# ORAL HISTORY 2 TRANSCRIPT

MAXIME A. FAGET
INTERVIEWED BY CAROL BUTLER
HOUSTON, TEXAS – 19 AUGUST 1998

BUTLER: …This is an interview with Max Faget, on August 19, 1998, in the offices of the Signal Corporation, in Houston, Texas. The interview is being conducted as part of the Johnson Space Center Oral History Project. Carol Butler is the interviewer, and is assisted by Summer Chick Bergen.

Thank you again for agreeing to be interviewed. Thank you for coming down today. We'd kind of like to focus today on some of your activities with the Space Shuttle Program, if that's all right with you, but we can go off in other directions, because we are trying to capture your oral history. My first question would be, what was the impulse or the impetus to begin the design on the space shuttle?

FAGET: Oh, that's very interesting. Actually, this happened during the time when George [E.] Mueller was head of the Manned Space Flight Program up in Washington, and he started talking to the people at Marshall [Space Flight Center] about a new system. I don’t know [if] Mueller and [Dr. Robert R.] Gilruth [got]…along very well…[I’m not sure what happened], but he got the people at Marshall started on this, and it looked like we were going to be left out. [But] we didn't want…that [to happen].

The idea was to make something that would be reusable, and we started with the idea that all stages were going to be reusable. Marshall was taking the approach of asking industry to study this and come up with some designs, and there were a number of designs by industry that came up, none of which looked very attractive to me, to tell you the truth. But there was one aspect to it, is that Lockheed had proposed to use hardened external insulation.

That's what it was called at that time...[They] turned out to be the tiles, and that overcame one of the great big concerns I had about reusability, because everything that we'd gotten back from space prior to the shuttle used ablative material. You could cover the shuttle with ablative material, but it certainly wouldn't be very reusable if you had to take all the ablative material off and put new ablative material on... So these external tiles looked like a very neat way to go.

Now, it turned out that what you might call the "accepted" approach by the whole community was to [use shingles], metal [shingles]…made of material like cobalt and columbium and stuff like that, it was very heavy material, but the [shingles], of course, would be very thin, and that was the approach everybody was taking. Now, I didn't care a darn for it. I really didn't think it was a good idea, because the maintenance on those tiles was going to be rather severe. They either didn't have high melting points or else they would tend to oxidize.

Now, there's two kinds of oxidation that can take place on a metal. The kind of oxidation that takes place on aluminum creates a new material called alumina, which is a very tough material with a very high melting point. Now, what happens to iron or steel is, you get rust, which flakes off. Well, this alumina was not the kind of material that would flake off. It would stick there. In fact, it, in many ways, had better material properties than aluminum itself, except it wasn't very malleable like aluminum is. It wasn't a true ceramic, but it was…[a metal coated with a ceramic].

Now, most other materials, including the ones we're talking about, didn't have the—see, this is kind of a self-protection system on aluminum. That also takes place on other light materials such as—[magnesium and] oh, I'm trying to think of the name of the material. My memory is really bad these days.

BUTLER: That's okay.

FAGET: I just can't think of the name. Name is what I'm having trouble with. Magnesium is one, and another one is beryllium. Those are two very good materials which form, self-protective coatings on the material. Aluminum, magnesium, and beryllium are very, very easy to oxidize. The fact is, you can make a wonderful fire with something like magnesium logs, if you could consider magnesium logs. They'd just burn like the deuce. It would get hot enough where it would melt the protective coating off and continue burning.

To give you an example, in the old days before there were flash guns for taking pictures, they'd use a tray full of magnesium powder to take a flash picture, and have a little igniter on that, and, bang, that would go off and make a very bright light. So that's the way indoor pictures were taken up to the end of the 1920s, when they started getting flash bulbs. Of course, the flash bulbs themselves had magnesium in them. They were used only once. Finally we've got a pretty good flash system now for cameras.

But let me get back on the track. I didn't like the tiles. I knew they were going to be heavy, and I thought they'd require a lot of maintenance, so what came out of all the studies that Marshall did was the idea to use these hardened external insulation. We now call it [tiles]. The ceramic tiles that go on the shuttle, and they've been improved a lot. Once we decided to build a shuttle, we had an intensive program to make those things better.

We first thought we'd make both stages reusable, but as we got into it, the first stage got so big for the requirements, the Air Force got in on the Shuttle Program early and demanded a very large vehicle that would carry a lot of weight. They had a vehicle that would carry 60,000 pounds in orbit. That 60,000 pounds was dictated by the Air Force, who said they wouldn't support the funding unless we met some of their requirements. Well, it turned out that it was very important to get extra support from Congress, so, you know, they'd say, "bend," and we'd say, "Well, how far have we got to bend?" [Laughter]

So we accepted that. The 60,000 pounds, by the way, was not important to the Air Force, but 60,000 pounds in orbit at low inclination translated into 30,000 pounds in an orbit of high inclination, which is what they wanted, and, of course, they were not advertising the 30,000 pounds as being important to them, but that was a fact. They wanted something to put their spy satellites up with. The size of the payload also was chosen by the Air Force, and again it was associated with what the Air Force thought they would like to have for their spy satellites, which were rather large things with big antennas and large solar arrays on it and things like that. So they said it ought to carry a payload sixty feet long and at least fifteen feet in diameter, which is what we ended up taking as the requirements. Well, once we churned those requirements into what the shuttle would look like, it began to look like the first stage would be terribly large.

