Transcript of the
Joint FAA/Industry Symposium
on

Level B Airplane Simulator Motion Requirements

Part 5 of 9

Transcript of Day 1

Washington Dulles Airport Hilton
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Transcript of Day 1

MR. LONGRIDGE: Let's get started. I believe everybody has taken name tags. If you have not done so, please do so, as the transcriber will need to refer to these in order to record who is talking. So please put these in a position where our transcriber can read your name.

Welcome to this distinguished group, my name is Tom Longridge. I'm going to give you a very brief overview of why we are having this meeting and in general what we are looking for to come out of it. For those of you that were at our last meeting I apologize, this is repetitious, but a number of you weren't. So I will simply say in terms of background, the FAA has a problem. We issued a commuter rule around the first of this year, that commuter rule was intended to establish one standard of safety for regional airlines, for commuter airlines, as well as major air carriers. One of the requirements for one standard of safety, of course, is the quality of training and the use of training devices.

The problem is that for the commuter airlines we don't have the availability of simulators that we have for the major airlines. The reason that we don't, as you all know, I'm sure, has principally to do with the cost of these devices for commuter airlines. The cost of a full flight simulator may actually exceed that of the aircraft, certainly the cost of conducting training is arguably more expensive in a flight simulator for some of these regional airlines as it may be in an aircraft. And yet the FAA is committed to get commuter airlines into training equipment and full flight simulators.

So that's the essence of this particular project, we are viewing the considerations that have to do with the cost of full flight simulators and trying to come up with recommendations that will make the costs of those devices more accessible to that community.

I'm the manager of the Advanced Qualification Program. The Advanced Qualification Program is an alternative to the traditional requirements for training and checking pilots. It does offer considerably more flexibility than do the standard Part 121 rules with regard to the use of training equipment, but even in the Advanced Qualification Program, which is focused on the use of scenario based full crew training and checking, even in that program we require a full flight simulator. We require a full flight simulator in order to execute the types of scenarios that are appropriate for checking the full range of operations for that community.

The Regional Airline Association, which is a lobbying group that represents commuter airlines, has come to the FAA with a proposal, that proposal is "well, because of the cost considerations associated with full flight simulators, what we would like to do is be able to take a flight training device and equip it with a visual system, and maybe some type of motion system." There are different proposals, some of them are based on the entertainment industry, and they are saying to us, "look FAA, if you want us to use training equipment you have to make some compromises, you are going to have to change the requirements to make this equipment accessible to us." We have looked at this proposal, we have certainly given it serious consideration, but we have determined at least at this point that agreeing to that type of proposal is not consistent with the original goal of one standard of safety for the major airlines and for the commuter airlines. We feel that the types of enhancements that would have to be made to flight training devices in order to permit their use for these purposes, those types of considerations could also be applied to a full flight simulator. So what we would like to do is to review the existing requirements for Level B full flight simulators with the idea in mind of trying to achieve the cost goals that these commuter airlines have for the use of flight training devices.

The FAA has settled on what we call a Level B simulator in this country, for those of you that are from overseas, and that is because our existing rules permit a Level B simulator to be employed for 100 percent of the recurrent training and checking requirements for airlines. So that to the extent that we can review the existing qualifications standards for Level B simulators and achieve the cost goals that the regionals have for enhanced FTDs, we can achieve both their goals and the FAA's goals, enhanced quality of training for that community and also more affordable training equipment.

One of the advantages of this approach from our perspective as well is that it would not require any change to the existing regulatory language as pertains to the use of devices whereas the use of flight training devices, the use of simulators I should have said, whereas the use for flight training devices, that would require changes in language. For the FAA changes in regulatory language can take years.

So the bottom line is what we are trying to achieve is an increase in affordability without degrading the standards or quality of a Level B full flight simulator.

This is the second such meeting that we have had. What we are doing, our strategy, which has both a short-term component and a long-term component, is to convene the best experts that we can find in the various domains that pertain to reviewing the qualification standard for devices and the cost considerations, to come up with their recommendations on how we might achieve our goals, and for that matter whether those goals even in fact are achievable. We recognize that what we are proposing to do may not be achievable, or may not have a significant enough impact to achieve the desired goals.

So the focus of today's meeting is on motion cuing, the focus of the first meeting that we had a number of months ago was on aeromodeling. It was a very productive meeting, I think we did achieve recommendations that will result in cost savings without degrading quality. So we wanted to conduct a similar type of review as pertains to what I have called whole body motion cuing, which could be interpreted to mean platform motion. But we would, I think, entertain other approaches to whole body motion if any such approaches indeed exist or might be feasible. We already have, of course, a great body of knowledge in this area, we already have qualifications standards that speak to the motion cuing requirements of a full flight simulator, Level B. We know that, we recognize that. But we also know that we have now got 20 or 30 years of experience in the use of these devices; what we would like to do is to take a second look at those qualifications standards with the idea in mind of updating those standards to identify what might be considered to be the essential motion cues to the extent that modifications might be made in the cuing capabilities of motion systems that would also reduce cost.

And in view of what we have learned in the past 20 or 30 years, to make updated recommendations concerning the limits, tolerance and dynamics of motion cuing, what can be done in that regard to reduce costs without compromising that essential motion cuing.

Now, I need to add a caveat right now. It may be that some day the FAA will delete the requirement for platform motion from some level of device. We are not going to do that at the present time. And so it is not our purpose in meeting today to decide whether or not we need to retain or not retain platform motion for Level B simulators, we have made an arbitrary decision in the FAA that we are going to retain motion cuing for Level B simulators. But we are interested in the extent to which the costs associated with doing so can be reduced. We will in the future, I think, entertain the question of motion, no motion, but we are only going to do that when we have solemn empirical evidence that will enable the FAA to make that kind of change while still assuring the flying public that there has been no degradation in the quality or safety of training that is provided to air carrier pilots.

So we have both a short-term strategy, that short-term strategy is embodied in this meeting, that is to come up with the best expert recommendations that we can come up with regarding the changes that might be appropriate and to make those changes in our advisory materials that define what the qualification standards are for devices, for Level B.

And we have a long-term strategy, we would also like to seek input from you regarding having to do with future research that might be done to resolve still unresolved questions, I mean this is an area that we all know has been the subject of research for many, many years, decades.

And still we don't have the resolution of some of these issues. The FAA is prepared once again, after I guess a long hiatus of research in this arena, to initiate a systematic program of research addressing motion issues, and as we finish up tomorrow I think what we would like to do is to get the recommendations of this group on, given the limited resources that we have, what might be the highest priority for the research areas that might be addressed in motion.

Okay. I will just mention some session ground rules. As you can see, we have a transcriber present. I can tell you that this transcriber is very, very accurate. She doesn't miss a thing. If you burp, it will be in the proceeding. So based on our last experience, the transcript of the discussion that's going to take place today and tomorrow will be very accurately captured in writing. And each of you will be provided with the original drafts of these transcripts so you can make any corrections to your comments that you feel might be necessary. Based on our last experience, very few such corrections were in fact required.

Because we are transcribing, we need to abide by certain rules. One of them is of course one person speaks at a time. Our transcribers will quickly, I think, learn your names, however, during the, I think the first hour or so, you might want to identify yourself to facilitate transcribing the correct speaker.

The only problem that we had last time was occasionally people would mumble, she is not at all bashful, she will stop the proceedings and ask to you speak up, so I will ask you right now, please speak up so she can hear you.

We would like to stay focused on the session goals and agenda. All of you will have received a straw man set of tables[1] that was prepared by Ed Boothe that will provide the basis for most of the discussion. However, I'd like to say that we can by mutual agreement divert from our agenda, for example those of you that might have come prepared to make presentations that are pertinent to our goals today, I think that those presentations might be helpful, you are certainly encouraged and welcome to do so. I believe Sunjoo [Advani] has one such presentation.

MR. ADVANI: At some point I do. I have to take care of the technical difficulties in printing it out.

MR. LONGRIDGE: Okay. Also, I'd like to say, you know, we are not here to rubber stamp the FAA's opinions about anything, we really want an independent expression of thought, so that while consensus is always desirable, if it makes it easier, because it makes it easier to make decisions, alternative viewpoints, disagreeing points of view are certainly encouraged. That was our experience last time, we would also welcome those kinds of divergent viewpoints today. Time permitting, everyone's point of view will be heard and documented.

Everyone should have picked up an agenda as you walked in. If you don't have a copy of the agenda, I believe the pile was originally over where Sunjoo [Advani] is seated. We will more or less abide by this agenda. Our first break is at 10:00, we are going to have lunch, catered lunch at 12:00. There is a discussion—discussion will end approximately 4:30, we will have a cash bar, because the government is not permitted to pay for your liquor, we will buy your meals. Actually we can buy your wine.

MR. BAKER: Time for a revolution.

MR. LONGRIDGE: We will have wine tonight. But we can't pay for the drinks at the cash bar. So that's from 6:00 to 7:00, and the dinner will be from 7:00 to 9:00. Both of these will take place in Grand Ballroom 3, right through those doors, this evening. We will have a continental breakfast again tomorrow from 8:00 to 8:30. And as you depart tomorrow, this is for your information if you don't already know, the buses leave for the airport on the hour and half hour.

The materials you have in front of you can be left in this room overnight. So you don't have to bundle up all your stuff. Leave it here and it will be safe.

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[1] The final set of tables resulting from the Symposium can be found in Appendix 2, 08*apndx2.pdf.*

Any questions pertaining to housekeeping or to the goals that we have for today and tomorrow? This discussion will be moderated by the distinguished Mr. Boothe. However, before doing so, I would like to give Paul Ray the opportunity to make a few comments.

MR. RAY: Thanks, Tom [Longridge].

Really my thoughts are few, not nearly as eloquent as Tom's [Longridge]. Primarily it's an offer of thanks to everyone that's shown up. The invitations, your presence here, is not taken lightly. We went through a rather lengthy list of potential participants in this effort. What we were looking for is an objectivity that we think each and every one of you bring to the table to discuss what can be a very, how should I phrase it tactfully, difficult subject, discussion of motion, its use or nonuse.

The point I would like to reinforce and put up at the pinnacle of our discussion is the fact that the device we are talking about is used for pilot assessment, maintaining that level of safety in regular flight of the airlines, whether it be a regional airline, commuter, or a typical air carrier. We are using simulators to not only train, as Tom [Longridge] accurately had on his slide, but also the checking of those pilots in devices that are fixed to the ground as opposed to going out and flying the airplane. We all know the value of what that simulation can do for us, but some discussions tend to waiver when you get into the area of what is training. If we keep our focus on the fact that simulators are used for pilot assessment, I think such a focus could or may keep us on track. What's valuable for training? There is a plethora of devices used for training. However, these devices are used for pilot assessment. My personal thoughts on how or why discussions on motion have become so heated in the past is that we tend to look at the entire motion envelope of an airplane. Airplanes can fly upside down well for some short period of time in some cases. However, is that characteristic reasonable to look at from the standpoint of motion for devices that are used in checking in an IFR environment?

Personal opinion, we may need to put an envelope around what motion we are talking about. Typically, in any training or checking environment you are talking about, generally speaking, plus or minus 45 degrees of bank. And somewhere in the neighborhood of plus or minus 30 degrees of pitch.

To address motion from the standpoint of inverted flight, or high g maneuvers, people typically want to take a fighter aircraft, an F-16 or F-15, and try their best through implementation of various motion cuing techniques, simulate that complete envelope. That just doesn't work very well in the commercial world, or the practical application of simulation.

I offer those thoughts as a potential for looking at the practical motion simulation envelope as opposed to the full flight envelope of an aircraft.

Again, thank you for taking time out of your very busy schedules to come in. We look forward to the interaction that's going to occur. I hope some very heated discussions occur. If they don't, then we did something wrong.

And thanks again to Ed Boothe for the outstanding work that he has done in preparing a program, the agenda worked extremely well for our look at aerodynamic data requirements, I'm sure it will again. Thanks again for your participation. We look forward to a very productive two days.

MR. BOOTHE: Mr. Toula is not here?

MR. LONGRIDGE: Yes, he is not here.

MR. BOOTHE: I would like to add my thanks to you all being here. I know this is a disruption to your schedule, a donation of your time that certainly could be more productive doing what you normally do. So I think it's quite a sacrifice on your part to come and join in a group like this to offer your expertise to the government, as Bruce [Baker] likes to say. I thought Tom's

[Longridge] comment about the FAA having a problem was a bit of an understatement in today's environment. I probably won't discuss that.

One administrative thing I would like to do before going on is that we have promised to pay your transportation cost. In order to do that I will need to know the total amounts so that I can request that amount and, in turn, when you invoice me, pay you. So if you would be kind enough to have your ticket receipt available after lunch so that we can just copy all the ticket receipts and later I can add them up and invoice for that amount, I'd appreciate it. That doesn't mean that you are covered, what that means is we simply know how much it is. Then it is still up to you to send me the original ticket receipt and some sort of company letterhead or company invoice so that frankly when I get audited I have an excuse for having had this cash flow. So if you would bring the tickets after lunch and let us copy them, I would appreciate it, and some people from the first meeting have never collected, I don't know whether that means they are not going to or what, but I've got money to get rid of.

MR. SMITH: We can help.

MR. BOOTHE: I think the people present here are from a variety of representations, that was purposely intended so that we have a good input from different points of view. I think what we don't have is any people who are adamantly opposed to motion. Of course, there are such people. But I suppose we could have included people like that. At every place where I have ever been where motion was discussed in any serious nature, those people always seemed to be there. And they have some legitimate points of view and some points of view worth listening to, I just happen to disagree with most of them because I guess I can tell you up front I'm a pro-motion person and I think motion cues are important to pilot certification.

So that is something to keep in mind as we do, we don't have that kind of distracter, if you will, in the discussion, I don't think any of you are adamantly "no motion" people. But keep in mind that those people are there and whatever we do, whatever we conclude, I think we have to certainly be in a position to defend what we conclude and the FAA has to be in a position to defend our conclusions by being able to say, particularly in this case, to regional airline operators, that this is what you need, here is the minimum you need and here are the reasons that you need it. So just to say "you need motion because you need motion is not good enough." We have to be able to justify why we need motion and what does it do, what does it accomplish, and I think that's the thoughts to keep in mind.

Of course, I gave you this picture[2]. If I were king I would probably say there is the solution, if you want a Level B motion system, go with that. But that wasn't really the purpose. This particular system has some unusual features that we don't normally see. It's a bit reminiscent of the old FSAA at NASA-Ames. But I only point this out to ask you to think beyond what we normally think about in motion systems. We normally think of a synergistic six degree of freedom system and seem to go from there. But there are other ways of doing the job. Perhaps those other ways would be appropriate to conclusions that we might draw from our two days here. I took this out of Jane's [Defense & Aerospace Information], I'm not sure what it is, I think Don [Irving] said it's a Mercedes car simulator.

MR. IRVING: Yes.

MR. BOOTHE: I think it does say "get full lateral cues in a driving simulator." Anyway, that's not necessarily a starting point, it's a starting point for thinking in terms of perhaps something other than what we normally see on a commercial flight simulator.

[2] Figure caption: A sophisticated hydraulic system with six degrees of freedom moves the projection dome to and fro, thus reproducing the subjective impression of accelerating, braking or cornering. Following the latest developments, the impression of lateral acceleration - for instance during lane-changing or evasive manoeuvres - can be created with 100 per cent accuracy. This extra realism is achieved by a new cylinder with long 5.7 m stroke, which imparts lateral movement to the 18 tonne simulator.

Now, about the table,[3] actually the table begins with this page which addresses transport delay, drive equations and so on. I want to emphasize that this is only one person's idea. And certainly nothing more than that. I took the advisory circular for simulator qualification, I looked at the subjective test area [AC120-40B, Appendix 3], because that is the area that really identifies tasks that will be done in a simulator that closely relate to training and certification tasks. I looked at each of those and said if I were the sole person deciding this, what would I think, what cues would I think would be necessary to stimulate a pilot in this task? And I want to tell you up front, I could be totally wrong. It's just my idea, this is just a—just like the picture, just a starting point.

You may look at this and say "boy, he is crazy." So that's all right. But what I have done is simply list an area of operation, if you will, and some tasks associated with that, and then the degrees of freedom of motion that I thought would be pertinent to that task. I have an acceleration velocity and displacement column that has no numbers because I certainly don't know what those numbers should be, and in fact without feedback from people like you I would be reluctant to put a number in because sometimes if you see a number you might decide that's good enough and discussion ended.

So, I don't know what the numbers should be, I don't know whether there should be numbers for all of those things. It may be that if acceleration were the number, then the rest of it to have something within the physical limits of possibility, the rest of them would automatically be decided. Or we may find out the acceleration we would like is not possible. So those are things that hopefully we can think about in these two days.

I have also tried to write some kind of objective as to why I think or what I think motion accomplishes in that particular task.

Now if you look at the first one, which is surface operation pushback/powerback, I have listed four degrees of freedom, there is acceleration, velocity and displacement column and the task, our motion objective column fits all of that one block. But if you go to the next block, I have written for those four events or tasks, ground handling and nose wheel scuffing and brake operation and brake fade, the same four degrees of freedom I thought applied to all of them in that block. But the motion objective is slightly different for each of them, so if as we go through this table it makes sense to only me, please ask me and we will clarify as we go. It's simply a way of having something to somewhat guide the discussion, and really I didn't intend it to be anything more than that. My thoughts were that the recommended solution from us could be anywhere from nothing to full six degrees of freedom. Tom [Longridge] has changed that in his presentation saying that nothing is not an acceptable solution now, so we think Level B needs some motion cuing.

MR. LONGRIDGE: Yes, that's true. But let me clarify that. I recognize that the issue is really task specific, so for a given task the group may decide that motion is not essential, and I did mention recurrent training but let me reemphasize, what we are talking about here is the use of a device for training pilots who are already qualified in the aircraft, we are strictly dealing with the requirements that would be necessary and relevant for recurrent training.

MR. RAY: There is a supplementary part of that in that the devices we are addressing could likewise be used for what is generally referred to as 85 percent of initial flight training requirements. Pilots would still be required to go to the airplane to complete the initial training. However, Tom [Longridge] is absolutely correct, the recurrent training issue is the foundation of what we looked at, but the device look-wise could, and would be used for initial training.

MR. LONGRIDGE: Yes, but that's not relevant to this discussion, you are talking about the aircraft, supplemental device with the aircraft. Our concern is what would be the minimum requirements that would satisfy us for the use of the device to satisfy all of the requirements for recurrent training.

