three to two. I used to dump the high gas back into the nozzle of the chamber ______________. It hadn't been done previously at Rocketdyne. So that the one and one half pass would, with the turbine exhaust gas and dump, which is entirely self-contained within the engine was _______ that had some performance advantages and it was easier from the standpoint of the envelope. What really was coming through this super _______ list? I asked the program managers of the thrust chamber, _______ electrical, various to give me a list of technology and there this list, they put some rough ideas together and this list was put together by one of our folks by the name of Bob Taylor from their input. So you kinda collated it all. Yeah, he started it about 2 o'clock yesterday. Its a very valuable. Actually, it breaks down along those lines.