I might mention that at the beginning, we never conceived of having a droppable tank, an external tank. It was going to be two stages, and all the propellant was going to be carried inside. We had another requirement come up, which was silly, but Marshall convinced Mueller that that ought to be one of the requirements, and that was that they use the same engines for the first stage and the second stage. Well, in order to make it work, we had to have a hydrogen and oxygen engine in the second stage. But nobody in their right mind would use hydrogen and oxygen in the first stage. It doesn't make sense. It's not the best way to go. You ought to use kerosene and oxygen in the first stage because it doesn't take so much volume.

The first stage is carrying a lot of weight, mainly the second stage, anyway, and you want to keep the volume down. So we started off with some very difficult requirements which were very hard to meet. The Air Force had another requirement, and that had to do with cross-range. They insisted we ought to have at least 800 miles of cross-range, which really meant that aerodynamically you had to have about 1,200 miles of cross-range to what you might call operationally get [8]00 miles, because of all the contingencies that might come up. It would be difficult to fly an ideal reentry. Everything is going into cross-range and there's nothing left over for changes in atmospheric density, unexpected changes in things like that.

So we ended up with a shuttle that would do all these things. The Air Force never used the shuttle. [Laughter] Although it was their requirements. On all our shuttle missions, we've never really needed that much cross-range. We could have gotten by with a lot less. A couple of times we flew some cross-ranges of perhaps half that much, but it was a matter of convenience as opposed to a matter of necessity in every case. The only reason you'd ever use cross-range is that you didn't have your mission planned out ahead a time. If you plan your mission ahead of time properly, you're going to be going right over the landing site when your planned time of coming down is there.

We had some contingency air fields, contingency landing fields, in the event that White Sands [Missile Range, New Mexico] would have bad weather, which was rare. We landed, I think, a couple of times in—not White Sands, a couple of times in White Sands, as opposed to the Pacific Coast, Pacific landing, at Edwards [Air Force Base, California], and finally, of course, we also want to land back where we launched from, which we do routinely now. So we usually come back and land where we intend to land, at the launch site, and we very rarely need any cross-range. [Laughter] We can plan the missions pretty good.

That's some of the background on it. During the development period, we first decided that we were just going to make it an expendable first stage. So we started off with an expendable first stage, and the second stage would be recoverable. That eventually turned into using solid rockets plus some propellant from the main tank. Finally, we kept putting external tanks on the shuttle. The external tanks, if you'd put the liquid oxygen externally, which is a compact tank, you could carry the tanks pretty simply, but you still had this tremendous volume of hydrogen that you had to put inside the shuttle. Finally I really thought of this. I said, "Why don't we just put the external tank underneath the shuttle, and being it's heaviest, have the first stage push the external tank instead of push the shuttle?"

That represented a breakthrough, because up until then we were trying to push the second stage with these external tanks by [pushing] the first stage right onto the return vehicle itself. So you had a lot of loads going through this return vehicle that were unnecessary, when it turns out that the external tank has got—I guess it's got six to seven times the weight when it's full as the shuttle does, the shuttle itself. So you've got to push on the right buttons, I guess. So probably the final thing was the idea of pushing on an external tank with a rocket, and I was thinking in terms of a liquid rocket.

John [F.] Yardley came up with the idea of putting two solid rockets on there, on the side of the tank, and that had two features that people like[d]. One was the fact that you could light the motors off. All the [Orbiter's] motors could be lit…for liftoff so you would know they were running before you fired the solid rockets. Another one was, of course, that you could use the motors of the shuttle throughout the boost period, which improved the performance and made the solid rockets not as big as they would have been if we had had to light the [Orbiter's motors] later on. So that was what we went through.

We encountered a couple of things as we went along that we didn't expect. For one thing, previously all our rockets with hydrogen propellant were started at altitude, and we didn't worry about fire in the rocket compartment, but now we were going to light these hydrogen rockets on the pad, and we didn't want to take a chance on any hydrogen leaking [on the pad] and all of that, so we essentially made a special compartment which is atmospherically sealed, and filled it full of nitrogen prior to launch so that any leakage or stuff like that wouldn't cause some burning outside of right where we want to burn in the combustion chamber. That turned out to be one of the things that I don't think we completely anticipated when we finally made that decision. Not that we would have done it otherwise, but it turned out to be one of the troubling aspects of the shuttle.

The other thing, of course, is that we designed a vehicle that would have high cross-range, and that meant that it had to have good lift-to-drag ratio during entry, and it precluded what I wanted to do, which was to have a vehicle that was [designed to have a low] lift-to-drag ratio but with better landing characteristics and lighter by using straight wings. We would probably [should] have gone with a straight-winged shuttle. Everything else being equal, we'd have probably ended up with twenty or thirty thousand more pounds of payload, and operationally it would probably have been satisfactory, although the crew would have gone under a higher deceleration than we do with the shuttle now, but it wouldn't be much higher. In essence, it would be in the neighborhood of 1.5-G as opposed to now you never see [much] more than 1-G, and they don't see that till they get down over [hyper-sonic velocity], but you'd be getting up to 1.5-G with that approach.