[3] The final set of tables resulting from the Symposium can be found in Appendix 2, 08*apndx2.pdf.*

MR. BOOTHE: Thank you. I was getting to that point as well. I think that's an important point. So I will just perhaps add to it just a little bit. I want to reemphasize if you have something you would like to present, and even if you need help in getting that ready, I think that help is available here. If you decide this morning that you want to make some handwritten slides and go get transparencies, that opportunity is available and Don Eldredge can assist you—not to put you on the spot prematurely, is that correct, Don [Eldredge]?

MR. ELDREDGE: Yes.

MR. BOOTHE: —in doing that. So if you in the discussion come up with an issue that you feel strongly about and would like to make some transparencies and use the overhead and make a presentation on that issue, I would invite you to do that because I think it's important for us to hear your point of view. That's really why we are here. If you feel that's the way you want to do it, by all means just let Don [Eldredge] know and let me know and we will certainly do that.

Sunjoo [Advani] is doing that and it's up to Sunjoo or any of the others of you who want to do that to let me know when you want to do it. Perhaps an appropriate place in the table, or if you want to do it at some particular time of day, like after lunch or now, just let me know and I think we can accommodate that.

And back to the events, I know I'm bouncing back and forth here a little bit, I just want to reemphasize what Tom [Longridge] and Paul [Ray] have said, we are interested from the regional airline perspective, and from the AQP perspective, primarily in a simulator to support pilot recurrent check. So we are thinking primarily of pilots who have been initially qualified, either in a high level simulator, or perhaps they completed their certification and their qualification in an airplane, and now they are facing recurrent qualification. So these are people who we have to consider to be certified for the airplane they are flying. But the recurrent qualification check, it could either be, correct me if I'm wrong here, but it could be in a conventional FAR [Part] 121 program, which now all regionals who fly airplanes of ten or more seats I believe will have to phase in to the FAR [Part] 121 training and qualification requirements, or it could be in an Advanced Qualification Program where recurrent is often associated with a Line Oriented Evaluation, which is an in-context evaluation and may not—well, it's not always the same, and so it could include any of the maneuvers or tasks that we are talking about here but not necessarily all of them.

So we are talking about certified pilots for the most part, but as Paul [Ray] aptly points out, someone could use a Level B simulator in an initial training program and complete that training in a real airplane. So we can't dismiss the idea of such a device being used in an initial, and when I say initial I would include those other things like transition and upgrade, but the primary emphasis I think for us is the recurrent training. But it's pilot certification or recurrent certification, it's not, and I say just, it's not just training transfer.

When we speak of pilot certification we have to think as the total package this person is being totally requalified in the simulator without having to be validated following that simulator session, without having to be validated in an airplane. So Level B could end up in a pretty wide spectrum. As I said, our policy is for recurrent, it is the end of the line vehicle, there will be no further validation in the airplane, so the person then goes, having passed this recurrent qualification check, goes back to flying the line.

Those are just some thoughts to keep in mind as we talk about what this device should do. So before we go into this specifically, I would like to have, if none of you object to you introducing yourself to others, I know most of you have met but we haven't had a chance to discuss who you are by profession and what you do, and I think that's important for us to know. So perhaps if we could start over there with you Don [Eldredge], and go around the room, because it's important to bring out the variation of experience and expertise and background that we have in the room. And it's quite a variation and I think that variation is important.

So if we could, Don [Eldredge].

MR. ELDREDGE: I'm Don Eldredge from Battelle, we are sort of managing the logistics for this meeting. So if you need help on anything, let me know.

MR. CARDULLO: I'm Frank Cardullo, Department of Mechanical Engineering at the State University of New York in Binghamton. And I guess what I do is I teach mechanical engineering and do my research in the area of man-machine systems and flight and ground vehicle simulation. And I do a little bit of consulting in that area as well.

MR. REID: I'm Lloyd Reid, at the University of Toronto. I'm with the Institute for Aerospace Studies. We are the aerospace engineering arm of the University of Toronto. I run a lab, flight simulation lab there, in which we have a flight simulator based on a six degrees of freedom hexapod system, and we do studies into flight simulation technologies and also we use the flight simulator in human performance and operational problem investigations. And as with Frank [Cardullo], I do some consulting to various organizations. I guess one that relates to what we are doing here today, I'm working on the NADS driving simulator motion base system with the prime contractors, so I have been involved in the simulator business a bit.

Originally we did a lot of work on motion simulation, in the last few years we have been working on helicopter simulations and using the motion system but not necessarily studying the motion.

MR. SUSSMAN: I'm Don Sussman, Chief of the Operator Performance and Safety Division of Volpe that supports Tom [Longridge] in this project. Our division does a lot of research using motion simulation, mostly for the evaluation of proposed high speed ground systems. For about 15 years I have served on the Technical Advisory Group for the United States on human exposure to shock and vibration for the International Organization for Standardization.

MR. BAKER: Bruce Baker, President of Servos and Simulation, Inc. I've been in the simulator business mostly on the engineering sides for about 30 years. I've been—I've had the opportunity over the years to program a number of motion bases and had some relatively good experience with that.

We also make a product line of low cost electric motion platforms and they start at fifteen thousand dollars, so low cost is low cost. We can do six axes up to fairly large payload, up to eight thousand, ten thousand payloads. Those don't cost a few thousand dollars, however, nevertheless there is an opportunity for us to get our oar in the water in terms of some sales, possibly. And I have programmed a number of motion platforms for people and always had, I think, some good pilot reaction and I'm willing to tell everybody what I know about that. Or what I think know about it. It may not be the same thing.

MR. SMITH: Hilton Smith, aerospace engineer, FAA, seven years. Retired, Lockheed Georgia Company, 30 years, stability and control engineer, conducted design analyses as to stability and control and performance of business jets, prop jets and large transports.

MR. IRVING: Donald Irving, CAA and part of the great European dream or nightmare JAA. I've been with CAA for about eight years, and what's of greatest interest to me recently is low cost simulation, what we think is a low cost Level A standard. Prior to the CAA, I worked for Rediffusion, and was involved in the flight modeling and certification with Mr. Boothe and other people like that. I convinced them that the simulation was good enough.

MR. WILLMOTT: Stu Willmott, I currently work with SimuFlite Training International in Dallas. For about 19 years I was with the Link Commercial Organization. And of course worked with motion systems and the aerodynamics involved with those simulators.

MR. HEFFLEY: I'm Bob Heffley, I'm an independent consultant. I work with a fairly broad range of flight simulator topics. A fair amount of my work is simulator math modeling development, some flight tests from time to time, and simulator research, predominantly concerned with handling qualities. This covers fixed wing, helicopters, and from time to time some automotive simulation.

Most of my experience has been in using the simulator facility at NASA-Ames, and these days that center uses the very large amplitude motion simulator, the Ames VMS (Vertical Motion Simulator), and in fact my most recent experience is last month doing cargo helicopter handling qualities research involving sling loads and motion was an important aspect of that. That's it.

MR. BOOTHE: Thanks Bob [Heffley].

MS. BÜRKI-COHEN: I'm Judith Burki-Cohen, I work at the Department of Transportation Volpe Center in Don Sussman's division, I'm an engineering psychologist. I'm the overall Project Manager for the FAA of this project which is supported by the FAA's Office of the Chief Scientist for Human Factors and the person responsible is Dr. Eleana Edens, we are serving Tom Longridge's research needs.

MR. STOCKING: Charles Stocking, I'm in engineering in vehicle dynamics for Hughes Training, I worked for Stu [Willmott] there for a while in the commercial division, I was there for 18 years. I work in primarily aerodynamics and motion, equations of motion, ground reactions. I did the most of the motion software we used in the commercial division, and I just recently finished the motion cuing system for the B-2.

MR. ADVANI: My name is Sunjoo Advani, I'm the Director of SIMONA International Centre for research and simulator motion and activities. I gained my simulation experience in the beginning working with Dr. Lloyd Reid. And then I moved to Holland and established SIMONA and its facilities. I was the prime founder of that. SIMONA is mainly dedicated towards developing simulation technology, establishing new standards and looking at things such as what we are talking about at this meeting. We have high performance research simulators, a generic reconfiguring device. But moreover it uses the latest in all of the technologies that have been selectively addressed to bring together a system with the highest possible performance for the physical cues, the visual and motion and so on. It features all composite flight deck, a new motion system approach using fairly standard equipment but using the latest possible technology in the motion system. So we consider that we have a Level E motion cuing device. We work in close cooperation with industry as well. We also operate a Cessna Citation II aircraft for in-flight evaluations. I'm currently completing my Ph.D. on motion system design.

MR. HARRIS: I'm Geoff Harris, I work for Thomson Training and Simulation Limited. I currently hold the role of product specialist for control and motion systems. I am responsible for the control and motion systems within Thomson. I normally do design and development on these systems for civil aircraft typically 30 thousand pound payload. We do single seaters and helicopters, but most of my experience is heavy payload systems. This is a new departure for me.

MR. BLUTEAU: My name is Normand Bluteau from CAE Electronics. I'm the senior group leader of the motion system engineering group. For the past ten years I've been involved in design of cuing algorithms for motion systems, control schemes for actuators, motion system geometry design, and I've been involved in many customer acceptance and certifications of simulators.

MR. MARTIN: I'm Ed Martin, I'm an engineer with the Air Force Armstrong Laboratories, Human Engineering Division. This is a job that I have jumped into a little over a month ago. Prior to that time I was with the Aeronautical Systems Center acquisition office as an engineer. From the early '70s to the late '80s I was involved in various types of simulator technology research, including dynamic seat benefits that might be derivable for both performance in the simulator and training transfer, as well as some time delay work that we did using the Wright Laboratory's NT-33 variable stability aircraft. Some of that might be germane to this discussion.

Prior to that I had about ten years' experience working at the Link University up at Binghamton.

MR. FOSTER: I'm Bob Foster with USAir. I'm manager of Simulator Development Engineering, which is one group in our whole simulator support group. My department, or my group, is responsible for all modifications to existing simulators, either to reflect changes in airplane configuration or training requirements, and in addition to that we have a big role in the procurement of new equipment. We are currently supporting one simulator, a Dash 8 for the USAir Express carriers, and looking at developing programs to support the other regional carriers that are affiliated with us or owned by us.

I'm also very sensitive to representing our maintenance department, who looks at the, primarily the long-term costs of maintaining simulators from the standpoint of maintenance and utility costs and those types of things, which are significant. And of course in today's environment, with all the airlines we are all very cost sensitive and are looking more at life cycle costs rather than just the initial capital costs of simulators.

MR. BOOTHE: Thank you, Bob [Foster]. Bob, I didn't mean to add to what you said, but Bob's is the user's perspective, which I think is important to the rest of us as we talk about what we think it ought to be. He is the guy at the end of the line that has to keep it working and afford it or afford it and keep it working.

I'm Ed Boothe, consultant these days and some mornings I ask myself how did I drift into simulation. I think it had something to do with that NT-33 that Ed [Martin] mentioned, but I'm basically an engineer who worked in handling quality research and a pilot. Paul [Ray]?

MR. RAY: Paul Ray with the National Simulator Program. We will have the ultimate responsibility of incorporating the product of this effort into changes to the advisory material and potentially the regulatory material that applies to training and checking of U.S. airmen. It may necessitate, as Tom [Longridge] alluded to earlier, depending on what the outcome of this meeting will be, potential regulatory changes. For example, if there is a consensus of something more than three degrees of freedom required for a Level B simulator. That question is certainly open and on the table.

But the position I would like to take in this meeting is that of the ultimate user, which is a pilot. We were, and I think Stu [Willmott] would confirm this, offered some level of criticism when Tom [Longridge] and I briefed the product of our aero efforts in Orlando with the RAA and took some, I hope it was fun, poking at the fact that a bunch of engineers sat around a room and designed something for a pilot. In defense of the ultimate user I hold the hat highly at this meeting of that of a pilot. I'm going to be the person receiving the benefits of this effort. I know there are other pilots in the room and I trust all will provide a user's perspective.

MR. BOOTHE: We will keep that benefit in mind.

MR. LONGRIDGE: As I mentioned, I'm Tom Longridge, I'm the manager of the Advanced Qualification Program, which is an alternative to the traditional Federal Aviation Regulation requirements for pilot training qualification, certification, it does have considerably more flexibility. It's almost a blank check compared to the traditional FARs, we have used the AQP to enable carriers to reduce the full flight footprint requirements by the use of lower level devices like FTD.

On the other hand, what AQP does that's different is it replaces the maneuver oriented proficiency check with a line operational evaluation. This is a scenario based evaluation, so that the pilot is required to exercise the maneuvers for evaluation purposes in the full context of decision making, workload prioritization, communication, so on and so forth. We feel it's a much better screen than a traditional program is with regard to a pilot's readiness for line operations.

Nearly all major carriers, certainly all the large ones are currently participants in the Advanced Qualification Program and many of the larger commuter airlines are also participants, it's a growing program. That's it.

MR. BOOTHE: Allison [The Reporter]?

THE REPORTER: I'm Allison Hoyman. I'm with RealTime Reporters in California, and we have the honor of reporting you ladies and gentlemen today.

MR. BOOTHE: Are we clear? I don't know if we have enough time before the first break to really discuss transport delay or latency or lags, but perhaps we could get started on that and just say well, at 10:00 we will stop where we are and pick up after the break. That may be putting the toughest problem first, or an easiest problem first, I really don't know. But I've listed here or written here what is the current latency or delay permitted for Level B simulators. It's 300 milliseconds, that 300 milliseconds applies to both the Level A and Level B, but we are primarily concerned with Level B. But I have a feeling that some of this is going to drift into other areas, like Level A, because it just seems to work that way. I don't think that most modern Level B simulators have delays of this magnitude.

MR. REID: We better hope not.

MR. BOOTHE: So Bob [Heffley] is ready to start the discussion. I'm ready for you.

MR. HEFFLEY: The 300 milliseconds certainly does jump out to any of us who have done much simulation. Where does this come from and how does it fit into the scheme of things right now?

MR. BAKER: I think I know where it came from. I was going to make a comment that says this is—these delay numbers basically to a large degree are based on what the available technology would do at the time the reg was written.

If you watch, for example in the military, they keep trying to squash these numbers down. They are talking about 100 milliseconds right now because the visual system needs about 60, okay? And everybody else needs a little bit. Now I don't know that there has been any serious psychological work or testing work to say 300 is a good or bad number, it just goes back to historically what the devices were capable of when the reg was written. I personally believe 300 is a bit on the high side for anything you would call a real high fidelity simulator. Maybe they are getting by with it on 300 or maybe the fact is they are much better than 300 millisecond time, that's why the trainers are working. But I think 300 milliseconds is big enough to adversely affect the handling of the airplane. And to some degree I can prove that analytically. Although we would have to agree on what the model of everything looks like. Certainly in the context of a one hertz control loop or even a half hertz control loop, 300 milliseconds is a long time.

For example, I would be very surprised in a Level B sim if the motion cues are lagging anywhere near 300 milliseconds, I would suggest they are probably lagging on the order of 100 milliseconds, or something like that. The visual cues are driving that 300 millisecond number.

MR. BOOTHE: I think this number is a holdover from the past. I think you are right about that.

MR. WILLMOTT: I think that this is a holdover from the past. When these latency numbers were first put in there, there were visual systems that had latencies up to one second.

MR. BAKER: It's easy to do to get one second.

MR. WILLMOTT: And of course the problems that were encountered were pilot-induced oscillations. I think the gentleman that was principally involved with getting that number put into the performance was Jim Copeland, and at the time I think what he used for that was the studies that were done on the space shuttle where they had found, when they first flew that aircraft, if you call it that, that there were pilot-induced oscillations on approach.

They did simulator studies of that and found in fact that the problem was delays in the control system and at the time I think it was around 300 milliseconds. In simulator studies where they introduced increasing delays in this control system, they found that they started getting pilot-induced oscillations when they were around 300. I think that type of motion where you are controlling the shuttle on approach is a much tighter type of control than would be used in simulation, although of course you have to fly accurately on approach, but it was felt I think at the time that that was adequate.

But I don't think in current simulators that there are any pilot-induced oscillations involved with the simulator even if it has a latency of 300 milliseconds.

MR. MARTIN: Yes. The work we did with the NT-33, indicated that performance started degrading—that is, the handling quality ratings went from Level 1 to Level 2—at about 150 milliseconds delay. So you will probably start seeing performance degradation with that much delay.

The delay in the NT-33 work was defined differently from the way the FAA defines delay. That delay was defined in terms of phase lag. It included the equivalent delay introduced by the aircraft beyond the classical lateral and longitudinal modes.

MR. BOOTHE: Was it a time constant?

MR. MARTIN: No, it was a pure time delay that was injected into the control system.

MR. ADVANI: May I comment on that? As I understand from your reports, any delay above the aircraft time delays in excess of 50 milliseconds, if I understand you correctly, was judged as degrading the handling quality. So I think the criteria is in fact 50 milliseconds above the aircraft—

MR. MARTIN: No, the 50 milliseconds came from the fact that if you interpret the FAA requirements for the amount of delay that's permitted in an aircraft, you can have up to 100 milliseconds equivalent delay in the aircraft. If you allow for an aircraft equivalent delay of 100 milliseconds, then you can allow another 50 milliseconds for the simulator.

MR. BOOTHE: Perhaps I could say a word by way of interpretation here. In the FAA measurement if you use the latency measurement, which is difficult because you are looking for small changes in long analog traces, the 300 milliseconds is additional to the airplane's natural lag or latency. So if you were to include the airplane's natural delay, you could have something considerably more than 300 milliseconds from pilot input to response using this number. If my memory is correct, human response time is something on the order of 200 to 300 milliseconds.

MR. HEFFLEY: One hundred.

MR. BOOTHE: Is it 100?

MR. CARDULLO: Depends on what you measure.

MR. BOOTHE: So if the task is such that the transport delay or phase lag falls into the human response time, you are likely to end up with pilot-induced oscillations, which I think simulators are somewhat notorious for. So perhaps 300 is the wrong number. But I don't think most simulators have this much delay these days.

MR. BAKER: Let me make a comment about that, also. First of all, there is an area which is—to sort this thing out, there is a test on the simulator which will probably sort this out before the simulator is certificated. That is, somebody who is a qualified pilot will get into it and fly it and say yes, it flies like the airplane. And I guess my concern is that if 300 milliseconds stays in the advisory circular and somebody says well, gee, these guys are supposed to know what they are doing, they have told me 300 milliseconds is an acceptable number, he designs to that and turns on the simulator and the pilot comes in and says "blah," then we kind of led the guy down the primrose path. I would suggest that we probably ought not to do that, we probably need to give the guy a little better guidance.