I think that's about where we started and where we ended up. There's a lot of questions in between. The use of tiles was—actually, I like to cite a statistic, and that is that when you complete your initial preliminary design, you should include at least twenty percent to twenty-five percent extra weight in the vehicle for weight growth. You know, you ought to design it like it weighed twenty percent more than it did in figuring out your landing speed and a number of other things. And sure enough, during the shuttle development, we encountered about twenty percent weight growth, as expected. There was one system on the shuttle that gave back weight, and that was the tiles, during the development of the tiles. [Laughter] They turned out to be about thirty percent lighter than we initially expected. So that saved us from--if that would have gone twenty percent weight growth, we would have been well over our twenty percent margin that we started off with.

So the tiles turned out to be a very good decision. It was one of the decisions that was strongly contested, particularly by the old-order people at Langley Research Center, who said they'd put a lot of experimental and development research in making metal…[shingles] and we didn't use their metal [shingles]. [Laughter] They were heartbroken about it. But nevertheless, the tiles, which everybody said they were going to fall off, but they didn't fall off.

We did have an experience when we built the first shuttle. We put it on top of a 747 to get it from the West Coast, where it was built, to the Cape [Kennedy Space Center], where we were going to launch it. When we got to the Cape, a lot of tiles were missing. It turned out that there was a fault in the way that we attached the tiles. This had to do with the fact that the attachment of the tile was such that we had to allow for motion and expansion due to heating and so forth of the skin, the external skin of the shuttle, which was under the tile, and the tile itself. So we put a pad in there which was made out of felt and a high-temperature material that could withstand the expected temperatures at the bottom of the tiles, something like seven or eight hundred degrees.

This felt, when you attached it to the tile itself, we found out it was only stuck to the tile in a few places. The tile was also made up with quartz fibers, just like the felt had fibers, but the quartz fibers—I won't go into detail about how we made it—were much smaller, much [much] smaller, and the number of fibers on the surface per square inch was probably, I guess, 100 times more than the number of fibers per square inch on the felt. But the only place that the felt could be attached to the tile was where the felt met the tile. So essentially the felt was pulling little pieces of the tile out because the interface wasn't such that they could put the load into the tile from the felt evenly, evenly according to the tile's criteria.

You know, once we found out that was the problem—and we found that out shortly after we carried this vehicle across the country—we put a skin on the tile, a skin of stiff material. We just essentially sprayed it with some stuff and let that set up, and then, of course, all the little pieces of the tile that had some place to roost in that skin and all the few places in the felt would find a place to roost in that skin. We knew this felt was strong enough. It was just that it was pulling little pieces of tile out. So we had this interface plate of the hardened skin on the bottom of the tile that circumvented that problem.

We went on from there, and we've never really lost a tile since then. We've had some tiles that have been broken, primarily by ice coming off of the external tank. It gets coated with ice on the wrong kind of day when it's cold and you fill it full of liquid hydrogen, the ice—rhine-ice, as they call it—will form on it, and of course that will come off at liftoff. Some of those pieces were big enough in cold weather as opposed to normal weather or rainy weather, that they would fly off and damage the shuttle tiles. But from the standpoint of a tile actually coming loose and falling off during flight, that really never happened.

BUTLER: That's good, I'm sure.

FAGET: An interesting thing. We had a group, and I was traveling in this group that was supposed to not solve the problem, but to overview the people who were solving it, which were primarily the people in my Structures Division and the people at Lockheed who were making the tile and the people at Rockwell who were doing the Shuttle. All these groups were coming up. So we would meet from time to time. One of the guys on that committee, and I'm not going to name him, but he was from Langley, and he couldn't give up his grudge. I can't think of anything else. But after we finally got to the point where we said, "Okay, the tile is fixed," and we went to the committee and told them, "The tile is fixed," and myself and I think there were about six members, myself and four other members of the committee said, "Fine. You've done a wonderful job."

And "Mr. Grudge"—I'm going to call him that—said, "Oh, no. I don't think they're going to work. You shouldn't fly with tiles, and I will take a minority position and say the tiles are going to come off."

Well, okay. We've got to get on [with] this thing and the committee says it's going to work, so let's go on ahead. As a matter of fact, we have a minority. Well, that rascal got up, and he wrote a letter to the administrator of NASA saying, "The tiles were not going to work. Don't let them fly the shuttle." [Laughter]

BUTLER: Oh, my.

FAGET: But they worked. [Laughter] That shows you that there's some strong personalities in the business. People believe in what they do much more than they believe in what other people do, but that's human nature.

I don't know. You're going to ask some questions. is that right?

BUTLER: Okay. I guess one question that kind of follows along is that, after "Mr. Grudge," as we'll call him, after he saw the shuttle fly successfully, was he convinced of the accuracy of the system?

FAGET: We never heard from him on the subject again. He’s [a big ego]. I will say this, that the letter that was forwarded to Dr. [Christopher C.] Kraft [Jr.], who was at that time the head of the Johnson Space Center, he told me he was going to keep that in his files. [Laughter] I don't know what he was going to do with it. He also told me he was writing a book. He said, "It's not for publication, just for my family," but I'm sure that incident's is going to be in his book. [Laughter]

BUTLER: I guess, kind of along the lines, talking about different personalities and everybody working in different areas but then having to work together, too, did you have a team when you were designing the Space Shuttle, and do you remember who kind of made up the team or what different areas they might have come from?

FAGET: Well, when we saw what was going on in Huntsville right there at the beginning, I came back and reported to Bob about that, and Bob told me—Bob [Dr. Robert R.] Gilruth—he said, "Well, you ought to think about that, and maybe we ought to get in the business of trying to design a reusable shuttle, a reusable vehicle," which I did. It was a straight-winged version, and it was unique in that it had—I knew it would work, but I designed a balsa and paper model and used it to demonstrate this. It could glide, like anything could, or it could fall like a parachute. [Laughter] It had two points of stability, one coming flat down like this and one gliding like that.

The idea was that if you use a straight wing and you're at a lower angle of attack, your leading edge will burn up, but if you flew at a high-angle of attack, the stagnation point would be behind the leading edge, and because you had a blunt body, a blunt wing there, the heating rate was low. The heating rate is associated with the radius of curvature of what the air sees first. So you've got a flat surface that's looking at the air, it's got a very low heating rate compared to something that's either sharp or has got a small radius, has a very high heating. Of course, the idea was to be able to slow down at high altitude without a high heating rate, anyway.

The other thing that was good about being able to fly at this high attitude, it gave you a little L-to-D, but the main thing is it had a lot more drag. It had a lower L/D because the drag was high, not because the lift was low, and consequently, it slowed down in about a third of the time that the other vehicle would slow down, which meant that it not only had a lower heating rate, but it was exposed to that lower heating rate for a shorter period of time. So the tiles could be made a lot thinner because the heat wouldn't soak through the thin tile any faster than it would soak through the thick tile which was seeing the heat for a longer period of time. We call that "heat load," which is the heating rate times the time, the integration of heating rate and time over a period of time is the heat load. So you not only get a lower heating rate but you also get a much lower heating load.

If you are going to use external insulation, heating load was a very, very important factor, because that more or less dictated how thick the tile had to be, and so we could have saved a lot of weight on the shuttle if we used straight wing, and after reentry just go into a glide attitude just by dropping the elevators and nose down into glide, you come on in. Another thing you end up with straight wing, you end up with a much lower landing speed. Consequently, you don't need these very long runways. You're then [may be] able to land the shuttle on any--it would have a low enough landing speed that in the event you had a problem, you could come down right away, and any commercial airport that services airlines would probably have a long enough runway to land on. So those are some of the things that I promoted that never got done. [Laughter]

BUTLER: Transferring from the straight wing to the delta, then, the delta wing was what the Air Force wanted?

FAGET: That's what we have on there. [The delta wing is needed for cross-range which requires the higher L/D that is provided with the delta wings.] Well, they wanted the cross-range, so they had to have the delta wing, and, of course, there was a lot of guys—the people running operations, you know, our op control centers, they wanted the high cross-range in case they had to come down in an emergency, but they completely overlooked the other facts, that with the straight wing you could land at many more airports and, not only that, you saved enough weight so that you [c]ould always carry extra fuel aboard so that you wouldn't have to come down in these contingencies, which is the main reason they would come down. I think they would have gone along with it. I think we could have settled the argument in-house, but the main argument was coming from out of house.

BUTLER: Looking a little bit into work that's being done now in the X-38, they're looking at more of a lifting body shape. Is there a difference?

FAGET: I think that's silly.

BUTLER: Okay.

FAGET: I think it's actually silly. It's regressive. We've had lifting bodies. That's old technology. We ought to get on with something that's new technology. Right now, if I was running the Space Center, I wouldn't let those guys do that. I'd have them working on something that would take advantage of all the new technology that's been approached. I would try to go, like I said, with this low cross-range straight-wing thing, but in addition to that, one of the earlier requirements we had on the shuttle was the ability to what the pilots like to call a go-around capability. In case they didn't make a good approach, they could fire up the engine and go around and make another approach, which, of course, anybody who flies an airplane, the engine had always got go-around capability unless he's run out of fuel. So this made it a much more conventional vehicle to land.

Well, it turns out that now engines weigh a lot less than they did then, about a third as much per pound of thrust. So it wouldn't cost you an awful lot, particularly if you had a straight wing, which gives you a high lift-to-drag ratio wing [at sub-sonic speeds]. The delta wings are miserable from the standpoint of lift-to-drag ratio [at landing speeds]. If you'll notice, the shuttle comes in very steep and just flattens and flares out at the last [second]. That's so they'll have enough energy to make their landing. It's catering to the fact that it has a very poor lift-to-drag ratio. If you had one with a higher lift-to-drag ratio and you put a smaller engine on it, you not only would have go-around capability, but you'd probably, without carrying too much turbo-jet fuel, you'd probably be able to cruise two or three hundred miles after entry, which again would get you to the point where why don't you build a vehicle, if you're going to come down, that you can land anyplace on the world? You don't have to worry about emergencies; you just come down and land.

This X-38 is supposed to provide a vehicle for the astronauts aboard a space station to come down in an emergency. Well, even with the delta wing on the shuttle, if you clean up their rear end, because you don't need those big pods on there, you can make a nice aerodynamic [improvement]—you can get up to a lift-to-drag ratio of eight. Well, a lift-to-drag ratio of eight just means that you have to have a thrust-to-weight ratio of eight in the engine. [Laughter] So you would build an engine that has sufficient amount of thrust, and it wouldn't be a big penalty to the vehicle to carry an engine.