And secondly, I would also suggest that pilots will learn how to fly these things, given a little bit of simulator time they will change the control laws they have inside of them to account for the time delay and put some artificial lead in there which they wouldn't do in the airplane. Neither one of those situations is desirable. We are trying to avoid retraining a pilot between the simulator and the airplane. I think everybody would agree on that.

MR. BOOTHE: Bob [Heffley]? Did your comment go away, Bob?

MR. HEFFLEY: Yes, it did. Everybody said the right things.

MR. BOOTHE: Let me catch Frank [Cardullo] here.

MR. CARDULLO: I was talking with Bob [Heffley] about this before we sat down. It was in the first line of the thing. And it just floored me. I don't think it ever hit me as hard when I had seen this before as it did in preparing for today. But my opinion is that if the simulator has 300 milliseconds delay in the motion, it doesn't matter what you do in the motion system. The motion is going to be useless.

MR. ADVANI: You can turn it off.

MR. CARDULLO: So the rest of the discussion is moot with that long of a delay. I think if we look at some of the higher bandwidth piloting tasks, that start to push up around one to two hertz, at two hertz, you are looking at 220 degrees of phase lag, clearly the system is unstable if you just look at it as a system.

MR. BOOTHE: Right.

MR. CARDULLO: It's going to be unstable. So even at one hertz you are not going to have very much phase margin. So anything, anything else that you do in the motion system is not going to make any difference. You might as well have a shake table under the guy to give him some vibration, because the lead that you want to get out of the motion system just isn't going to be there.

So I would strongly recommend altering this number if we are going to seriously address this problem.

MR. BOOTHE: I think Frank [Cardullo] makes a good point. If we leave it at 300 maybe our job is finished.

MR. CARDULLO: We can go drink beer for the rest of the time. But we will have to pay for it ourselves.

MR. SMITH: I just wanted to make the comment that the last six or seven years, with the computer capacity and speed increases we have experienced, that my observation of the simulators that we have been evaluating, that the motion latency on Levels C and D is typically now, you know, anywhere from 70 to 80—most often less than a 100 milliseconds. And I don't see that Level B is going to increase that because computers aren't that expensive. You are not going to get a less capable computer for, I don't think, for a Level B than you would for a [Level] C or D, because there is not that much of a cost savings.

But the visual systems, because of that increased computer speed and capability, haven't reduced latency because they add scene features and they are still pushing 150 milliseconds which I brought up to all the operators and sim manufacturers, a question—do we need to look at—we say the motion should be before the visual, but now we are getting differences between the motion and visual of, you know, 60, 70 milliseconds. Should we be concerned about that? If we have a limit of 300, it might be that we would have motion latency on the order still of, I would suspect, 70 to 80. Now you could go with a lesser expensive, you know, IG, and come up with latencies of 250 or so. If there is no phase requirement, then I think perhaps, does that constitute a problem, is the question?

MR. BOOTHE: Can I ask you to rephrase the question?

MR. SMITH: Okay. If we left the requirement at 300, possibly would we not wind up with motion latencies on the order of 80 to 90 and visual latencies of say up to 250, or it could be up to 300 and still be acceptable if that's the requirement? Would that be a problem?

MR. BOOTHE: I don't know, but I don't know whether we want to address—if we do, we do have motion and visual phase relationships, I guess that's a legitimate question. I don't know the answer.

Bob [Heffley]?

MR. HEFFLEY: Well, just maybe to complete the thought there, one important aspect of quality of simulator cuing, of course, is the reasonably simultaneous occurrence of motion cues and visual cues, they need to be pretty well synchronized. If there is much of a phase distortion there you really start to destroy the quality. I think one crucial question here is specifically what flight tasks are we really considering? And there will be probably two or three critical flight tasks that really force the level of motion and visual fidelity that if you have a flight task where the pilot is having to close a very tight precise loop on something, that's what designs the motion. And that's what designs the visual, that's what designs the amount of transport delay, that's acceptable.

And possibly one thing to do is go directly to what those critical tasks really are for the application that we are talking about today.

MR. BOOTHE: I think you have to consider for this the most demanding task. If you are suggesting that perhaps we should leave this and go through the task list and let that—consider that as we go, and when we identify what we might perceive as the most demanding task then address it at that point?

I do agree it has to be the most demanding task that the pilot would be doing, which is usually some high gain close—let's see some—Bruce [Baker]?

MR. BAKER: I wanted to make another comment with respect to the history of this thing as the best I understand it. Let me say I'm not a good historian on flight training simulators. But I would suggest that perhaps that the 300 millisecond number, besides being historical from a hardware technology standpoint, is also historical from the standpoint when the Level B simulators, most of them that exist were built, most of them were large aircraft. We are talking about smaller aircraft now which are more responsive. And that may, you know, if we had the time to investigate it thoroughly we would probably come to the conclusion we need to drive that number down quite a bit just because we made the airplane smaller.

MR. MARTIN: Let me just make a comment on that. In the NT-33 studies we looked at representative dynamics for a range of aircraft. The delay tolerance seems to be a U shaped function. For the very heavy transports, it's less forgiving of delays than it is for some of the smaller aircraft in between, then as you get to the very agile fighter type aircraft it becomes less forgiving of delays again.

MR. BOOTHE: So there is an in between area.

MR. MARTIN: That's a little more forgiving, yes.

MR. BOOTHE: I would have not have predicted that, that's interesting.

MR. MARTIN: For transports you probably don't have a less restricted requirement simply because you have a large aircraft.

MR. REID: Ed [Martin], when we are talking about the control loop with the pilot in it and worrying about the delays, time delays in the motion feedback loop, we have got to remember that the washout algorithms are filtering the signals being put through the motion system, thereby creating phase lead at the lower frequencies and maybe frequencies up to the frequency of the critical control frequency bandwidth of the control loop. So that's one thing we should think about a bit, I guess, at the same time.

And the other thing is that it is possible to put in lead compensation software to try to compensate for time delays, so again those software routines will also be influencing what the pilot is feeling in his closed loop control.

Just so I have a chance to say this, I have always had a little problem with the simple step input electronically generated measurement of pure time delay to qualify the systems, because in actual fact as we have been talking, the tasks that seem to be most critical are high bandwidth continuous control tasks that may be less than three hertz in bandwidth and it's quite possible that the phase lags that the pilot is experiencing at these frequencies when doing normal control activities can be assisted by lead compensation and maybe even inadvertently by what the washout filter is putting in in the way of leads.

In some sense I have always felt that this simple time delay measurement, though it's simple to do, was putting the simulator manufacturer or the people trying to qualify the simulator at a bit of a disadvantage in that it may be saying the simulator is worse than it really is to the operator as far as the human pilot is concerned.

MR. BOOTHE: Frank [Cardullo]?

MR. CARDULLO: I'm inclined to agree with a lot of what Lloyd [Reid] just said. You and I have talked about this before, that the U.S. Navy has gone to a broader definition of this issue in qualifying their simulators. In that they do both a time domain and frequency domain specification of this problem. And so in the frequency domain you measure the phase lag, and that of course is really what Lloyd's [Reid] point is. And I agree with that. Of course if you do have 300 milliseconds, that's going to add quite a bit of phase lag that you are going to be stuck with, and it's possible to compensate the phase but you are still going to have the pure delay left with you. But the phase is what really affects the pilot performance. So, yes, I would say that Lloyd's [Reid] recommendation here, as I interpreted it, is to broaden this definition and to at least include, if not solely make it a frequency domain specification.

MR. BAKER: Let me make another comment.

MR. BOOTHE: Two more before—

MR. BAKER: Before the break?

MR. BOOTHE: —before the break.

MR. BAKER: Let me say I agree with what Frank [Cardullo] and Lloyd [Reid] have said about the motion platform getting an advantage from the washout filtering in terms of lead compensation. If the computer doesn't add too much delay to it then the motion may be exactly following the airplane simulation model at around one hertz, which is a good number. I think most of the delay that you would measure if you looked in the frequency domain would become, if any existed, they would be coming from the time delay and probably the reason we are getting by with that is the fact that the motion cues are, I think, what the pilot uses primarily to close his fast loops and the visual cues is what he uses to close the maneuvering loops. How does he line the airplane up on the runway and that sort of thing.

The maneuvering power spectrum density, from the little information I have, is down around a sixth of a hertz. At a sixth of a hertz even 300 milliseconds isn't going to be too bad of a problem. I'm just throwing this out as a suggestion as to how we are getting by with systems the way they are and the visual lag, which I believe is always the greatest lag in the system, is not totally destroying the handling qualities of the simulators.

MR. BLUTEAU: I would like to add my experience with the small aircraft simulation. Our experience has shown that on smaller aircraft for maneuvers such as landing with heavy turbulence, the pilot input was actually very lively, so was the aircraft response. As a result we experienced that high performance throughput delay was actually a requirement to produce the reality of the aircraft. We have had problems with pretty good models not being found to be flyable by pilots just because, as has been said before, we are dealing with a smaller aircraft, the loop response being what it is, the throughput delay is actually a fairly important criteria for reality.

The other point I would like to make, since the whole idea of the session is cost driven, how to make—how to reduce cost, how to address cost issues, I think we should consider the ratio of training value of something versus the cost of that feature. In the case of throughput delay, it may turn out the training value associated with high performance throughput delay does not actually cost a lot of money because the technology, it has been said already, technology is almost there worldwide, very good performance. If you look at the ratio of the training value versus the cost, it's actually very good, it's very advantageous, I think, from a money point of view, to get that additional training value that good throughput delay would bring us.

I think possibly we would have to look at issues from the point of view of cost as well what the money can buy us in terms of performance.

MR. BOOTHE: I said two more before break, if I could hold you till after break, Geoff [Harris], I would appreciate if you could keep that thought. As they say on commercial TV, it's hold it till after the break.

(Break taken.)

MR. BOOTHE: If we could get going again, I'm in a different location because I was apparently ignoring some folks over here who had their hands up and I couldn't see them. They asked me to take a more central position so I could get questions from this side of the room as well as the other side. So the advantage you have over here is gone.

MR. BAKER: That didn't take long, did it?

MR. BOOTHE: So Hilton [Smith], you wanted to reintroduce that question that you had, and then Geoff [Harris] was holding a thought for after the break.

MR. SMITH: Well, I'm just, I guess due to my experience in evaluating simulators, Levels C and D, in the last six, seven years I have noticed the motion has been running 70 to 80 milliseconds and visual still pushes 150. As a matter of fact, we evaluated one recently and I'm not sure it met 150. But I'm just asking, is that a problem? Especially in light of leaving this at 300, I suspect we might get motion systems with latencies of 80 and visual systems, I suspect you could design a cheaper visual system if you only had to meet 300 and it probably would just meet 300. Is that delay a problem? That's the question now.

I wanted to just make another point of interest on airplane responses. Back in the late '60s when jumbo jets came on the scene, 747, C-5, DC-10, engineers were looking at those things, the size of these airplanes based on wing area, which says the inertia goes up as the cube of the wing area ratio. The C-5 compared to the C-141 has twice the wing area and the inertia came out about ten times. Everyone was concerned about response, especially on the flight path. We actually added a longitude stability augmentation system (SAS), that had lead functions, that added elevator as a function of stick position, in other words if you wanted one degree of elevator it would put in two, for the landing configuration. And the first thing they did, in the preliminary flight test, they decided they didn't need that. As a matter of fact, the only thing that's in the C-5 pitch SAS now is a half degree of elevator per degree per second of pitch rate damping, and it was really determined in the most critical maneuver, which is air refueling, they ran a bunch of pilots through in the airplane, they couldn't tell when the pitch SAS was on or off. But they had to leave it on the airplane because they had designed the autopilot around it.

But anyway, on the instrument panel in the cockpit it says if you engage the autopilot the pitch SAS has to be on. That's just a point of interest, in aircraft response, you can move those aircraft if you put high enough rate actuators in the control system you can move the control surfaces and obtain the desired aircraft response.

MR. BOOTHE: Thanks, Hilton [Smith]. Let me ask Geoff [Harris], do you still have that thought?

MR. HARRIS: Yes, I do. A number of things, first in terms of pilot input versus the aircraft response. In small aircraft, private aircraft, there are papers that say there should be less than 100 milliseconds delay between the pilot input and the aircraft response. We are talking about an additional delay of 30 milliseconds. With small feeders, which are more lively than the big aircraft, the 30 milliseconds response is obviously far more important than for a jumbo jet, the delay should be less than a jumbo jet, 150 mil is not good enough, it should be 100.

The third point is that typically these days the computer power minimizes the delay between the pilot input and the math model out to the motion system, they can be very small, 150 is way in excess of what we can achieve, we get better than 100 on all the jobs. On high performance take it down to 50.

This doesn't correspond to the visual system, of course, it typically takes 150. It takes time for visual to paint the picture, it's worse on lag time because you have to paint more stuff. The critical thing is phasing between motion and visual cues. If the motion leads by a lot you get—pilots get simulator sickness, nausea, headaches, occasionally vomiting, this sort of thing. So the phasing between motion and visual cue is important. The latency between the pilot input and motion cue should not be a problem these days. We have the technical abilities to do this.

MR. BOOTHE: Okay. Thank you, Geoff [Harris], I wanted to—Paul [Ray]?

MR. RAY: Just one point. I believe I'm hearing 150 milliseconds is reasonably achievable as a no cost driver, essentially a no cost driver, to a Level A or Level B, or simulation in general. If that's the case, I see no reason for anyone to interpret 300 milliseconds as the holy grail. If that response should be changed to some lesser figure without driving cost, then it's certainly reasonable to do that. If there is a similar addition of language that needs to be embedded to address the issues of phase lag between motion and visual, then certainly we should do that. We have an obligation, I think, as a user, if you want to phrase it that way, to do that. If we can write more effective words to address the issue of transport delay, then we have an obligation to do it. If we need to change it, let's change it. Particularly if it's not, if I hear correctly, not a cost driver.

MR. BOOTHE: Well, I will be right there. I think cost is important, we are looking for lower cost Level B simulators, in fact. So I guess it's yours and Tom's [Longridge] prerogative in this proceeding, whether or not in the process we say we can make it technically more acceptable without affecting cost, and that's an okay solution, or whether we have to keep lower cost in mind, say we can only make it technically more acceptable if the cost is lower. That's not a question that I think you can answer. So that's just a thought to keep in mind.

MR. SUSSMAN: Don Sussman, Volpe. What you are hearing though is two things. It depends on the flexibility of what you can do with the guidelines. You can accept that the motion simulation is no lag, is no longer a cost item. You can think about establishing the guidelines as a proportion of the plane's response that you are simulating. Perhaps when you look at the question of visual simulation, which is, to a large extent is how complex the simulation is, maybe in terms of proportion with the response to the aircraft and the phase lag of the slowest input, which is the visual, maybe those are the guidelines we should look at.

MR. RAY: We have an item on the agenda that may be pertinent to our discussion here. We plan to start an effort this fall to completely address, among other parts of Part 121, Appendix H, which contains simulator technical standards for Level B through D. The issue we are discussing would necessitate a change there.

MR. SMITH: I just wanted to add I may have misunderstood what you said, but I think you are correct in saying to go with 150 for motion or even lower is not a cost factor. However, the phase shift between the two might be a cost driver on vision, from what I've heard.

Just another point of interest, I was talking to Ed [Boothe] on the break and he said I might bring it up, a point to keep in mind when we are talking about the Level B as a recurrent trainer, it won't support, or the visual system will not support a LOFT scenario. Currently the standards—

MR. RAY: It will.

MR. SMITH: That's the difference in the visual requirement on a Level B and Level C, Level B is not required to have gates.

MR. RAY: It depends—pardon me for butting in. A Level B or Level A simulator is capable of supporting a LOFT scenario, at least certain LOFT scenarios. Does it support the Level C or Level D LOFT requirements in Appendix H? The answer obviously is no. But you can accomplish, as we have been accomplishing under Part 121 for years, LOFT scenarios with a single channel visual in a Level A simulator.

MR. SMITH: I may be wrong. I thought you had to have a gate. You don't?

MR. BOOTHE: Bob [Foster]?

MR. FOSTER: I would like to say that one of the things we should be careful doing here is to say anything we do say or recommend is a cost driver. Because what we are asking people to do is to step back and look at designing simulators in the future, not taking today's current simulator and downgrading it to a Level B. We have tried that for flight training devices and for those types of things and in general that's not an economical method of doing it. And it's going to be this combination of what comes out of—what came out of the data and the fidelity of the aero requirements with the visual requirements and the motion requirements that's going to set the basis for asking various manufacturers to design a new simulator whose top end is going to be Level B. It's not going to be a Level B that can be made into a Level D, or a chopped down Level D, so consequently it's going to enable them, the innovative manufacturers, to step back and look and say with a fresh look at this, what kind of a simulator can I design as Level B, and it's all it's ever going to be.

The other thing, and Hilton [Smith] brought it out a little bit, I think to be honest about this, we have to look and say it's not just going to be regional carriers that are going to use these. In today's world everybody stands back, the [Part] 121 carrier stands back and says, especially for a new airplane type, not necessarily a new airplane or introducing a new airplane in your fleet, you stand back now and you say, especially in light of AQP, you stand back and say what is the best training program? How can I best put a training program together, to bring my pilots up to speed and keep them trained?

Now you would have be able to look at this full range of saying "okay, maybe I will do my initial training in a Level D sim, if I'm going to have 60 or 70 of these airplanes I have now a certain initial requirement and I also have a recurring requirement." I will say "geez, maybe I'll buy a Level D and buy Level Bs to do recurrent training [and] checking." It's not just for the regional carriers, over the years it's going to grow and the major carriers will use them as well. I guess my biggest point is what we say here is going to set targets for a new type of simulator.

MR. LONGRIDGE: Yes.

MR. BOOTHE: It's an important point, thank you, Bob [Foster]. I think Geoff [Harris] was vying for time here just ahead of you.

MR. HARRIS: Two small points. Assume that the 300 milliseconds we might grandfather in existing simulators, no argument there. Something we haven't touched on so far which is important in our local community is sound cues. It's not anything we mentioned nor is it part of the comments, but it might be worth bearing in mind for future, particularly touchdown, where you get the bump of the motion, the cockpit rattles and later on you get a pop through sound system and the pilots say what the hell is that? So synchronized issue of sound as well as the other cues.

MR. BAKER: I think, first of all I think we don't want to beat this to death, and I really feel that the 300 millisecond number is historically—today is being driven by the visual system and not the motion platform. It's not that hard to get the motion platform delay down. I think I would suggest again that we might want to put some more words in here to advise the reader that 300 milliseconds may not be satisfactory. He is going to have a problem if he designed to 300 milliseconds in some applications. And give him a heads up. Because I have run across some extremely naive simulator builders in the last several months and I would hope that we would give them advice here that would be useful and pertinent to achieving a satisfactory result with a simulator.

This is not a spec, most of this is not a spec, most of it is an advisory that says if you do it this way, it's probably going to work. So I think we have an obligation to tell the guy maybe not everything we know, but enough of what we know that he can achieve a good result with a simulator. The CAE guys and the Thomson guys, I don't think we have to teach them how to do this. There are some folks out there that are somewhat more naive than the big guys are. And I think it's important that we try and give them advice in this advisory circular that says, you know, the present requirement is you can't do any worse than 300 milliseconds, but we think to achieve a good result you ought to look at numbers more like 100.

MR. BOOTHE: Thank you, Bruce [Baker]. We, I think, or let me say I don't think the FAA wants to give design advice, but simply lay out a performance standard and however one meets the performance standard is up to them. I think that's proper. But to set a reasonable performance standard that does the job and does it in context of the correct parameters I think is an important consideration.

Let me just ask, Paul [Ray] brought up Appendix H, I don't know if all here are familiar with Appendix H, which is the appendix to regulation 121 that describes the advanced simulation program. If you are not familiar with that, I think I have a copy upstairs and I can have it copied and available to you after lunch. And it may be worthwhile. I will do that if—I think I have one.

MR. LONGRIDGE: Is this the new one? The latest?

MR. BOOTHE: I have the one that's in the rule. Is there an amendment to that?

MR. LONGRIDGE: Yes.

MR. RAY: We finally have Levels A, B, C, D, nothing else did that.

MR. BOOTHE: The one I have still says Phase 1, 2, 3. Do you have a copy?

MR. LONGRIDGE: I have nearby, but not with me.

MR. HARRIS: I have one here.

MR. BOOTHE: Is there a significant enough thing, we can all say Phase 1, 2, 3 translates to [Level] B, C, D, it's either here or it's not. Let me check and see if I have it first. If you want to go to the office—

MR. LONGRIDGE: I don't think it's necessary.

MR. BOOTHE: I will grab that at lunchtime and we will copy it so you can see where the regulatory basis for advanced simulation is and then additionally to that there is an Advisory Circular 120-40B, which is still current.

MR. RAY: Unfortunately.

MR. BOOTHE: That would be a lot to copy for everybody, but I do have one here if there is a question about it. So I will get that for you at lunchtime.

I think what I'm hearing is that Geoff [Harris] and Norm [Bluteau] and others have said what's the big deal, we can meet 150 milliseconds at no additional cost. Is that a correct statement?

MR. BLUTEAU: Yes.

MR. HARRIS: Yes, I think so.

MR. BOOTHE: Ed [Martin]?

MR. MARTIN: I think we may be talking about different time delay definitions without being real explicit about it. I mentioned that in some of the studies we have done time delay is measured in the frequency domain. The point at which we started to see handling quality degradation, that is

150 milliseconds, included the aircraft equivalent delay. That could get you down to about a 50 millisecond budget for the simulator—which might be a cost driver. I'm not saying that we need to necessarily get down to that level for training devices or training simulators, but we probably ought to make sure everybody is clear on how delay is defined in a given context.

MR. BOOTHE: Very good point. Whether or not that's within—whether or not the airplane response is within that 150 millisecond or whether it's additional. Traditionally it has been additional to the airplane response. And when we have measured transport delay it has been just a pure time delay that one could practically take a worst case calculation and get the same answer.

But what I'm hearing that I would like to follow up some, is first of all, it's not a cost driver in terms of additional cost to get from the current spec of 300 milliseconds in addition to airplane response down to 150 milliseconds. But I hear Lloyd [Reid] and Frank [Cardullo] and some others saying we need to talk some more about frequency domain, and phase lags, and important parameters in that terminology and how we might apply that. And I'm interested in hearing more about that. Because if you here as the experts on the subject say that the FAA, just specifying this transport delay is really not a proper thing to be doing and it really doesn't tell you anything, and I can put in a lead network to take care of that and maybe ignore the real phase lag or the real frequency domain important parameters, but I think we need to hear that and hear how would we implement those kinds of performance specifications in a simulator requirement. Bob [Heffley]?

MR. HEFFLEY: I think that the frequency domain definition is really crucial to approaching all of this. There are things that fall out of a frequency domain that are easy to miss in the time domain. But in order to apply frequency domain you have to be thinking in terms of, well, what frequencies here are really relevant to be looking at? If you are going to apply some sort of a phase mismatch as a standard, that has to be set at some frequency.

Well, there is a relevant frequency and it depends on the task. Some tasks are inherently high bandwidth, some are inherently low bandwidth. And one thing that is missing, and I think needs to be kind of put on somebody's list to pin down in the future, is some array of training needs and flight tasks for regional transports. How do we get to these task bandwidths that we ought to be using in the standards? We are really starting to talk, I think, about three basic characteristics.

One is the basic simulator versus aircraft match, and that can be expressed as some match in terms of a phase mismatch at a particular task bandwidth. I'm using this term task bandwidth for, I don't know, for want of maybe a better term. But we have the basic match between aircraft and simulator. You like those to be pretty much one-to-one because then the simulator is behaving like the airplane.

Another important one here that Geoff [Harris] and I think others have just mentioned, is the motion-visual mismatch. Again that can be expressed very conveniently as a phase mismatch. But again that has to be specified at a particular frequency and that frequency again depends on the task, this so-called task bandwidth.

The third crucial element I think has been mentioned here, something maybe we can talk about in terms of some added transport delay, you know, what we are really talking about here in terms of transport delays is some amount of really undesirable, unwanted transport delay that we just have to live with. And the significance of this transport delay is that transport delay is a really nasty sort of response characteristic to be present in something that a pilot is trying to control. It takes five times the amount of first order lag to have the same effect as the same amount of transport delay. In other words, for 100 milliseconds of transport delay, you could basically tolerate a half a second first order lag and the pilot would have to contend with about the same amount of difficulty there. It's a very important and a very insidious thing, and transport delay you generally can't see. But it's got to be pulled in here because we have to live with that in the world of digital computers.

And finally, this matter of transport delay again is expressed in terms of some sort of a phase lag, and that phase lag does have to be tied to a frequency, and again it comes back to what the task is and what that relevant frequency is for a particular task. And there is going to be two or three crucial tasks and they are going to have the highest frequency. You have to pin down the task, you have got to relate that to a particular frequency regime and then these other things I think tend to fall out. We can't just really talk about these things without the context of a task.

MR. BOOTHE: I don't know who won the contest.

MR. BAKER: We need buttons, don't we?

MR. BOOTHE: We will get you both.

MR. BAKER: I have a short one, I think. Basically I agree with everything Bob [Heffley] has had to say about this. Let me add one I think important point to it. The thing you would really like to know to evaluate the effect of transport delay on the sim is what the pilot's phase margin is. I was hoping that Frank [Cardullo] or Lloyd [Reid] or somebody could illuminate that question a little bit. Because I'm not aware, but I'm not the guy that would be aware of measured data on pilots in high bandwidth requirements. You know, in terms of a low bandwidth requirement, it's reasonably—it's a reasonable supposition that the phase margin of the control loop is fairly large and therefore if we disturb it somewhat we are not going to make a fat lot of difference on a pilot's response, the response of his tracking task if he has 30 degrees of phase margin, which I think is not unusual in a high bandwidth task and we add another 30 degrees of phase lag to it one could assume you are in a lot of trouble.

MR. CARDULLO: Yes. It's all going to—

MR. HEFFLEY: What you are talking about is I guess what I was trying to get at with this idea of this task bandwidth or however you want to express it. That is the place where you have to have 30 degrees of phase margin.

MR. BAKER: PIO is the place where the phase margin goes to zero. I would like to know if any of these guys that are more research oriented than I am have numbers that say we have measured this thing, it's around 30 or 60 degrees for this task.

MR. BOOTHE: Ed [Martin] is burning over here.

MR. MARTIN: To make a comment, I agree with this idea of task bandwidth and the frequency at which you really want to measure this delay. Frequency domain measurements capture the effects of transport delay, so that's really rolled up into it. When we talk about aircraft dynamics being included in this 150 milliseconds, or whatever number we talk about, we are only talking about what looks like a pure time delay, the equivalent transport delay of those aircraft dynamics. We are not talking about the classical roll dynamics or pitch dynamics, rather it's the dynamics due to higher order effects that appear as a pure time delay when you are down in the zero to two hertz manual-control range. I just wanted to make that point.

MR. BOOTHE: Stu [Willmott]?

MR. WILLMOTT: The purpose of this test in the first place, why it was first put into the requirements, was that the pilot-induced oscillations were occurring because there were inherent delays in the architecture of the simulator. There were dead times between the pilot doing something and getting the required response out of it. And it was involved with visuals and to some extent motions. But the purpose of the test was to try and find out what the dead time in the simulation was due to the architecture of the simulation. When it first came out like that, there were a certain body of people that had simulators that could not meet those requirements, and I guess the test was then changed to make that additional dead time on top of the airplane response. In that way certain simulators could still be qualified.

Now the FAA allows us to do just a response and compare that with the airplane within the given latency time, or to go back to the original purpose, which is to see what the dead time was in the simulator. And, you know, I'm not sure what talking about all these phase things and putting frequencies of responses really into the system do us. But I remember working on a visual system and the proof of it meeting its particular requirements was by putting in a sine wave, and indeed they had lag compensations in that and they could show that the visual system matched the airplane beautifully. But in fact when we did a simple test input on it, it took 400 milliseconds for the thing to respond. And that was on a commercial simulator, and I found out later that our military group had the same visual system on an F-4 and it could roll 360 degrees before the visual responded.

And, you know, you could put lead lag networks in there up the kazoo and you will never solve the problem. You are really trying to find what the dead time is in the simulation. If you do anything more than that, I think you are getting into the airplane responses and things like that. I'm not really sure what it is you are going to do with a frequency input. What is it that you are going to compare it with? Do you have airplane results for different frequencies that you could compare the simulator to as far as the responses?

MR. MARTIN: The bulk of the research literature that talks about the effects of delays on the pilot in these closed loop situations is based on frequency domain data. It's probably easier to relate frequency domain measurements to the effect of delay on vehicle operator control than it is for time domain transient measurements.

MR. BOOTHE: Thank you. I'm going to take this side in order in just a second.

Are you suggesting that maybe transport delay is an improper measurement and we should look at—

MR. MARTIN: I'm not sure how you interpret the results of time-domain measurements in the context of the available literature.

MR. BOOTHE: Let me start with Frank [Cardullo] and work the way down the side.

MR. CARDULLO: I have a few comments here, one with regard to Stu's [Willmott] comment. Folks oriented themselves towards this pure delay initially because they didn't understand the system implications. I don't think that the complete man-machine system idea was ever thoroughly understood. And they knew that going from analog computers to digital computers was adding some pure delay to the system. So folks concentrated on that and it's really subsequent research that started looking at the total human-machine system and the frequency domain implications of phase lag. I'm an advocate of really measuring both from the standpoint of when you measure the pure delays, you find out what the digital system is adding, and that's an important parameter to measure.

But from a human-machine system standpoint in terms of performance it's phase lag that really determines whether the system is going to be stable or unstable. Ed [Martin] is correct when he says that if you do a frequency domain measurement everything is in there. But if you do both, and that's really what the Navy is advocating these days, you get a better idea, I believe, of where to apportion the differences. And that's why I advocate doing both.

And to add in Bob Foster's comment or a reference to his comment about cost drivers, the pure delay issue doesn't add much in terms of cost because most of that is coming from the digital computer and how fast you are executing the programs. But if you look at a motion system, from the standpoint of the frequency domain and phase lag, you can be talking about a significant cost driver.

Most of the motion systems I think that have been out in the field for some period of time now are, you know, one and a half to two hertz bandwidth motion systems, so at the pilot operating frequency they are going to be adding a substantial amount of phase lag. Newer motion systems that have bandwidth of four, five hertz, are obviously adding less. The cost driver there is really in the size of the motion system, because if you can get away with a smaller stroke motion system, then it's a lot easier to meet the requirement to have higher bandwidth. Because of the effects of actuator stiffness, basically, that enters into that.

So to just sort of summarize that, the transport delay issue is not a cost driver. The bandwidth, the frequency domain or phase lag issue, can be a cost driver when coupled with the size of the motion system. So if we want to try to reduce the cost, we ought to be looking at whether we can reduce the stroke of the motion system. Then that will reduce the cost. And by the way, I think we can.

MR. BOOTHE: Thank you, Frank [Cardullo]. Let's see.

MR. BAKER: I'm the last guy to put my hand up.

MR. BOOTHE: Did I miss somebody over here?

MR. SMITH: I have a question for Norm [Bluteau], it may be dumb, but you know we do three other tests on the sim and we check response of the hardware motion system, we check frequency lag and phase lag and we do this with sinusoidal input and three frequencies, I don't remember what they are, it seems like they are one, two up to eight hertz. When we do transport delay that's included. It's usually done at the high frequency end because it's a real fast step input. Do we not get that included in there at the most critical, what we consider the most critical condition of the high frequency?

MR. BLUTEAU: That's a point I wanted to make. The FAA's AC120-63 includes both transport delay requirement on top of high frequency response for phase lag tolerances, that Circular actually including both concerns of addressing phase lag on top of pure delays in the computing system.

MR. SMITH: We don't specify the tolerance, we say whatever the customer has defined as his design requirements. Right?

MR. FOSTER: Yes.

MR. RAY: That's [AC120-]40B, not [AC120-]63.

MR. SMITH: We are not covered? Maybe Frank [Cardullo] can—

MR. BOOTHE: Maybe we ought to copy the [AC120-]40B motion requirements when we copy Appendix H. I don't know that you are—most of the frequency response stuff that I have seen is, excuse me, Bob [Foster], but it's useless that I've gotten from operators when I was there because quite often it was at one frequency and it was not a frequency response. In fact there are only a very small number of manufacturers I have ever seen that really produced a frequency response of a motion system in the context of a Bode plot or something that one would be used to seeing. I don't think a couple of jolts at different frequencies does the job.

Anyway, let me see, was Sunjoo [Advani] next?

MR. ADVANI: I just wanted to add to a few comments. I do agree with Frank [Cardullo] totally. We should recognize [that the] motion system is after all an acceleration cuing device. But we also have to address the issue of the good cues versus the false cues, that's also where the time delay issue comes in. The only way to address that is to then split it up into time and frequency domain because again, like Frank [Cardullo] says, it's the phase which affects the man-machine interface. I think we all do agree on that. But how do we go further? I think there is some major holes that are open for research.

MR. BOOTHE: That seems to be the case. I think Bruce [Baker] is next.

MR. BAKER: I want to make one comment on something Frank [Cardullo] said a minute ago about cost of motion platforms. I have taken old Link cascaded systems and old Reflectone six axis systems and pushed them up above five hertz, and it's very cheap, you just have to know how to do it. I do it by subterfuge and smoke and mirrors as opposed to brute force. But there are ways, and I've got measured body response data on the two platforms from like a tenth hertz up to ten hertz. I can show you what I'm talking about. I made the measurements from essentially putting an input into the host computer motion drive equations at that point, which include the washout and the leg drive equations and measure with an accelerometer on the platform and you can fairly easily discern from the Bode plots that response to motion basis is quite good and you can see the effects of the oil spring and so on, which really is the limitation which does get better if you get down to a shorter actuator, but goes the other direction if you go to a smaller diameter.

MR. CARDULLO: Sure.

MR. BAKER: I don't believe it's necessary to go to a ten hertz position loop or five hertz position loop on a six axis motion platform to get very good performance. You can leave the bandwidth of the servos down even under a hertz and get incredibly good performance out of the motion platform. Essentially it's just a matter of doing some algebra on the equations and putting the poles and zeros where you want them.

MR. BOOTHE: Thank you. I'm going to get to you. I think Don [Irving] has a comment.

MR. IRVING: I like the smoke and mirrors comment. That seems to me to encapsulate what I was thinking. The improvement, I have noticed as a doer of these things and trying to fiddle the results past Mr. Boothe and his colleagues in order to be one of these people trying to understand what's going on. The improvement is due to the ingenuity of mankind as much as it is technique. Mr. Boothe was kind enough to say most of the response was rubbish. The regulations for the frequency was just the motion frequency response, it's not a system response.

One of the delays we used to have was in controls going to anywhere, maybe that delay is now gone, I don't know, Geoff [Harris] and Normand [Bluteau] might comment. Whatever we do has to be simple. I'm still deeply suspicious. The ingenuity of mankind is what confused me rather than technical facts whether we get 80 milliseconds or 100 milliseconds or 300 milliseconds, I don't think that's always a measure of the system, that's a measure of the ingenuity of mankind, whatever we do has to be simple when it goes in the regulations.

It may be as a result of a complex and clever research, but we have to try and capture a test or a measure or something which is simple and unambiguous, otherwise we are going to confuse the industry. I'm getting confused.

MR. BOOTHE: Very good point. I agree. I see we go from here to there and back. Bob [Heffley]?

MR. HEFFLEY: Okay. On this subject of frequency response, I guess in hearing some of the remarks it's important to maybe keep in mind that frequency response is a way to—is a way to get at system response in an overall way, that it pulls in a lot of individual little components, but you are trying to crunch things down to just a very few very relevant parameters.

And as kind of a historical note here, the use of looking at these kinds of things in the frequency domain was very painfully adopted in the past few years by the handling qualities community and has found its way into the basic handling qualities specifications for aircraft. In particular for helicopters, that's where the—where this way of looking at things has really been most successful. But in order to do it, there really are some kind of new tools that have to be used to get a frequency domain measurement. It is not a matter of putting in discrete frequencies, that's one way to do it, but it's a tough way to do it.

If we are to be measuring a system in terms of frequency response, typically what's done these days is to drive the system with some sort of a range of inputs, you can actually have a pilot sit in the cockpit and start to drive the system through a range of frequencies and actually it's as simple as starting with a very slow oscillation of the control and then more and more rapidly until you really kind of span the frequency range. Then you take that time response and run it through a Fourier transform computer program that winds up giving you a classical Bode plot, frequency response plot, amplitude and phase versus frequency. The end result is a fairly easy straightforward way of looking at how a system responds.