Now if they want to get off the space station, they can get off anytime they want and worry about where they're going to land after they get off. [Laughter] They can come down right away. One of the b[ad] things about that X-38 is that it can only land in a few places, a few designated locations. In order to get to those designated locations, they have to loiter in orbit for some period of time before their flight path will take them over one of the designated landing points. Well, if you've got something that can land at any airport in the world, you don't have to worry about that; you just cut loose and come down. I pointed that out to those fellows over there, but they don't seem to be very interested in doing anything like that. I've talked to John [W.] Young. He thinks it's a grand idea. [Laughter] But he's a flyer. He knows what you've got to do.

BUTLER: Sure. Talking a little bit about engines, you mentioned that engines nowadays are lighter.

FAGET: Well, they're lighter for a given amount of thrust.

BUTLER: For a given amount of thrust. Okay.

FAGET: They are what they call turbo fans instead of turbo jets. They're not quite as compact, but they sure will give a lot of thrust for their weight. That's why you find that airplanes are putting their engines in their rear and not worrying about them. You know, they're not heavy. Normally you didn't want to put stuff in the rear. It would make the vehicle hard to trim.

FAGET: There's an old story. When I visited the RAE, which is the Royal Aircraft Establishment, he was talking about World War I airplanes. They had this guy that was head of the design team of the—oh, what the hell was it? It was one of their biplanes. Anyway, I'll think of it later. But he had his design team. You know, they designed the thing, and after they finished designing it or got down to the nitty-gritty, he would put a brick in the rear. He'd say, "Now you've got to make this thing fly with this brick in the rear." We could have learned that trick. When he got ready to test-fly it, he'd take the brick out and say, "All right. Now you can fly." [Laughter] But weights have changed an awful lot since then.

The airplane was what they called the SE-5. That doesn't mean anything to you, but it was a neat airplane. All the airplanes then, half the weight of the airplane was engine. They could only go maybe 120 miles an hour. That's about as fast as anything could go, and half the weight is engine. Nowadays you don't even worry about the weight of the engine, and you go 600 miles an hour in an airplane. [Laughter]

BUTLER: Things have changed quite a bit. Gracious. Along those lines, a couple of articles I read mentioned that you had considered using the Saturn V engines on the space shuttle.

FAGET: Yes. Well, in order to improve the performance—the shuttle was designed for 60,000 pounds, but it never did manage to get to 60,000 pound weight-carrying capacity. But if you'd use some other propulsion in [place of] the solid rockets, you could do that. One of the things would be to build a couple of fly-back stages which would use a couple of Saturn engines, or you can also use some of the engines we [have been] getting from Russia. Russia's got better rocket engine technology than we have, we find out now that the Cold War is over and they're trying to sell stuff to us, but their engines are actually superior.

But you would make a booster that would have wings on it and use liquid propellant, and it would have a turbo-fan engine on it. After it finished doing its job, it would glide back into the atmosphere. Now, mind you, it's not going very fast. It's only going about five or six thousand feet a second, so the heating is not very severe. As a matter of fact, if you made the skin out of aluminum, aluminum's got a lower melting point than steel, but pound for pound it's got a much higher heat capacity. So the heating can get absorbed in the aluminum, and you wouldn't have to hardly put any external insulation on this thing.

As a consequence, when it got back into a glide, you turn on the engines and you power it back, they both come in and land at the airport. It turns out that from the time of liftoff to the time those guys are back on the ground is something like twenty minutes. They go out there and they turn around and come back.

BUTLER: All in a day's work.

FAGET: So it doesn't take long, because they're not going that fast and they don't go that far out. The trajectory is still not down range as much as it's still climbing when they burn out.

BUTLER: You mentioned that Marshall had some of the industry people looking at the design work for the shuttle, and then when you all got involved it was primarily—

FAGET: No. Their approach was to have industry come up, to have a competition, have industry propose a number of designs. Yes, when we decided that we'd get into the business of a reasonable shuttle, our first approach was to design it in-house, and we created an internal design team in my organization. I would review them maybe two or three times a week, but we put a man in charge, a guy named Jim [James A.] Chamberlin, one of the Canadians that came to work for us during the Project Mercury Program, and Jim did a pretty good job of moving the design along.

We were able to establish at that point, when they started taking it serious, that we would build the part that goes into orbit, the part that carried the astronauts, and Marshall would build the first stage of this two-stage reusable vehicle. So that's the way it started off, and it turned out after a little while that the two-stage reusable vehicle ended up not being reusable on account of weight considerations. Reality got into the thing, and that's the way it is right now.

BUTLER: Was Caldwell [C.] Johnson also on that design team?

FAGET: Oh, yes. Caldwell Johnson, yes. Absolutely. You asked me who else you should interview, and he'd be one of the ones I was going to recommend. I've got a mental list of people I'll give you.

BUTLER: Okay. Great. We've actually had an opportunity to talk to him a couple times already, but hopefully—

FAGET: You have talked to him?

BUTLER: Yes, we have talked with him a couple times.

FAGET: He did a lot of stuff. He was with the program almost from the start. The first sensible drawing of the Mercury capsule, he made it, you know, turned the concept into something that looked fairly real when we got going on it. He'd been involved in every other vehicle, [of] that area, the manned space vehicle[s].

During the period when we were trying to come up with the space shuttle design, I think they had something like about fifty-eight versions as we went through time.