What falls out are these things that we are talking about like transport delay and basic aircraft response. They are all mixed up together. The one crucial element here in this I think that's fairly new, in order to handle this, is the ability to take the time domain responses that are generated and translate those into the frequency domain. But that's a matter of software and it's reasonably straightforward. But it's a different way of looking at it.

And as I said, the handling qualities community got to this very painfully because it required a lot of new ways of thinking and looking at things. But in the end it's a way that is really quite successful in handling a lot of different kinds of systems and a lot of different kinds of components and we have the issues of motion, visual, aircraft response, they all, you know, in the end they all get pulled together, the pilot doesn't see these individual components, the pilot is just some sort of a processing system that takes the overall. And so you don't need to break things down into components, especially in the end. That's what the frequency domain way of looking at it gives you.

MR. HARRIS: A small point first, we are talking about column stiffness, all column stiffness in motion systems depends on the length of the stroke, most critically depends on the mass of the payload of the platform that you are moving.

The second thing has to do with Bode plots of aircraft and motion systems. We can track demanded acceleration of the aircraft and the response acceleration of the platform, it's very straightforward, you can model acceleration with the model of the aircraft. What we can't do is the frequency sweep of the aircraft itself. To put a frequency sweep on the control column of the aircraft is very difficult and probably fairly unsafe, so we can't put half hertz, one hertz, two hertz in the control column and model the aircraft.

MR. BAKER: It's been done, by the way, on helicopters.

MR. HEFFLEY: Disagree.

MR. BAKER: On actual aircraft it's been done.

MR. STOCKING: It's been done in the commercial.

MR. BOOTHE: I'm sort of losing track here. There was somebody I missed over here, maybe you gave up.

MR. WILLMOTT: I'm looking back to the ground rules of the meeting which were—we were to identify motion cuing considered essential for specific recurring training and checking tasks. To my knowledge, there are a lot of Level B simulators out in the industry right now that are perfectly satisfactory that have used 300 milliseconds as the latency test. And one comment is if it ain't broke, why fix it? For the higher level of simulators we have already got 150 milliseconds, and now we are talking about, you know, doing other types of tests that aren't even being considered for Level C and D devices.

And the ultimate purpose, I think, of this get-together is to try and reduce the cost of the simulators, which right now are in the range of ten to 15 million dollars, down to even less than half that. And I'm not sure that the CAE and Thomson organizations are capable of going downhill from the [Level] C and D devices. There are a lot of other people out there currently trying to get involved with simulation. There is one organization that is currently producing a Beech 1900 simulator to Level B standards, and you know they believe they can do it for around 2.5 million dollars. And I think to consider, you know, tightening up the requirements for people that are trying to get into the business, if you like, using standards that have been accepted over the last ten, 15 years, is something that we don't really want to do right here and now. And I would like to recommend that we stick with the 300 milliseconds that is currently in the requirement.

MR. BOOTHE: Thank you, Stu [Willmott]. I think Sunjoo [Advani] had a comment.

MR. ADVANI: I simply disagree.

MR. MARTIN: I would like to make a statement that supports the idea of both the time and the frequency domain characterization. Tom [Longridge] had earlier said he is interested not only in defining the immediate cost reduction requirements, but also identifying research issues. Frequency domain measures do not capture transient response. You are going to get different delay values from the frequency domain measurements than you will with step input measurements. You may want both—and you may want different tolerances for both.

MR. BOOTHE: Bob [Heffley]?

MR. HEFFLEY: That's an important point that Ed [Martin] makes. At the same time, look, to me the reason for bringing up the frequency domain aspects here is that it's a way to look at that high frequency end of things. Where you have these issues of transport delay and the match in the phasing between motion and visual. Those are things that are of concern in the very, very short term. And certainly still have to have things correct in terms of the basic, let's say, response of the aircraft, short periods, load weights and all that good stuff. That's got to be in there.

One other short point is back to what Stu [Willmott] just said. I think it's terribly valid to say, you know, if it isn't broke, then why should we be trying to fix it? But look, if we are really trying to get down to the matter of reduced costs on some of these crucial components, particularly motion, you have got to know how to make the trade-offs, you have to have some ways of saying well, look, if I do back off on motion amplitude, how does that—how does that balance out with any of these other basic characteristics in the simulator? And that's what I think does force you to start thinking in terms of some of these different approaches to how you look at systems.

MR. BOOTHE: Okay. Let me get these two questions. Thanks, Bob [Heffley]. Then I think we have to discuss where we are going from here. I don't know which of you was first, but Sunjoo [Advani], then you and Frank [Cardullo].

MR. ADVANI: I would like to quote Paul Ray's comments last year at the Making It Real conference, where he said we should also consider the cost of not doing these things and the cost of not making these kinds of revisions. To address the bidirectional behavior of the pilot. I think we should keep that as also a primary guideline in this discussion.

MR. BOOTHE: Agree. Frank [Cardullo]?

MR. CARDULLO: Well, in response to Stu's [Willmott] comment, I go back to the first comment I made. If the simulators out there actually do have 300 milliseconds of delay, then we can cut the cost of the simulator by forgetting about the motion system and that's going to cut it substantially. We can just put a vibration system out there. I don't know that we know that they are perfectly okay. Just because they pass certification requirements doesn't mean they are okay.

MR. BOOTHE: It doesn't. Not to butt in, I'm sorry.

MR. CARDULLO: That's okay. You are the chair, you can do whatever you want. If you have a pertinent comment, go ahead.

MR. BOOTHE: I was just agreeing.

MR. CARDULLO: So, you know, putting Bob's [Heffley] most recent comment into the context of all this, if we are looking at this problem, we have to look at the whole problem and we know that 300 milliseconds is going to cause problems. It may be that there are no simulators out there with 300 milliseconds, but if someone all of a sudden wants to come along now and try to design something that's really cheap and gets in there, we might find that we do have problems. So I think we really have got to address this problem.

And one additional comment I would like to make. I have made reference a couple of times to what the Navy is doing. I really wish I'd brought some documentation on that, because they have really done quite a bit in terms of test methods, trying to define criteria, in terms of relative phase between motion and visual as well as just overall delays in both time domain and frequency domain, and one of the interesting things that they do in measuring transport delay in the time domain that purely gets at what the computer is adding is that they actually take the vehicle dynamics out of the loop when they make that measurement. They keep the integrations in, essentially they keep the equations of motion in there, of course, depending on what kind of integration algorithm you choose, you can really screw up the problem, right? So they leave the integration algorithms in but they take out the aircraft dynamics. So they really get just a pure delay. So I think it would be instructive, really, to look at what they have done, rather than try to repeat work that's already been done. I wish I'd brought that stuff, I didn't think of it.

MR. BOOTHE: Maybe we could get it at a later time.

MR. CARDULLO: I could certainly send you the stuff and you could distribute it to people when we review the proceedings, maybe it can be integrated.

MR. BOOTHE: Okay.

MR. BAKER: Let me make one quick comment. I looked at the stuff Frank [Cardullo] is talking about and I think it is a good piece of work. I think it bears looking at.

MR. BOOTHE: I would like to see it. Let's give Stu [Willmott] one chance to reply here and we need to—

MR. WILLMOTT: I was going to comment that of course when you have one of these tolerances in the requirements it doesn't mean people are going to design their systems so they back right up onto the maximum values, they are still trying to do better than that. I think many of the systems out there are considerably better than that. I think if those latencies give a problem from a piloting standpoint, that is one of the things that the FAA subjectively evaluates as part of their flying evaluation of a simulator at initial acceptance. And if it's found, if the simulator is found, to be unacceptable in doing the tasks, then they can raise the flag on that and something has to be done about it.

And I don't know if you want to continue talking about frequency response, I'm still not sure what you are going to do, but I have listed a number of variables involved with doing frequency response. Of course it depends on the axis that you want to do this in, you have six axes, of course you have the stroke that you want to use, and that gives variability on the response that you get. What attitude of the simulator that you are going to use for doing that, whether it's just zero pitch or whether you are going to have it up at some pitch attitude where perhaps you want the response to be better, like engine failure after takeoff, where you want the real quick response. The frequency and then other things like the oil temperature, and the filter standards, and all sorts of things like that. And as far as I know, what you are aiming to get out of this is some sort of a, I guess a phase, either a delay in time, or a delay turned into phase lag using the input frequency, versus the frequency.

So here is this picture and you have a whole family of these things and now you have got them, what are you going to do with them?

MR. BOOTHE: One more comment.

MR. HEFFLEY: That's why it has to be done in the context of a specific task. And that task dictates how you look at that frequency response because you are right, you can generate an awful lot of stuff that, you know, you don't want to bother with. But there are a few relevant things and it's going to depend on that, especially that critical task, that's the design elements.

MR. BOOTHE: I think you keep leading us in a direction, Bob [Heffley], that's probably proper. There are a couple of comments I would like to make. I don't know if we got the point across about frequency sweeps in airplanes, I think they have been done and they are possible, so I just want to clarify that point that even in large airplanes frequency sweeps can be done.

In terms of the 300 milliseconds being "if it ain't broke, don't fix it," I think perhaps it has been getting fixed through subjective or other types of evaluations. I think it's pretty much a rather ignored specification because it gets measured but because of subjective measurement and subjective tuning, if you will, of motion systems, I think it's—I'm not sure, but I think it's more or less meaningless in the qualification of a simulator these days.

Of course it's measured, but does that really mean anything? I think we are at a point here where, as I said in the beginning, we could either—the easiest or the hardest of the whole book and it turns out that it's not the easiest. So I think we could spend the rest of our today and tomorrow on it, and of course we can't do that.

Bob [Heffley] has made the suggestion several times as we discuss these things unrelated to a task we really are not zeroing in on the problem, I guess I could say. So maybe what I can suggest is that we agree that, or at least I think we have a majority consensus that 300 milliseconds is not satisfactory, I think Frank [Cardullo] put it in context if that's what we are going to do, maybe we could go drink beer for the next day and a half and not have to worry about the rest of it. So we have also, I think, had suggestions that 150 milliseconds, if we are going to measure transport delay and latency in the manner that we have measured in the past, 150 milliseconds is at no additional cost in today's technology. Is that a fair statement?

MR. HARRIS: Yes.

MR. WILLMOTT: It's the major manufacturers.

MR. BOOTHE: Well, today's technology, I think, applies to whomever. I don't think that's restricted to major manufacturers.

A third suggestion is that we should look at frequency domain and measure phase lags, that certainly sounds like a reasonable thing to me. However, as Don [Irving] has pointed out, we still have to keep it simple. And I think that's important to a performance specification and that's a very important point that Don [Irving] made, we do have to keep it simple. So we have got all those things to consider.

And so my suggestion would be let's at least in the interim of the two days accept 150 milliseconds as a starting point, assuming that we are going to continue to measure transport delay, let's keep frequency domain measurements on the table, we don't know how to, at this point to keep it simple or how it might be done, but I think we cannot discard that, and proceed through the table and as we proceed perhaps we can identify that critical task and at that point perhaps then we can say well, here is the one we really have to look at in terms of addressing a performance specification, if you will, for motion. And we might want to at the same time consider the motion and visual system relationship and a phase difference of those two systems.

But I think if we continue to talk about only motion transport delay, phase lag and frequency domain in sort of open loop, without having a task to close that loop, I think we are going to be here two days and still talking about it.

So is that an acceptable progression to move on with keeping those thoughts and try to address them at the appropriate time? And I should, I guess, ask, is 150 milliseconds acceptable to you from the FAA, that we could go on on that premise?

MR. RAY: I see no reason not to. What I would put on the table with your list of notes there, Ed [Boothe], is the potential of a number, the one I have in my mind is 50 milliseconds, but visual cannot lag motion. It's a synchronization issue of visual lagging motion and the number that comes to mind is 50. If, for example if you have motion that occurs and you have got a high fidelity system, high quality system and you are getting let's say 50 milliseconds on motion, you may end up imposing on yourself, and rightfully so, a 100 milliseconds tolerance on that delay if you have a number that links motion and visual together.

MR. BOOTHE: Well, I have a problem with that number but I can't defend it, either. I don't know—

MR. RAY: It just appears that 50 milliseconds is defendable from some of the studies I've seen, Ed [Boothe], and others I hear Ed [Martin] and Frank [Cardullo] talking about.

MR. BOOTHE: That falls into the same thing we have been hearing, maybe a number is not the correct approach.

MR. RAY: It may not be. But in the context if we are going to embed a relationship between motion and visual within 150.

MR. BOOTHE: We will start at the end.

MR. CARDULLO: I'm a little bit concerned about that from the following standpoint: Obviously we must be concerned about the relationship between motion and visual. But for [a] purely time domain characterization of it, I don't know if any number is really defendable. What we want to be concerned about is what really is the phase relationship. And you want to make sure that the whole system does not drive you into a point where your phase margin is too small and renders the whole system uncontrollable. And why I'm a little bit reluctant to put a time domain specification on this synchronization issue is that the motion information is what provides you generally a lead, and if you get the sense of motion, I'm not sure how much missynchronization is tolerable and I don't know how much you can really allow the visual to lag. It depends somewhat on how long you can sustain the motion cue. So we are in a really touchy area and I'd rather say nothing than say something that's wrong.

MR. RAY: I agree. If there is a better way of phrasing it—

MR. CARDULLO: I don't know what everybody else thinks about that, but I'm really kind of uncomfortable with that. Because we simply don't know.

MR. RAY: It's certainly an issue to lay on the table now.

MR. BAKER: The other thing I would like to suggest in that area is, as Frank [Cardullo] said, the motion provides you with very fast cue compared to the visual. And it would be a mistake to drive somebody into the position where they have delayed the motion cues so that the synchronization is better because you are going to have more problems with the phase margin of that fast control loop, which I believe is almost 100 percent from the motion cue and not from the visual at all. So I wouldn't want us to put anything in here that even suggests that it's a good thing to delay the motion so it more matches the visual delay, okay?

MR. RAY: That's exactly the reason I mentioned the 50. Because I know there are systems out there that are capable of less than 50 milliseconds and you are going to find people playing games. I appreciate your comments, because that was the reason I said—you don't want to see people taking a high quality system and playing with it just to accommodate the visual.

MR. BAKER: Or just to accommodate a spec and perhaps degrading the actual performance and flyability of the system just to meet a spec requirement.

MR. BOOTHE: Very good point.

MR. SMITH: I hate to bring this up, but I'm more concerned about the phase lag after the discussion this morning than I was before because there is some indication that we are not getting a true indication of the latency of the visual system because we are just measuring the line on it rather than waiting till the whole scene is computed. And the video system delay may be much greater than what we were getting. And so—

MR. RAY: It's true.

MR. CARDULLO: We don't understand a lot of the psychophysics that is involved here and most of the knowledge that we have from the literature has not been derived from simulator literature. The experiments involving the relationship between vestibular stimulation and visual stimulation that Young and Dichgans and those other folks did were not done in simulators, and that's the only place that I know about that that information exists. Another factor is that they were not task loaded, they were not doing something, it was just a purely psychophysical experiment. So we are really at a loss for supportable data.

MR. ADVANI: I would just like to add that we recognized there was a lack of data five years ago and that's why we put so much effort into designing a system which allows us to go into that kind of study. If we had begun with an existing system we are already infiltrated with those kind of phenomena of the time delays and phase lag and so on. So we put all the efforts into reducing the inherent lag of the system so we can simulate all the various types of situations and introduce lags, introduce discrepancies in visual and motion. So I think there exists an opportunity here to do research.

MR. BOOTHE: Geoff [Harris]?

MR. HARRIS: Going on at the moment there is a European research directive, it's under a Euclid title, it covers all aspects of simulation, visual, motion, the various aspects, the phase and the timing. It is still in draft, due out in three, four months' time. If it is available, then I will bring it to the session and we can distribute it. It does cover all aspects. There is about 300 papers referenced at the end, including the psychological aspects.

MR. CARDULLO: Psychophysics. Who did this work? The group?

MR. HARRIS: Dassault Aviation and IMASSA-CERMA in France. Roke Manor Research and Thomson in the UK, NLR Netherlands. With references outside to U.S. papers, European papers.

MR. CARDULLO: So is it a literature review or experiments?

MR. HARRIS: It's a literature review. They were not experiments as such.

MR. SUSSMAN: Is this to form the basis of a CEN standard? What's the purpose of the review?

MR. HARRIS: I don't know at the moment.

MR. HEFFLEY: I guess I just wanted to mention also along the same lines there is some ongoing work right now that's really relevant to what we are trying to talk about today. At NASA-Ames, I guess NASA is the one that's doing it, but basically looking at what are the motion cuing requirements for simulators. Right now it's really centered on perceptual as opposed to training. They are not really looking at training right now. But they are looking at what is required to successfully fly certain flight tasks. Jeff Schroeder is the main contact there, but this is being done on the VMS, so there basically is, at least in comparison to the typical airline training simulator with VMS there is pretty much unlimited motion, so you are kind of working back into smaller amplitudes. But all of this really hinges on getting down to specific flight tasks, that's the only way, really, you can start to get a handle on these things.

And number two, the frequency domain approach is very heavy because of that being the most successful tool for how to look at and how to define the sorts of things we are talking about.

MR. BOOTHE: Paul [Ray]?

MR. RAY: If I could add to that. We have had one of the members of our staff participate in the effort at NASA-Ames. And if memory serves me correctly, he indicated that they use the entire envelope of that system and then work downward to specific degrees of motion that are available.

MR. HEFFLEY: They start out one-to-one; yes.

MR. RAY: He has the results in his desk from his effort and he said it was so clear, the need for motion to do a task, the removal of motion and the task became basically non-doable.

MR. BAKER: Somebody should tell the Air Force.

MR. RAY: Regardless of what was done. Contrary to some of the blue suit reports out there.

MR. BAKER: Exactly.

MR. RAY: So we have had someone working on it.

MR. HEFFLEY: I have a copy of one of the papers I think that is currently out there on the—I think it's mainly looking at yaw axis isolated, and if you want to make a copy of that for anybody—

MR. BLUTEAU: One last comment on the frequency domain approach. There may be value in that method, I'm not sure whether we are all ready to agree with that today, because of time constraints we may decide to postpone the final decision. It is interesting.

I think the delay is in two parts, the delay due to transport delay and the delay due to motion response. The way many people have approached this problem in the past is to check those two elements separately, the transport delay first, the motion frequency response and the phase lag checks second, and separately makes it easier for the manufacturers to identify the source of the problem, to pinpoint whether it's a computer architecture problem or whether a motion servo controller phase problem.

So we addressed the problems separately. But in effect I guess we achieved the same result, we ensured the phase information is proper, that the overall system as seen as a complete system actually has a proper phase shift.

So this new method may sound new but it may actually be already in the circular, at least in AC120-63, where I think phase tolerances are specified, I believe. So this may seem like a new one, but it may in fact already be used.

MR. BOOTHE: Have we experience yet using the helicopter advisory circular and those motion requirements that we established there several years ago?

MR. SMITH: We have looked at a couple, I don't know if we evaluated one since it's been published but we did a couple under XX and I don't remember the motion test results.

MR. BOOTHE: Draft XX did not contain motion requirements. Well, it's getting close to lunchtime, actually it might be best to break a little early for lunch rather than trying to start this task-by-task thing, and then come back a little early because I do think we need to progress on to the task-by-task discussion, and keeping in mind that we have tentatively accepted that we will look at 150 milliseconds if we are going to retrain a transport delay.

We will entertain frequency domain measurements, but as Don [Irving] said, we have to keep them simple. So as we go through I think it would be proper at each task we address to ask the question, is this critical? And we may not know that until we get to the end because you might look ahead and see what's in there and perhaps can make some decisions about where you think it's going to be critical as we go. It's not a very long list. I think that's my recommended approach. If you have a different idea of how we should proceed, I would like to hear it.

MR. BLUTEAU: I think it's a good idea to keep in perspective the cost of the simulator. I think we should possibly identify what are the parameters that are cost drivers in a motion system. And when we look at the elements on the table, determine whether—how critical those maneuvers are and what effect do they have on those motion features that are costly, to possibly be able to reduce those motion features that cost a lot of money.

We have talked about, obviously, frequency response as being a cost driver and we covered that one. But there may be other cost drivers, the length of the actuator would be one of them. Maybe length of the actuator. How long an actuator we need. There are other cost drivers in motion systems, smoothness is one of them, turn around bump, maybe we should have a list of cost drivers and really ensure that we actually need those features.

When we get to the end of the session we will find out some of the cost driver issues can be simplified while meeting the essence of those requirements so they do address the costs and we know how those issues actually correspond to the training value.

MR. CARDULLO: I was going to suggest something along those lines. I agree that that's a good idea. But along with that, identifying what we think are the most critical parameters of motion cuing. What are the critical parameters in a motion system design, those parameters that are critical to motion cuing. You mentioned smoothness, it turns out it's not only costly but it's also critical. But there are some other things maybe that aren't so critical, like how critical is static accuracy which we often impose as a requirement. I suggest we look at what are the critical motion system design parameters and then also determine whether they are costly. Therefore, I would just add a dimension to what you are suggesting.

MR. BAKER: I would also like to hear from you guys that make simulators, what are the big cost drivers in the total simulator? So we can put the motion based costs in perspective. Because I'm going to get the feeling before we are done with this session tomorrow that we are going to figure out a way to get the motion based costs down to a relatively small number compared to some things like EFIS instruments and visual displays. Because I know what those things cost, they are quite dear. So I think you guys can probably give us a pretty good indication of what's driving the cost of simulators right now so we can put the problem in perspective. In other words, I don't think we ought to worry about taking one thousand dollars out of the motion platform, we are not going to get the simulator down ten million dollars by doing that.

MR. CARDULLO: I quote the results of a Rand study done a few years ago for the Air Force where they calculated the 25 year life cycle cost of adding motion systems to the C-17 simulators, and it added four percent to the total life cycle cost, which included building cost, heating and air conditioning costs because of a larger building and all of that. For cost purposes they were looking at a synergistic six degree of freedom motion system. So four percent of life cycle cost is probably a small number, it seems to me though, I guess four percent of a big number is a big number.

MR. BOOTHE: That's true that they did come up with four percent.

MR. BLUTEAU: I'm not sure how long ago the research was done, do you remember the year it was done?

MR. CARDULLO: It's probably getting close to ten years now. Whenever the Air Force was contemplating the C-17 simulator, maybe Ed [Martin] recalls when the Air Force was seriously considering the configuration of the C-17 simulator. So it's probably ten years.

MR. BLUTEAU: Why I'm asking is because technology has changed a lot since then. And when we look at smaller devices, like commuter aircraft simulators, and because we are looking at really providing the industry with something very cheap, then maybe those figures do not apply as well as we would think.

MR. BOOTHE: You are saying it could be even less life cycle cost?

MR. CARDULLO: More. I think he is implying more.

MR. BLUTEAU: More, yes.

MR. MARTIN: For example, you may have a rudimentary simulator having a TV set in front of some sort of cockpit.

MR. BOOTHE: In that case, yes.

MR. CARDULLO: You are talking about a wide field of view visual display with relatively high resolution. That certainly drives the cost very rapidly. If you are talking about narrow field of view visual, a TV monitor, it could be less impact.

MR. BOOTHE: Any other—

MR. HARRIS: Just is there a clear definition of what the simulator will be used for?

MR. BOOTHE: We are going to talk about that after lunch. That's what these tasks are all about.

MR. HARRIS: I was thinking will it always be a commuter? Will it have windshear? Will it only be used for landing and takeoff?

MR. BOOTHE: Well, yes. We said earlier that the simulator we are addressing is primarily or our considerations are addressed primarily to recurrent pilot certification. Which includes all of the pilot certification maneuvers and procedures. Windshear I have put here with a question mark because I don't know whether or not we need to consider windshear. Paul [Ray] is saying yes. But right now I think the rule permits operators of turbo propeller airplanes to do windshear training in the classroom environment and not have to do it in a simulator. But we cannot assume that our conclusions will apply only to turbo propeller airplanes because there should be one standard and one level of safety and if somebody wants to make a Level B 777 simulator, they are certainly permitted to do so, and in that case windshear would of course be a requirement.

MR. HARRIS: Okay. Windshear certainly effects the geometry of the motion system.

MR. BOOTHE: I know. That's why I had the question mark. That's a question I think we need to ask, does every simulator have to do windshear or does the operator simply have to find a simulator in which to do their windshear training? I think the latter is true, but in our consideration of a Level B and the thoughts of trying to lower cost, do we want to include that? Because that could be a significant driver as to what kind of motion geometry.

MR. LONGRIDGE: You should probably address both. The turbo prop operators do not have to address windshear in a simulator. Clearly the focus of this meeting is on commuters, nearly all of whom at present fly turbo prop aircraft although that is changing. But you might want to consider having two versions of the table, you know, one for turbo prop, which is our majority concern here, and the other for those that are operating regional jets.

MR. HARRIS: Do the aircraft incidents that we are concerned about—aircraft safety, is it more predominant in windshear situations?

MR. BOOTHE: I don't think I understood the question.

MR. HARRIS: If a turbo prop or any other aircraft is flying through windshear, is that where incidents occur? Is it more windshear or more aircraft that causes the fault?

MR. LONGRIDGE: I'm not sure I even want to address that question. It's from a regulatory perspective, for those operators operating turbo prop aircraft, we don't have to provide a simulator capability for training windshear.

MR. HEFFLEY: Why is that? Why that distinction?

MR. LONGRIDGE: Well, there again I didn't make the rule but I think the thinking—

MR. CARDULLO: Because it's tough.

MR. LONGRIDGE: You don't have a spool up problem, you have got positive thrust, quick response. You can fly out of it. It's not an issue.

MR. SMITH: You have power to lift that, you don't have—

MR. RAY: There was an assumption made, does that tell you anything?

MR. BOOTHE: Bob [Foster] had one comment there, did you still have a comment?

MR. FOSTER: Just about windshear, turbo prop people are not required to have windshear detection and avoidance equipment in the airplanes either, whereas all turbo jets have to have it.

MR. BOOTHE: I ten minutes ago said we were going to break for lunch. Now we are late.

MR. WILLMOTT: I just wondered if there was one general consideration we will give to motion when we are going into each of the items. That is, it seems to me there are three purposes of motion, one is something like an engine failure where a motion happens and a pilot must respond to it.

The second thing is where he does something and expects a response from it, and the third thing is whether there are things in the motion system that are nice to have for realism, like flap buffet, and I wonder whether we ought to address these items when we are going into each of the items here.

MR. BOOTHE: I think we do indirectly through those, what did I call them, motion objectives that I have written I think do address those issues but if you find they don't then by all means bring them up and we will do that. So let's plan to—if I can find the agenda, I think we have an hour for lunch, we will reconvene at 1:00. I will try to have a copy of Appendix H and some other stuff.

(Lunch break taken.)

MR. BOOTHE: I think we can get started again. Back to the administrative duties, first. Did you remember to bring your ticket receipts so we can copy them?

MR. BAKER: I did, but I still didn't go get it even though I remembered. Can I get it right now?

MR. BOOTHE: Or at break. We would like to get them today. Those who have them can give them to me.

Some of these are not just receipts but they are tickets, so we do have to be careful about getting them back. If you don't have it now, just get them during a break. If you do have them now, if you would pass them to me then I will in turn get them to Don [Eldredge] and we can copy them.

There have been a couple of reconsiderations during the lunch period and people have ideas of things that we might do to improve our understanding. And what I would like to do is, Sunjoo Advani had a brief presentation that he wanted to make. And following that there has been—there was some discussion before lunch and then during lunch in terms of before we proceed to identify some critical design parameters and major cost drivers and Frank [Cardullo] will speak to that in a few minutes. I think we might want to stop and do that so we can keep those as considerations as we proceed through the table. So let me ask Sunjoo [Advani] to do his presentation and we will proceed after that.

MR. ADVANI: Thanks, Ed [Boothe]. I will keep this quick. I didn't know how this workshop would go, but I just made some view graphs to express our concerns and our viewpoints on the issue of motion, our viewpoints being SIMONA, just very quickly what SIMONA is all about. You should have a copy of a recent Flight International article in front of you.

The goal of this program is to develop simulation technology and look at the standard with the new technology in a research environment. The focus being on the physical cues of motion, and visual as well as audio. With the utility of the high performance modular research simulator as well as a Citation II laboratory aircraft. It's a multi-disciplinary project in which we work together with a lot of industries as well. In fact through this type of collaboration we are also a sort of simulator developer on our own. So we are quite aware of the reality issues and with constraints of university budgets we have to think of low cost approaches to things without compromising the quality. And as I said earlier, our goal is to develop a system which exceeds performance levels so that we can address all of the performance issues. This is a view of the device synergistic motion system. One interesting thing is we have looked at not just purchasing an off-the-shelf system, but looked at issues such as the optimization of the motion envelope by changing the geometry of the system.

There is in fact a lot to be gained by changing, say, the gimbal spacing, change the arranging of the motion system to give the cuing in a particular degree of freedom more emphasis.

One of the interesting conclusions about our research is that in order to improve the motion system performance, you have to put a lot of effort in reducing the inertia of the visual display system because that contributes to the coupling dynamics, contributes to the lag of the motion system response. So the flight deck and the visual are built from advanced composites to keep their contribution to the inertia as low as possible.

Now about this meeting, I just wanted to reiterate a few points. We should be looking at the criteria from the point of view of the specific forces and angular accelerations. There may be some discrepancy here about angular accelerations or rates at the pilot head position, the detection of false cues, so the detectable false cues should be thrown out as much as possible. And the fact that you should not be considering the positions, in fact it's not the roll position or pitch attitude but in fact the forces which drive those and drive what we are going to talk about now, the envelopes of the motion system. And we should have a very clear understanding of the time delays and phase lags.

And by the way, I know that we have discussed a lot of these issues, I made these slides on my way over here, so please excuse me if some of this is repetitive, but I will go through it quickly.

If you look at an aircraft motion in roll you see the simulator reaches its maximum very quickly in position. In velocity as well. But acceleration can very closely follow it. And we should be then looking at something between velocity and acceleration. Just a point to keep in mind for the coming instructions review about the Level B motion requirements is that you cannot address this alone. If we want to simulate the pilot-vehicle interaction we have to look at the interaction and not say it should be based on just the standard, the way we have been going about it, that's our feeling. The value of training and the transferability is something else and we should address all the issues simultaneously in that respect. And the costs of training devices, as we have heard now, is driven not only by the motion system, but by many other factors. And we also discussed the fact that if we were addressing the commuter market it may require the highest motion quality, in fact inversion motion qualities for the size or the cost of the aircraft, which means we are—we have to do some very interesting work in the future.

Now, I just wanted to reiterate some of the issues about the time delay to make it clear that we have two things, the pure time delay and the phase lag. Pure time delay being something for example from digital computation independent of the frequency and the phase lag being dependent on the system dynamics. And the total sum of these at a given frequency is what we should be considering. I just made a rough sketch of these two factors, the pure time delay being a simple phase shift while the phase lag of course is dependent on the function. Now, we have talked something about the delays and effects on pilot performance, I won't go over that again, but just to reiterate some things, motion system delays can be caused by the motion controller hardware, the controller software, including all of the transfer functions in the software, we also have to consider the effects of the washout filters because that's not an independent article in the total system delay. It's part of that system. The servo valve also has a transfer function which should not be forgotten.

One thing we have done in our approach is to use a new type of feedback that is velocity feedback and closes the outside loop with pressure in the actuator control. And we are finding that the robustness of the actuator, the robustness of the motion system in various attitudes can also significantly affect the performance. If you double the load or change the position of the platform, you can have a totally different response. So we should be very careful in how we define these requirements. The platform itself also has a transfer function dependent on its own inertia. That has been one of our major efforts. Some of the sources of the delays can be, and this is for time and frequency domain, the sampling, if you miss the sampling period you can have up to one over that frequency in delay. You have the computation in the model itself, the integration scheme which is applied as in Tustin and as in Adams-Bashfort. These can also have an impact on delay and prediction of the algorithms and the testing methods for those. The D[igital] to A[nalog] conversion and the cuing device of course follow.

So I think we have all come to one conclusion so far, and that is we need to do research. So we need to understand variations in these parameters with the pilot, with the pilot in the loop, evaluations because we are talking about a man-machine system here. And it's a matter of understanding the synchronization of a multiple cue environment. And this is in fact what we have set ourselves up for to do in the future. This type of research. Are there any questions?

MR. ELDREDGE: Do you need a break?

THE REPORTER: No.

MR. BOOTHE: Thank you, Sunjoo [Advani].

MR. WILLMOTT: I had one question on that, Sunjoo [Advani], you said the criteria you are looking at is acceleration and not velocity or position. When you are considering longitudinal acceleration, for example, the position of pitch attitude is one of the keys to the acceleration, is that included in your acceleration?

MR. ADVANI: Yes. Well, it's simply the total sum of the forces and the rates or accelerations which you are driving your system with. Of course you have to accept some false cues but we should try to keep those within the threshold of perception. Those are what we feel are the important criteria.

MR. BOOTHE: Thank you. We have added to the weight of your briefcase for the trip home by giving you a copy of Appendix H. Tom [Longridge] has pointed out it is not the most current copy, so if you can mentally change Phase 1, Phase 2 and Phase 3 to Level B, Level C and Level D, I think that's the major change. But I think it's important for you to see where Level B simulator requirements are now recorded in the regulatory sense and those are here under Phase 1.

I have also given you a couple of pages from the Advisory Circular [A120-40B] Appendix 2 and on the page that is numbered 14 you can see the current motion system specification, or the lack thereof. And on the page numbered 16 are the 150 to 300 millisecond requirements, and interestingly enough sound is on that page. And either Normand [Bluteau] or Geoff [Harris] said that this morning, that we should consider sound because it certainly ought to be properly synchronized, I guess is a good enough word, with the other sensory input. So I just thought that was interesting that came out on that page. So those are for your reference as we proceed.

Rather than going directly to the table, I've had, as I said earlier, a suggestion that as we do that table we ought to know what the critical parameters are and what the cost drivers are. I think Frank [Cardullo] can explain that much better than I. And more importantly, or not more importantly, but also he has said that he would be happy to record these parameters on that easel there as we identify them so that we can keep them in consideration.

So Frank [Cardullo], could I ask you to explain that particular task?

MR. CARDULLO: Okay. Norm [Bluteau] started the idea with saying we ought to identify the cost drivers. And in connection with that, I think it's really—first identifying the critical design characteristics of a motion system and then specifying which ones of those are in fact cost drivers. So it's sort of a two-step process to get at what Norm [Bluteau] was suggesting.

And so what I thought we could do is if everybody just hollers out what they think the critical design parameters are, we can list them all without comment and then get a consensus from the group as to which are indeed the critical ones and then get a consensus which are the cost drivers. So we should be able to do that relatively quickly.

Do we want to do that?

MR. BOOTHE: Yes.

MR. ELDREDGE: If it's done neatly I will take the pages back and get them put in tables and submit them.

MR. CARDULLO: That's another constraint you are placing on me.

MR. BOOTHE: I'm not the one writing this.

MR. CARDULLO: Do we take off points for neatness?

MR. ELDREDGE: Of course not.

MR. BOOTHE: While we are doing that I might remind you the current Level B simply says a three degree motion system—three degrees of freedom motion system as you find in Appendix H. It does not say which degrees of freedom. Traditionally those have not been the correct ones in my opinion. But traditionally they have been heave, pitch, roll. I think there is more critical ones but whether or not you can have the others without having those, but that's really our starting point.

MR. CARDULLO: So I guess degrees of freedom is one design parameter.

MR. BOOTHE: Right. I got my piece in, now it's up to you.

MR. CARDULLO: Smoothness was one that we mentioned, right?

MR. MARTIN: Probably bandwidth with emphasis on the phase lag.

MR. CARDULLO: Phase bandwidth.

MR. WILLMOTT: What does that actually mean? Is that the servo or the electronic drive—

MR. MARTIN: System. I would tend to exclude washout from that. Normally you treat the washout independent of the hardware system.

MR. CARDULLO: We are talking about hardware first. And we might want to mention cuing algorithms separately.

MR. BAKER: Time out. The problem with leaving the washout out of this discussion is that the washout, part of the washout can be put into the servos of the motion platform and it works perfectly well, okay? And I don't know how to handle this exactly, but—

MR. MARTIN: That's the way it used to be.

MR. BAKER: Try and separate those two, then you are going to drive the thing to a point do you need a five or six or seven hertz servo on the motion platform, which I don't believe that's true. If the motion servo response is sufficiently linear, that is, it's the same response over large variations in amplitude, and it could be represented by an analytic function, then I submit to you I can compensate that in software and make it a five hertz or seven hertz system even though the servo itself is only a couple of hertz in bandwidth. Maybe even a half a hertz in bandwidth.