BUTLER: This has got some of those early— [Referring to *Space Shuttle: The History of Developing the National Space Transportation System – The Beginning Through STS-75*, by Dennis R. Jenkins, Walsworth Publishing Company, Cape Canaveral, Florida, 1997.]

FAGET: Yes, that's a lot of our versions right there. I don't know who got that together. You see there's a lot of straight wings, and then towards the end we went to a delta wing.

BUTLER: Were these all different versions that your team itself worked through?

FAGET: Yes. Well, by the time we got here, we had Caldwell's group working on it instead of Jim Chamberlain by himself. You see, we tried to make what was equivalent to a straight wing right here, even towards the end, still trying to get something that would have a reasonable lift-to-drag ratio. Here we're using canards. [That means that the tail is in]…front instead of in the back, right there. Yes, we had a lot of attempts.

BUTLER: A lot of different designs.

FAGET: Right. This was one of my ideas, to put the engines in there.

BUTLER: Some of these designs show the orbiter mounted on top of a booster.

FAGET: Yes. That was before we had the external tanks.

BUTLER: What was the benefit perceived in those designs?

FAGET: Well, it wasn't anything except we had to have a lot of solid rocket boosters. That's all we're showing here, is that you could do it with solid rocket boosters if you had a big bundle of them. But you can see a lot of them were built around the external tank. The external tank, you can see, is much smaller here, because we were using propellant from the external tank. We had to get it out of the booster, and the booster would get us up to a much higher velocity with the solid rocket stage off it now. So the minimum push you need after separation of the booster is a lot less than if you had a true two-stage vehicle. The shuttle is actually a one-and-a-half-stage vehicle because the solid rockets don't represent much more than half a stage, and that's why the external tank is so huge.

BUTLER: Talking a little bit about the solid rocket boosters, I know in your original design you talked about having a reusable booster. There's been some discussion, too, about whether the booster should have been solid rocket versus liquid rocket.

FAGET: The trouble with a liquid rocket booster, if you don't recover, then it is a pretty expensive affair, much more expensive. At least we thought it would be much more expensive than a solid rocket. So that's mainly what happened. We were trying to keep the cost of the whole program down. As a consequence, we ended up throwing the tank away, we ended up throwing the solid rockets away every flight, no small amount to be jettisoned, you know. What gets jettisoned every flight probably amounts to—I suspect it amounts to something like 75 or 80 million dollars a flight, just the stuff that gets thrown away, and that's just the delivery price to the Cape. It doesn't count all the fiddle-faddling that goes on there at the Cape, turning the vehicle around, attaching the solid rockets, a big team of people that do that. In the usual manner, for every guy that's actually touching hardware, they've got six or seven guys in the office. [Laughter] That's the way it goes.

BUTLER: Looking along a little further, dealing with boosters, in this Conference on Planetary and Space Mission Planning that was back in 1972, you had a report that you presented that talked about a chemical propulsion stage vehicle, which was basically a modified Saturn V booster stage and it would be used in conjunction with the shuttle for heavier launch missions, like for return to the moon or return to Mars. Do you think some such vehicle would still be—

FAGET: Well, we looked at it a number of ways. You know, by saying "we," the people in Eagle Engineering, myself, the industry—a number of different ways to improve the performance of the shuttle. Using liquid rockets, even if you throw them away, would improve their performance, there's no doubt about it. The solid rockets are kind of pukey. From that standpoint, we thought it was a good idea.

Also, some people say, why don't we just take the engines off the shuttle and boost other things with it, throw the engine component away. As a matter of fact, one of the best approaches to building a space station was to do just that. You make something that looks like a space station--now, you understand that the space station itself is a number of compartments, each one being about fourteen feet in diameter and so long. Well, an approach here, you'd make something twenty feet in diameter and maybe about eighty or ninety feet long, you'd take the engines that are on the shuttle and stick them on the back of that thing, and you mount the whole thing on the external tank. It weighs the same as the orbiter. The dry weight of the orbiter is like 200,000 pounds. Well, you can make a very big empty thing that you can pressurize to one atmosphere of pressure and would weight about sixty or seventy thousand pounds, and the rest can be all stuff that goes in the space station, and you end up essentially with a space station on one launch, and it's all over.

What does it cost? It costs you the one-time cost of building this big thing and throwing away the rear end of a shuttle, and the rear end of a shuttle is probably like, maybe--oh, I don't know. It would probably be 800,000 dollars or something like that, less than a billion dollars, but the whole thing wouldn't cost but three or four billion dollars and it would be over with. Done. Zip. [Laughter]

BUTLER: Nice and simple.

FAGET: They can do the whole thing with one year's funding of the space station, which is getting nowhere. [Laughter]

That was one thought. We had another thought which is also kind of interesting. You take the shuttle and you strip the wings off it, strip the tail off it, the whole payload bay. You seal that, you make that part of the pressurized area so that the crew can go back in there. Okay. And then where the wings are, you put some little stubs, you know, and inside those stubs you mount the solar array, which deploys out from there. So you're doing a lot of mods to the shuttle. It's probably about a billion and a half worth of mods to the shuttle.

Then you launch it unmanned and go rendezvous with it. [Laughter] It costs you the equivalent of two launches of the shuttle plus a couple billion dollars to modify the thing. These were all good ideas, but it turned out that the only one that was for it was Rockwell, because all the money would flow there to make these things, to do all this good stuff.