MR. CARDULLO: I don't think so, Bruce [Baker], for the purposes of what we are doing here, all we want to do is decide what the critical design parameters are. If you are talking about bandwidth being a critical design parameter, I don't know that we have got to get into where or how the motion cuing algorithm is split between hardware and software, right?

MR. BAKER: I don't want to say a five hertz motion is inherently better than a one hertz motion platform. Right now—admittedly, I haven't talked to all you guys in great detail on that. Right now I don't happen to believe that.

MR. CARDULLO: We can treat it as a total system.

MR. MARTIN: He makes a good point, that's the way we used to do it.

MR. CARDULLO: We used to do it that way. We found out that wasn't the best. Sunjoo [Advani]?

MR. ADVANI: Cross-talk is something. Cross-talk.

MR. REID: Do you bump—

MR. CARDULLO: Smoothness includes all that kind of stuff.

MR. WILLMOTT: Stroke length.

MR. CARDULLO: Excursion? Why don't we classify it as excursion and it will be included in each degree of freedom. It certainly ends up being ultimately stroke length—

MR. STOCKING: Payload weight.

MR. ADVANI: That relates to the maximum acceleration.

MR. BLUTEAU: Acceleration is the real factor.

MR. CARDULLO: Acceleration, then?

MR. ADVANI: Yes. You are going to—you can use brute force to overcome the payload weight but in fact what you are looking for is acceleration.

MR. CARDULLO: We have velocity, we have excursion—

MR. MARTIN: Cue duration.

MR. ELDREDGE: Is that the same as washout time?

MR. MARTIN: No.

MR. CARDULLO: How about, one thing that's often specified is accuracy, position accuracy. Personally I don't think it's very important but it's often specified.

MR. BAKER: It's often specified very tightly, too, as a matter of fact. It's something you can measure and the guy says it's ten percent, it's good, one percent is obviously better, and ten percent is better even, though I can't perceive ten percent.

MR. CARDULLO: That's exactly my problem. The [MIL-STD-]1558 spec specified a relatively tight excursion accuracy.

MR. FOSTER: How about platform size? Physical size.

MR. REID: Position accuracy doesn't matter much anymore, probably, but hysteresis.

MR. ADVANI: I think we shouldn't forget the criteria for motion system design that are specified in AGARD report AR-144 because they do cover a lot, the response to half hertz, whatever.

MR. CARDULLO: So you want me to put time to half amplitude?

MR. ADVANI: I'm not saying just one of the parameters but there are a number of parameters specified.

MR. CARDULLO: We have many of them here already.

MR. REID: Signal to noise was one of them, also time to 69 percent on a step response.

MR. ADVANI: Right. That's important.

MR. CARDULLO: But when we talk about bandwidth, those end up being included.

MR. REID: They are all intermixed.

MR. CARDULLO: You want me to put some of those?

MR. REID: Not me. I was just stating what they were.

MR. CARDULLO: I think they are included more or less in this category. You fix one of them, you basically fix them all. Any other suggestions?

MR. HARRIS: Do you want to consider external standards, AGARD[-AR-]144, MIL-STD-1558, the more recent 2714 that came through? Is that a requirement for our—

MR. CARDULLO: No, it's not, all we are trying to do is get specific parameters. So if there is some parameter in any one of those specs that you don't think we have on the list already, we want to add it.

MR. REID: Is stiffness a parameter like the actuator structural stiffness, the design of your actuator, it costs you more to make a stiffer actuator.

MR. CARDULLO: But it's not usually a specified design parameter. Of course it greatly affects the bandwidth.

MR. ADVANI: Stiffness is also dependent on the way you feed back your—

MR. REID: I was thinking of actual mechanical stiffness, you take your long rod and it affects how big your actuators are physically in diameter.

MR. CARDULLO: Right.

MR. REID: I can make a little spindly one that is flexible.

MR. BOOTHE: You don't mean stiffness from a frequency perspective.

MR. REID: No, structural.

MR. CARDULLO: We are talking about structural stiffness.

MR. BLUTEAU: We go for performance, we want to go for something that is going to meet certain requirements. I think bandwidth covers in terms of stiffness, in terms of structural design.

MR. CARDULLO: I just want to put a list up and then we will go through and reduce it to the most critical ones.

MR. HEFFLEY: Going just a little bit beyond the platform size, it's really the total real estate or physical size of the enclosure that costs money. I mean, size of the room or however you want to look at that, you are forced into by not only platform size but the excursion of the motion base plus cab.

MR. CARDULLO: This gets at that, right?

MR. HEFFLEY: Okay. Yes, I guess, yes.

MR. CARDULLO: Yes?

MR. SUSSMAN: There are also the environmental requirements, cooling, heating, air flow, all of the things that you buy into when you buy a system.

MR. CARDULLO: Might as well go over to another page.

MR. BOOTHE: I was hoping for a one-pager.

MR. CARDULLO: I should have written smaller, I didn't plan ahead.

MR. REID: What about safety factor? When you build a system you put in a safety factor, one, three, four, the bigger it gets the more expensive it gets, I assume. Should we talk about it?

MR. CARDULLO: It's a parameter in the military specifications, it's always subject to interpretation, do you test it one leg run-away, two leg run-away?

MR. ADVANI: One of the safety factors in SIMONA was the maximum acceleration in the buffers.

MR. CARDULLO: That's usually where you generate the highest forces going into the buffers at maximum velocity.

MR. HARRIS: The worst I have ever seen is running full velocity and shutting off the servo.

MR. BLUTEAU: The cushion or the buffers can be designed to be very smooth so servo reversal is typically the worst case.

MR. HARRIS: Also add to your list possibly the floor load of the building.

MR. LONGRIDGE: That's part of environmental.

MR. CARDULLO: It could be considered part of environmental. I think it's significant enough that maybe we want to identify it because this ends up being affected by both the payload and the acceleration and excursion, all of them because it moves the mass around, et cetera.

So any other ones?

MS. BÜRKI-COHEN: Maintenance and life cycle.

MR. CARDULLO: Pardon me?

MS. BÜRKI-COHEN: Life cycle cost, maintenance, is that part of it?

MR. CARDULLO: Well, life cycle cost isn't a design parameter, although I guess maintainability is a design parameter. Right?

MR. FOSTER: I would say it is because if you design, for instance, a type that uses three different types of actuators, just for lack of a better example, that is a much different case when you go to provide spares. If you have to spare three actuators rather than one common actuator, for instance if you use different servo valves on different actuators, those all become real issues and can come close to doubling the price of a motion simulator.

MR. CARDULLO: Would that come under life cycle cost?

MR. FOSTER: I think so. I'm trying to support her.

MR. ELDREDGE: Do you want to include computation and conversion?

MR. CARDULLO: What's conversion?

MR. ELDREDGE: Analog to Digital conversion. Or D to A in this case.

MR. CARDULLO: Okay, I guess we can just say computation includes that, that's pretty straightforward nowadays. Anything else?

MR. BOOTHE: How about the size of the building as the thing grows? The simulator bay may have to grow, too. Is that included in environment?

MR. CARDULLO: I think that's included in excursion.

MR. RAY: Environmental, I think you picked it up.

MR. CARDULLO: Well, environment is affected by that because you need more air conditioning and that sort of thing. And that ultimately affects life cycle cost.

MR. SUSSMAN: That environment would also include power supplies?

MR. CARDULLO: Yes. The amount of power that you use to drive the compressors. Sunjoo [Advani]?

MR. ADVANI: Just a very quick one. One interesting thing that we have found, one factor which determines much of the cost and the performance is the distance between the upper gimbal plate and the design height reference point. It's a strange parameter it may seem, but it's the most important parameter in the simulator.

MR. CARDULLO: That affects moment of inertia? I mean, moment of inertia then affects everything else but that difference between the centroid and the center of gravity affects the moment of inertia which affects acceleration and floor loading and everything else. So what if we just put up mass properties?

MR. ADVANI: Sure.

MR. CARDULLO: Which is CG location. Moments of inertia and payload?

MR. ADVANI: Fine.

MR. REID: What we are talking about mostly is hydraulically actuated systems, I guess, in the back of our minds, people are coming up with electrically driven hexapod systems. Why don't you put down motor source or power source, in other words you may have a choice, if it's a smaller system you may have a choice between hydraulic or electric. I don't know what else, pneumatic, who knows what you could come up with. But certainly electric. I mean, you can buy them now, right?

MR. ADVANI: Sure.

MR. CARDULLO: You might even buy one from Bruce [Baker]. He's got one outside just waiting to bring it in.

MR. BAKER: Actually, just a side note, we built a six axis electric motion seat for a training system, we built two of them, it's eight inches high and it sits in a 14-inch diameter circle and it will carry 300 pounds. We are not sure it works yet, we haven't had a chance to integrate it because their sim isn't ready, but they have some Apache simulators that have to be transportable, deployable. And the SMEs wanted to have some motion, and we said well, we can move the seat, that's about all we can do. I don't know if we are going to get good motion cues because of the relatively small amplitude of the stroke. It's a two and a quarter, two and a half inch stroke on the base. We will find out where the low end of things are one of these days. That will be sometime August, September of this year we will integrate those.

MR. REID: Will it take a Level B cab?

MR. BAKER: Not quite.

MR. BOOTHE: Delay, is that what you wrote?

MR. CARDULLO: I wrote delay because we mentioned phase bandwidth and I thought we should probably have delay up there, too.

MR. BOOTHE: You think we should start mission critical?

MR. CARDULLO: Unless somebody has some other parameters—yes?

MR. FOSTER: One question that comes up, does the instructor station have to be on board? That has a big effect on the amount of hardware on board and all that sort of stuff.

MR. BOOTHE: How would you give—

MR. FOSTER: If somebody could come up with an alternative method, video, an enhanced instructor station type of thing and enough audio, the audio is a difficult issue to address. Could it be done that way?

MR. BOOTHE: I have been told the Russians do it that way.

MR. CARDULLO: The military fighters do it that way.

MR. BOOTHE: So if the question is can it be done, I guess the answer is yes. If the question is would the FAA permit it to be done—

MR. FOSTER: That's really the question.

MR. BOOTHE: It's a different question. You are looking at the wrong guy.

MR. FOSTER: That's the question, really. Do you—if somebody could demonstrate a satisfactory off-board instructor station, would that be acceptable?

MR. ADVANI: We are going to demonstrate that.

MR. REID: He said FAA.

MR. IRVING: Paul [Ray], I find the answer is probably no. Probably.

MR. RAY: That's the tendency I've got right now, is probably no. I wouldn't close the door forever.

MR. IRVING: That's right. You need the instructor on board, but perhaps the question is do you need an instructor station or would a little VGA screen be sufficient?

MR. SUSSMAN: So the question is location and nature of the instructor station.

MR. RAY: I think right now my tendency is to say you need an instructor station. Maybe in the future—the immediacy of the feedback on the session. You jump back into the how good is the training program as far as the feedback of the pilot in the seat? All he or she may receive in the case of an external instructor station would be audio feedback as opposed to visual feedback from an instructor. I can't answer that.

MR. BOOTHE: Let me clarify something. Bob [Foster] said instructor station, did he not? And I assume that he did not include necessarily an observer. It could still be an observer on board if one were doing a pilot proficiency check, just as we do it today, but somebody else might have been operating the instructor station off board in that case. So you could still have an observer to do the things, in fact it wouldn't be much different than you would do in an airplane. After all, there is no instructor station there, most of the time. So that's a thought to add to that consideration. You could still have the observer there.

MR. RAY: My concern and focus on the instructor station is not the station itself as much as it is the instructor. The station could be a PC, a laptop sitting in front of you.

MR. FOSTER: The ultimate thing would be to take the whole back end of the simulator off so that from the cockpit door back there was nothing. But on the other hand, you know, the intermediate positions, like Ed [Boothe] was saying, do you really need to have a full-blown console mounted instructor station or could something less, perhaps as long as it provided the functionality, would that be acceptable?

MR. RAY: Sure.

MS. BÜRKI-COHEN: You can do more and more with telepresence technology, audio is not a problem and visual is not that much of a problem.

MR. LONGRIDGE: I think for the purposes of this discussion we want to assume that the instructor or check airman is on board and he does have sufficient facilities available to him at that station to control the direction of the scenario if it's a LOFT or LOE. There may be some possibility with respect to miniaturization of the technology for that purpose, but for all intents and purposes I think the answer to your question is yes, we want the operator station to be on board.

MR. RAY: Although it could be miniaturized or whatever. It's a weight consideration, is what you are looking for.

MR. CARDULLO: That's about really all that affects the mass properties.

MR. BOOTHE: One more comment.

MR. BLUTEAU: Many military simulators have no on-board instructors. But I would like to add that may not be a big driver for the weight, currently the big driver for simulator weight and mass property are the visual projectors and the support structure we have to build to hold those huge projectors, it's a big impact.

MR. CARDULLO: That's true. And not only weight but because of their location it gives you very high moments of inertia.

MR. BAKER: One of the things I wanted to bring up, I just wanted to mention so we get it mentally on our agenda, is the possibility of taking the visual system off the motion platform, particularly for motion platforms that have much less stroke than 60 inches, it may be a very reasonable thing to do that. I think there is development work that would have to be done, but you can certainly take a lot of money out of the problem if you get that weight and inertia off of there. And do it with a visual system that is on the floor.

MR. ADVANI: Or do some things to the visual system that bring the mass and the cost down.

MR. CARDULLO: Putting it on the floor, it's actually been done a few times. One of the first ones I knew about was done in England by Arthur Barnes. He did it with a small motion system. Boeing helicopter has done it with their V-22 tilt rotor simulator in Philadelphia, they have used a small stroke motion system and the big problem that everybody is concerned about is the necessity to do dynamic distortion correction, because as you are moving the eye-point relative to the screen distortion of the image theoretically results. However, my observation, purely anecdotal sort of thing, is that for small stroke motion systems, that distortion is not noticeable when you are looking at a typical visual scene.

If you put an orthogonal grid pattern up, we did this in England at Arthur Barnes's facility, you sure see it. You see the distortion. But with a visual scene for aircraft it was not noticeable. Maybe for a driving simulator where you are driving down the street and you have a lot of vertical edges, it might be a problem. I think for an airplane simulator where a lot of the scene is amorphous, it probably works, if you can use a small stroke motion system.

MR. BAKER: I would think some 24-inch stroke or something less than that would be appropriate. I believe that there are things that you can do to take some of that distortion out of the visual scene.

MR. CARDULLO: Oh, yes, you can do dynamic distortion correction, all it takes is a computer.

MR. BOOTHE: Maybe mass properties is one of the critical design parameters.

MR. CARDULLO: It is.

MR. BOOTHE: Why don't we start marking that.

MR. CARDULLO: We already defined that. I will put a C, okay? Do we have consensus that's a critical parameter?

MR. STOCKING: Yes.

MR. CARDULLO: Let's go down the ones on here and define which ones are critical. And maybe we ought to define what critical means. Critical to the performance of the system. And then, you know, critical to the performance of the system as a training simulator. Like we said before, accuracy, static accuracy is a design parameter, but it's not critical for this kind of a servo system. It may be for a robot, I don't think that is the definition we want to use for a flight simulator.

MR. HEFFLEY: Are we putting down cost drivers critical to operation?

MR. CARDULLO: Critical design parameters, if they are not critical then we can forget about them in terms of cost drivers. Once we define the critical ones we are going to define the cost drivers.

MR. LONGRIDGE: Are you saying it's possible to have something that would not be critical to performance and is therefore not a cost driver?

MR. CARDULLO: Well, if it's not critical to performance, then you can reduce the requirement on it so it does not become a cost driver. For example, there is the issue of accuracy, position accuracy. If the position accuracy must be maintained within one percent, it's going to cost a lot.

But if you say I don't really worry about it because I can't tell the difference between one percent, ten percent, 20 percent, then it's not a cost driver.

MR. LONGRIDGE: I still question whether or not that may be true. Let's see how it develops.

MR. CARDULLO: Maybe we can find a case where it's not.

MR. STOCKING: You can correct positional problems, too. We have got feedback programs that tell us where the platform actually is. And you correct for it.

MR. CARDULLO: Sure. You can't tell the difference, can you, between ten degrees of pitch and 15 degrees of pitch when you are sitting in a vehicle or in an airplane?

MR. STOCKING: In a gravity aligned system it's important to sustain cue. So yes.

MR. CARDULLO: Since you can't get all the way up it's all scaled down anyway.

MR. STOCKING: Well, in some cases, yes. Well, I will get into variable gain later.

MR. SUSSMAN: Before you do it do you want to limit yourself to two levels, critical, noncritical, or do you want to give a third level, without getting too fancy?

MR. CARDULLO: Ed [Boothe] says two.

MR. BOOTHE: We only have two days.

MR. SUSSMAN: Good point.

MR. CARDULLO: What else? Let's go down the list. Is delay critical?

MR. REID: It has to be critical but not a big problem.

MR. CARDULLO: We have to define—

MR. REID: I would say it would be critical.

MR. CARDULLO: It's a critical design parameter. It doesn't cost anything.

MR. REID: Fortunately it won't cost as much.

MR. CARDULLO: Environmental factors?

MR. FOSTER: If you are counting facility size, it is.

MR. CARDULLO: Pardon me?

MR. FOSTER: If you are counting facility requirements in there it becomes a critical design factor from a user standpoint.

MR. LONGRIDGE: But is it critical to performance? That's the problem with your logic.

MR. CARDULLO: As soon as I got to that one it becomes your counter example.

MR. BOOTHE: In our issue here, since we need to consider overall cost to a regional airline of having a Level B simulator, I think it is critical and probably a major cost driver. So we do need to mark that. Because if we can have a motion system with one-foot cylinders instead of eight-foot cylinders, that's going to be a big difference in what it costs to house it.

MR. LONGRIDGE: Clearly it affects cost.

MR. CARDULLO: Safety factor is critical, I think we can agree safety factor is critical.

Floor loading.

MR. BOOTHE: That backs into the environmental factor.

MR. CARDULLO: And mass?

MR. LONGRIDGE: Wait a minute. Your criterion is performance of the device, is the safety factor critical to the performance of the device? Are you mixing costs and performance again?

MR. CARDULLO: Well, no. Maybe the definition of—it's a good thing I have you checking me, Tom [Longridge]. Safety factor is an important design parameter, but because it affects the safety of the device.

MR. LONGRIDGE: Yes.