[Laughter] McDonnell-Douglas was very vehement in opposing all that foolishness because they'd lose all their contract, not that they did much with it. Boeing ended up with the contract anyway. Lockheed bought both North American and McDonnell-Douglas. [Laughter]

BUTLER: It's turning into a small world out there, a small world.

FAGET: Yes.

BUTLER: I guess we've kind of seen, as we've talked, that the space shuttle is really an exercise in compromise. If everything had been perfect and you had had all the money and didn't have to worry about what any particular agency wanted, be it the Air Force or what somebody else needed, what is the most ideal design, from your viewpoint, for the shuttle?

FAGET: Well, it all depends what you start with. I think the best approach was when we had the swing engines going in there. I think that, in many ways, was a winner. But that would have had to have been done before we set the size of the engines. The engine size got increased. It started off at 250,000 pounds, but NASA increased the size of the engine, so it was more like 400,000 or 400,000-something pounds now.

They did that because one of the engine contractors had been under contract to do part of the development of the 250,000-pound engine. [Laughter] And they wanted to have a free competition on the 250,000-pound engine, and they ended up picking North American instead of the people in Florida that had originally done it. There was a lot of politics in all the decisions that went along, and one way or the other, the politics, either directly or indirectly, influenced a lot of the design of the vehicle.

The engine that we ended up building was a stupid engine anyway. We should never have built that engine. [It was called a dual combustion engine], but Marshall wanted to build an engine like that. We could have built a [simpler and] much lighter engine with almost the same specific impulse that would have weighed…60 percent of what the present engine weighed. As a consequence, we'd have had better performance, much better performance, [a lot less development cost and an engine that would have been much reliable]. But that was not to be. [Marshall wanted the development challenge.]

BUTLER: Sure. Always a little politics in everything.

FAGET: The guys in Russia have come up with better rocket engine technology than we had. I don't know when they crossed this bridge, but they came very close when the race to the moon was [nearly] over, and they [ended] it up with a big explosion on the pad that we saw from spy satellites. During the middle of the [race], they blew up everything on the pad, killed a few people, it turned out, but it set their program way back. I still think we'd have beat them to the moon, but they were in there really working on it.

BUTLER: I think that's all my questions specifically on the shuttle right now. If there's anything else in particular that we haven't addressed that you think would be important to cover.

FAGET: You've been looking mostly at the shuttle lately, as opposed to the Apollo Program. I guess you did that last year, more or less.

BUTLER: Well, actually we are still working on the program as a whole. We thought for this interview we'd look mostly at the shuttle, because the one that you had done last summer with the Public Affairs Office at Johnson Space Center focused more on the other areas. But actually, if you would be interested, we'd like to have some other oral histories with you and maybe go more in depth into Mercury and Gemini and Apollo, if you're interested.

FAGET: Well...

BUTLER: Certainly not now.

FAGET: Yes. Well, I would be willing to agree to that. Right now, I would recommend you talk to—you said you were going to talk to Caldwell Johnson. You ought to talk to Guy [Joseph G.] Thibodaux. Caldwell Johnson's in design. Guy Thibodaux is in propulsion. You ought to talk to a guy named Ralph Sawyer. Now, these guys did do some work on the shuttle, but they really worked wonderful wonders on the Apollo mission.

BUTLER: That would be great, because we definitely want to cover as much of that early history—

FAGET: Well, you talk to those guys. Another person you ought to talk to, and he was gone during the shuttle Program, was Dick [Richard S.] Johnston, with a "T" in the Johnston.

BUTLER: We interviewed him last week. He had very nice things to say about you, Mr. FAGET.

FAGET: He worked with us particularly on the first three programs, Mercury, Gemini, and Apollo. By the time we got into shuttle, he was more or less in administration rather than engineering. And he left shortly. I think he left long before we finished the shuttle Program.

When you talk to Caldwell, you ought to talk to him about the first space station we put up, Skylab. He had a lot to do with the Skylab Program, among other things. He had his foot in everything.

BUTLER: Sure. Kind of like you.

FAGET: And, I guess, Bob [Robert F.] Thompson. Have you talked to Bob Thompson?

BUTLER: We haven't talked to him, yet. No.

FAGET: Well, you ought to talk to him about Skylab, and also about the shuttle, because he was the program manager. You know, we did the engineering support and he did the program management. When he got past what the concept ought to be, then he was the key man on the Shuttle Program. You ought to talk to him.

I'm trying to think of others that you might be interested in. There are others, but they're not here, so I guess you can't talk to them.

BUTLER: Well, we are making trips around to other parts of the country, so if there are people that are in other areas—

FAGET: Well, I'm trying to think of the Shuttle Program in particular now.

BUTLER: It can be shuttle and even the early people. We're very interested in that as well.

FAGET: There's a guy named Robert Chilton, who was in the program. I guess he was even in there when we started the Shuttle Program. He's a good guy. He ended up designing the attitude control system for Mercury, and take it from there.

BUTLER: This gives us a good list of several folks. We've done quite a bit over the last year with the program, and we're continuing on, and it's wonderful to be able to talk to you and to get some other names.

FAGET: There's one other thing I might say about the shuttle, going back to the shuttle, and that is, we have a hydraulic system on the shuttle, and the reason we put it on there is at that time all the aerodynamic services used hydraulics to move them, and we also needed hydraulics to move the engine, so we used hydraulic actuators. Hydraulics were highly developed, and the reason they were developed so well is that they were used on airplanes, and when your airplane is flying, it's got an engine and the engine can drive the hydraulic pump. So the whole time it's flying, you've got something to drive the hydraulic pump. In the event of a total engine loss, they have an auxiliary power unit which will drive the pump, but it's an air-breathing system. It gets its power by burning air.

So when we chose it, of course, there is no air up in space to begin with, and, furthermore, there's no engine running all the time. So using hydraulics was kind of a--I don't know, it wasn't a good decision. We started with it. We soon realized, at least I did and some of the guys working for me realized, it really didn't make sense and we ought to use electric-driven actuators. And we did develop a wonderful electric-driven actuator. It was eighty or ninety percent efficiency, stored electric energy or using electric energy from the fuel cells. It would have been lighter. The main thing about it, it would have been much more reliable and it would have been a lot easier to check out once you got on the ground and you're trying to turn the shuttle around for the next flight.

The present hydraulic system is driven by a propellant, what's normally a propellant. It's a monopropellant—[hydrazine]. Anyway, it dissociates…and the fumes are ammonia. [Vapors of both ammonia and hydrazine are quite toxic.] So every time you want to check [the hydraulic system] out in the hangar, you've got to get everybody out of the hangar, you've got to put a special vent system that sucks up the ammonia and stops the [fumes from contaminating the atmosphere in the hangar]—it wasn't the world's greatest stuff. [Laughter]

In orbit, the hydraulic system is [of] rather low efficiency. It's got to be running all the time. Well, it doesn't have to be, but you'd kind of like to run it all the time because you've got these hydraulic lines that are going all over the place. You don't dare let them freeze up. [Laughter] I think we might have a little electric pump that's moving the hydraulics now. The nature of the system is that in order for the thing to work, you've got a very small accumulator which accumulates the high-pressure hydraulics, and the pump's got to be running all the time to keep the accumulator filled. A lot of times nothing is happening, so you just bypass and you bleed the hydraulic back into the incoming line, and, of course, it gets hot, so you've got to find a way to cool it. [Laughter] It gets to be very complicated.

Cooling things without any air is not a simple matter. You've got [to] pipe coolant back there to cool it. So we wanted to use electric actuators and we came up with this thought, unfortunately after the shuttle got started, and there was just no way that we could convince them to do that. But the shuttle really ought to have an electric power-driven system. You could pump hydraulic fluid electrically. Now you only have the electricity you can turn on and off, but you couldn't turn this other system on and off that easily. It runs continuously. What happens is it makes too much pressurized hydraulic fluid. Ninety-nine percent of the time you're just circulating hydraulic fluid back, heating it up, whereas if you used an electric pump, it would only pump when the accumulator dropped down because it could start and stop, start and stop. The turbine-driven thing you can't start and stop, because of the nature of the stuff you drive the turbine with. It's a monoprop that dissociates, and if you turn it on and off, first thing you know, it's going to backfire on you and it's going to explode. So you've just got to run it all the time, not at full throttle, but at some [level]. It's always been a problem. We've had a lot of problems with the hydraulic system or the turbine that drives it.

BUTLER: Maybe they'll keep that in mind for whatever we come up with next.

FAGET: Yes. Well, that's why the thing we ought to do right now is, instead of working on an X-38, like I say, if they make a one-third scale model, one-third scale vehicle, one-third scale of the shuttle, and use that instead of an X-38. An X-38 has got these huge fins. They're about the same size as the wings on the shuttle and [it wouldn’t] cost much more to take them down and make wings out of them instead of rabbit ears. They're huge. The mold line would be different, but it'd be something that, like I say, you could land anywhere in the world.

There is an engineering term called the Square-Cube Law. If you make something that's half scale, the wing area is a quarter, because it's got half the span and half the cord, so it comes out a quarter, twenty-five percent of the full-scale model. The weight is not a quarter, it's an eighth, because if you had a block that was one-inch square, one-inch square, and you made it half-inch square, then it would have one-quarter of the surface, but it would have one-eighth the weight, because the volume in a cube is something cubed. I mean, that's why they use the word "cubed" instead of "squared." The surface of a square is something squared, so that's the Square Cube Law.

Now, why am I bringing this up? If you made a one-third scale shuttle, you'd end up with one-ninth the area and one-twenty-seventh the weight. What that means is we have a much lower landing speed. The landing speed would be way down, and you'd be able to land it on a runway without any other modifications. It would land at maybe 160, 170 knots, which all the commercial airliners land at. That's their landing speed. So you're right in the same landing speed [area] as these commercial airliners land, plus now you can afford the extra weight of putting that engine on there, you see. So, okay, so that increased your landing speed a little bit, but not very much.

So they're working on the wrong thing. It breaks my heart. And they're working on something in the past instead of something in the future, which is really bad. That's really bad.

BUTLER: Maybe you'll have to get out there and start a group up.

FAGET: I go over there to George's [George W. S. Abbey] office occasionally and pump him up a little bit, but he won't turn these X-38 guys off. You could use the same team of people to build a third-scale orbiter as are building this X-38.

BUTLER: Well, you'll just have to keep pumping him up, then.

FAGET: Yes. Right.

BUTLER: Keep him going. Well, I think that's all I have.

[End of Interview]