MR. CARDULLO: But it's not—in general a performance issue but it is a design issue. So we have to redefine—

MR. LONGRIDGE: Critical, what do you mean by critical? That's all I'm saying.

MR. REID: Because we have environmental factors in there, that's certainly not performance.

MR. CARDULLO: I guess maybe critical to anything. I can think of some safety issues that end up affecting design system performance, that's the redundant legs that were originally on some of the hexapod systems. They had added so much inertia—

MR. REID: The springs, yes.

MR. CARDULLO: They were actually hydraulic springs.

MR. MARTIN: More like shock absorbers.

MR. BOOTHE: I think safety factor is still a cost driver.

MR. CARDULLO: We haven't got to cost drivers yet.

MR. BOOTHE: I'm still hung up on what Tom [Longridge] was saying, are we considering cost drivers or performance? If we have to have them it's a cost driver we are concerned about.

MR. LONGRIDGE: Yes, both.

MR. CARDULLO: We have expanded the definition of critical. Critical doesn't mean just critical to performance but it means it's a significant factor in design. Whether it's performance or safety or other issues. But whoever is doing the design has got to be concerned with it.

MR. HEFFLEY: I have a question, Frank [Cardullo].

MR. CARDULLO: You know what, everything is going to come up critical.

MR. HEFFLEY: Everything will have a C.

MR. CARDULLO: When you expand the definition of critical beyond performance, everything—

MR. LONGRIDGE: Let's do cost drivers, then. You can keep the C.

MR. SUSSMAN: C is cost.

MR. CARDULLO: I will leave Norm [Bluteau] alone with his original idea. I think if we have constrained this to performance parameters, then that would have worked. But now that we have expanded the definition of critical, it no longer has any meaning. Very good. Okay.

So in terms of cost drivers, we don't think delay is a cost driver. We define delay as really being the computational architecture, et cetera, right? That's not a cost driver.

Environmental factors, we will use the C for cost driver. Environmental factors is a cost driver.

Safety factor, that would be a cost driver. Say a safety factor of eight as opposed to two. You have to take eight times stress.

MR. BAKER: I don't think that drives the cost very fast. We are going to have to try to separate the things that are not terribly sensitive to cost from things that are, because—

MR. CARDULLO: Okay. Is there a consensus on that? Does not drive it fast? Does environmental factors drive it fast?

MR. HARRIS: The building does.

MR. CARDULLO: Okay.

MR. HARRIS: If it's a new building.

MR. CARDULLO: Floor loading. That really is contained in this mass properties, right? And mass properties is a fast cost driver?

MR. BLUTEAU: Yes.

MR. CARDULLO: It affects—

MR. BLUTEAU: Everything.

MR. BAKER: Well, let's talk about fast and slow cost drivers for just a minute. What I had in mind when I said the safety factor doesn't drive it very fast, if I double the safety factor requirement I'm not going to double the cost. I'm going to increase the cost but I think some relatively small percentage. Now, mass properties I think drive it faster than safety factor does. If I double the payload I don't think I'm going to double the cost of motion base, although it's probably something more like a 50 percent increase in the cost of motion because if I double the payload size—

MR. CARDULLO: It's a significant cost driver because it affects frequency response, acceleration, et cetera.

MR. BAKER: It is a significant cost driver in that respect. I would like to throw some sort of qualitative criterion like that out on the table and say everything will drive cost, some things don't drive cost very hard and some do.

MR. CARDULLO: We are concerned about hard cost drivers.

MR. BAKER: If you start increasing the stroke of the actuators you will find costs go up very fast.

MR. CARDULLO: That's right. Power, I think, is a really a secondary factor because power is determined by mass properties. If we talk about hydraulic power, it's determined by mass properties, and if you talk about electrical power that's in the environmental factors, that are really driven by excursion and things like that.

MR. REID: If I specify I want an electric system as opposed to a hydraulic system, then I don't know what that does.

MR. BAKER: The power situation gets a lot better because the electric system is essentially conservative.

I want to get Bob's [Foster] comment on that because he is an end user, about how sensitive USAir is to power consumption. Is that something that the bean counters get excited about, or is that something they kind of ignore?

MR. FOSTER: No, it's become a hot issue, actually. We went back and retrofitted our existing machines with shutdown circuitry, automatic shutdowns and stuff, but it's still more like you said, it's not an essentially conservative system like we envision electric would be. If you are not driving the machine you are essentially consuming almost no power. Where even the big hydraulic systems when you are sitting there with three 50 horsepower motors running, you affect the power factor, you are killing yourself.

MR. BAKER: The electric system does better than that, it actually takes the kinetic energy out of the motion platform and puts it back in the power supply. So the regenerative breaking of the power amplifiers do that for you, all you basically have to get out of the wall socket is the power required to overcome friction and other dissipative type losses. But in a hydraulic system every time you run hydraulic oil under pressure through an orifice you are burning up power.

MR. CARDULLO: Let me suggest something here. Instead of saying power, what if we say electric versus hydraulic and then make an assessment, if that's a cost driver. Because that's really where this discussion is going, right?

MR. SUSSMAN: Does that go to maintainability, also?

MR. FOSTER: Yes.

MS. BÜRKI-COHEN: Yes.

MR. BAKER: Might affect that somewhat.

MR. FOSTER: Utilities in our facility, it's very sensitive to what you pay for electricity, but for a six axis motion simulator, the entire simulator, it's about 25 thousand dollars a year for electrical power.

MR. BAKER: I can see where the bean counters might pay attention to that.

MR. FOSTER: You get to the point where you start investing some money to save money, get some payback on auto shutdown features and stuff like that.

MR. CARDULLO: Is the difference a cost driver?

MR. SUSSMAN: Yes.

MR. REID: Is it a feasible technical alternative for a Level B simulator? Or are we dreaming something?

MR. CARDULLO: With today's visual systems and all and instructors on board, it may not even be feasible. So I don't know. I would kind of leave that out. And location and nature of instructor station comes under mass properties.

Maintainability, is that a cost driver? In the design? Yes?

MR. HARRIS: One extension to that is the life cycle expectancy, it's not just maintainability but how long do you expect that thing to last? 15 years, 20 years?

MR. LONGRIDGE: Is that a big cost driver?

MR. HARRIS: It is if you have to choose electronics that would last 20 years.

MR. BAKER: I think one of the things that—on a related issue, I think one of the things that surprised all of us over the last 20, 25 years, is how long some of these simulators are in service. And there was a conference in Atlanta a few months ago that addressed the problem with simulator maintainability. Frankly, there was more than a little bit of whining from folks who said we can't get parts for simulators built 25 years ago. I thought, you better get used to the problem, because it's not going to get better. Power supply technology has changed, computer technology has changed, it's not changing at the same rate it did 20 years ago, it's changing very fast. So I don't know that it's possible at this point to design a simulator that's going to have a 20-year life and expect to be able to buy the parts for it 20 years from now.

MR. HARRIS: You can choose a protocol that will last five years, at least five years instead of one year.

MR. BAKER: On the computer side of the market I'm not sure that's even true.

MR. CARDULLO: Can we agree, if we include all the "ilities" under this thing, reliability, maintainability, life cycleability—

MR. BOOTHE: I think it is a cost driver. If I understood correctly, the concept that Rediffusion did, had lots of considerations for maintainability strictly for that purpose, to reduce the life cycle cost. So it could easily get to various components and at least repair, replace them and so on. I don't think a manufacturer would have gone to that extent if it weren't a cost driver, so I think we should probably mark that.

MR. CARDULLO: Unless the customer was pushing in that direction.

MR. HARRIS: It's customer driven.

MR. BOOTHE: Why would the customer drive that?

MR. CARDULLO: Because some bean counter thinks it is necessary.

MR. HARRIS: It's important for maintenance.

MR. CARDULLO: I don't deny it's important.

MR. MARTIN: Is it sensitive?

MR. CARDULLO: Is it a cost sensitive parameter? If you double the life cycle of this thing, does it half the cost or something?

MR. HARRIS: If you can't make it maintainable, then it's—

MR. BOOTHE: That's a different consideration. Forget what I said. I think he put his finger on it, it's ease of maintainability rather than a cost driver that you have described. So maybe we could press on to the next page.

MR. CARDULLO: Computation. We didn't do computation. Computation includes the computational architectures, software, software development is included. Would you consider software development included in computation?

MR. REID: Is this for the washout and the control loops, or is this just the inner loops of a digital control loader—or a digital controller?

MR. CARDULLO: I guess it's everything. All the computation associated with the motion system. That would include the servo controller.

MR. REID: Sometimes it's part of the host.

MR. CARDULLO: Sometimes it's part of the host.

MR. REID: So where do you place it?

MR. CARDULLO: I don't know.

MR. BAKER: The servo guides who does it.

MR. HARRIS: The hardware is cost per unit. The software, you buy it once, you have got it forever.

MR. CARDULLO: For this application it's not a cost driver.

MR. HARRIS: I wouldn't say computation itself is a cost driver.

MR. CARDULLO: So we have two items here, mass properties, and environmental factors. Number of degrees of freedom. I think this is certainly a cost driver.

MR. BAKER: Is any degree of freedom—

MR. CARDULLO: It may not be cheap, but it is inexpensive.

Smoothness, is smoothness really a cost driver those days?

MR. BLUTEAU: Yes, it is.

MR. LONGRIDGE: Is it true that there is that much of a cost difference, let's say between a four and a six DOF system, do we say there is a big cost in degrees of freedom granted zero versus something, how about three, four, six?

MR. BAKER: We looked at that problem on the small motion platforms recently, we concluded an analysis to go from three to four is like 30, 35 percent increase in cost. So it's probably almost linear.

MR. LONGRIDGE: Really?

MR. BAKER: Most of the money is in actuators. The mechanical structures, are really not that expensive. Their costs don't change very much. When you add another actuator and all the stuff that goes with it, you are adding quite a bit of cost.

MS. BÜRKI-COHEN: What you are saying applies, however, to an electric small system?

MR. BAKER: I think if you talk to the guys that build hydraulic stuff they will tell you the actuators are a fair amount of the cost. Cylinders, the Weldment structure for the top and bottom platforms, they change the way they look but they don't really change the cost that much because they are not going to change in weight. You can almost buy those per pound, but let's hear from Geoff [Harris], he knows more about it.

MR. HARRIS: If you have a six degree of freedom platform, you have six legs. If you make less degrees of freedom you need to restrain the others. So you do away with two motion legs but you now have to add extra structure and pivots. You don't save that much money. But assuming you use the same category of actuators on a four DOF as you do a six DOF, you don't save that much money.

MR. CARDULLO: I understand your point. And I agree with your point.

MR. STOCKING: The other thing you want to think about, when you start talking about degrees of freedom, as a manufacturer if you can build one device that fits all your products, you begin to reduce the cost of that. And if you have two, three, and four degrees of freedom, five degrees of freedom systems, and you make two of these, three of these, they start costing more than a single synergistic system that falls across three or four lines, even though you may not use one or two of the degrees of freedom. It's actually cheaper to use a single synergistic system.

MR. BAKER: We don't recommend, for example, people build a five axis system, because you can build a six just as cheap. Because of the constraint problem. When you go from six down to three, I guarantee there is a cost savings. It's significant.

MR. STOCKING: Again it depends on what you are manufacturing. If you are looking just at the, we will say the commuter market where you are looking at a whole bunch of different aircraft, probably the minimum you could come up with on a commuter training requirement may be four. And I would be skeptical. I would go for six.

MR. CARDULLO: So basically what you are saying is, I think, the consensus at least between you two is that adding degrees of freedom is not a cost driver, in fact it may even be a cost saver?

MR. STOCKING: That is correct.

MR. CARDULLO: For overall—

MR. STOCKING: That's the way I view it.

MR. CARDULLO: The other thing is for something like a Stewart platform you have six identical actuators, whereas for a three degree of freedom system the actuators may be different if they are standard actuators. I guess that would make it cheaper. Do we have a consensus?

MR. SUSSMAN: Before the consensus there is one comment. Right now we are specifying three degrees of freedom, if you move beyond three, there is a cost—is that right, Tom [Longridge]?

MR. LONGRIDGE: For Level B, that's correct.

MR. RAY: That's what is there now. That's not to say it would be there tomorrow.

MR. CARDULLO: Except, Don [Sussman], that Geoff [Harris] is saying that it really doesn't cost any more to build a six degree of freedom than it does to build a three.

MR. HARRIS: If it's a comparable system, yes.

MR. BAKER: Time out.

MR. CARDULLO: Let's get Norm's [Bluteau] comment.

MR. BLUTEAU: I want to talk about a CAE experience. We had an experience where we had to replace the degrees of freedom by constraint, the constraint turned out to be just as costly as degrees of freedom. But our experience was very heavy simulators where the constraints themselves became very complex, I suspect if you go with lighter weight payloads possibly the constraints become easier to design. Easier to build.

MR. ELDREDGE: Let's take a break.

MR. BOOTHE: Let's take a break.

(Break taken.)

MR. CARDULLO: Where are we on degrees of freedom?

MR. BOOTHE: I don't know where our missing parties are, I guess they will be back.

I was hearing two things here. On this side I'm hearing that we are reducing degrees of freedom from a six degrees of freedom system. And it's no cheaper because of imposing constraints on a six degree of freedom system and you wind up with the same cost. But over here I'm hearing we are adding degrees of freedom by adding hardware and therefore it costs more. So I think if we are looking at progressing to some additional degrees of freedom that might be needed on a Level B simulator beyond the three that are now required, I think we are talking about increasing cost. Now if it comes out that we do need more than three degrees of freedom because that's what this group establishes, then that's what we need to do and in that sense it is definitely going to be an additional cost driver. But we don't necessarily need to do that by starting, I mean we may end up wanting to use a six degree of freedom system because it's the cheapest way to go, but for right now I think it is a cost driver and cost increaser, the degrees of freedom, so I think that's probably quite true.

MR. CARDULLO: I think what you are saying is if you are starting from scratch, it's a cost driver. If you are not starting from scratch it might not be, but is anybody starting from scratch?

MR. BOOTHE: Yes, I think they are.

MR. WILLMOTT: What about people like this gentleman right here that currently makes three degree systems that are going to be a hell of a lot cheaper than the CAE and Thomson six degree system and making it into a three?

MR. BOOTHE: I think we will find out when we go through the tables.

MR. CARDULLO: You are supporting what Ed [Boothe] is saying, Stu [Willmott]?

MR. WILLMOTT: I think it is a cost item.

MR. BLUTEAU: I want to say we had a similar experience where it was not a significant cost driver to add or remove degrees of freedom but I must say it was in the case where the payload was extremely large then the cost of constraint was possibly a factor. I'm hearing conflicting response from us and from Bruce [Baker]. He may be dealing with smaller payloads.

MR. CARDULLO: He is. Are there Level B systems now that use three degree of freedom systems, so there are systems out there currently being used on Level B certified devices?

MR. LONGRIDGE: Yes.

MR. CARDULLO: So I guess then it is a cost driver.

MR. BOOTHE: I think we need to, keeping in mind the calendar and the clock, we need to move right along here.

MR. CARDULLO: I'm sorry, were you saying?

MR. BOOTHE: No, just—

MR. CARDULLO: Is smoothness a cost driver?

MR. STOCKING: Before you get back to that I want to say one thing. On a three degree of freedom system, there are certain types of motion cues you cannot give and you want to make sure that those meet the training requirements.

MR. CARDULLO: That's right. When we get to the table we will deal with those. Smoothness. Today's state of the art, is this a cost driver?

MR. MARTIN: It might be the difference between using an entertainment quality electric system versus a hydraulic system with a hydrostatic bearings.

MR. BLUTEAU: The answer is yes.

MR. CARDULLO: Would smoothness alone drive that?

MR. MARTIN: Smoothness would be a consideration.

MR. CARDULLO: For example, you can buy a motion system from McFadden with either hydrostatic actuators or production actuators, standard actuators. Is there a significant cost in the difference of the two actuators? I don't know.

MR. BOOTHE: If we meet bandwidth, you don't think—

MR. CARDULLO: No, no, no. This is smoothness like turn-around bump and that sort of stuff. It's not a bandwidth thing. How about Norm [Bluteau], do you have an idea in terms of relative costs?

MR. BLUTEAU: Not precisely, but I know hydrostatic technology costs a lot more because of the accuracy required to achieve hydrostatic cushioning.

MR. CARDULLO: So you are supporting Ed [Martin]'s position?

MR. ADVANI: It also requires a higher flow volume because of leakage in flow.

MR. HARRIS: If you are talking about smoothness, you must consider also the servo valve, you need a higher performance servo valve.

MR. STOCKING: It's been my experience, I have seen good systems that were not hydrostatic that produced good smooth systems, but I have no relationship as to whether it was a cost driver or not.

MR. HEFFLEY: It depends on where you have a problem to begin with. If you have to spend a lot of money to smooth out what you got, then that can really be a cost, a lot of engineering.

MR. BOOTHE: Could I ask you, is smoothness a cost driver?

MR. BAKER: I would say it is. You can get by, as Geoff [Harris] mentioned, you can get by with some awfully grubby parts if you don't have to worry about smoothness aspects of it.

MR. HARRIS: Is it a requirement for the flight regime? When flying in an aircraft there is always turbulence.

MR. CARDULLO: That's right. But what is included in smoothness is any kind of spurious acceleration. What you really don't want to happen is, during a maneuver, to get a cue that may destroy any vection that you have been able to build or something like that.

MR. HARRIS: Turn-around bump in particular.

MR. CARDULLO: Turn-around bump is one of them, but cross-coupling can lead to that.

MR. ADVANI: You don't want pilot-induced turbulence.

MR. BOOTHE: I think we concluded that is a cost driver.

MR. CARDULLO: Right. Phase bandwidth.

MR. WILLMOTT: Turn-around bump requirements you have to meet at Level B anyway. You can't have turn-around bumps.

MR. IRVING: If you have a test you have to specify criteria to be achieved.

MR. WILLMOTT: If you define it—

MR. BOOTHE: It's in the Advisory Circular but it says as specified by the operator for simulator acceptance, which means we really have no—

MR. CARDULLO: No criterion.

MR. BOOTHE: No criterion, right. Bandwidth? I will throw out a yes and see if anybody agrees.

MR. CARDULLO: Or disagrees.

MR. MARTIN: See if anybody disagrees.

MR. REID: You are saying if someone demands more bandwidth it will cost more money? I have to agree with that.

MR. BOOTHE: So somebody agreed.

MR. CARDULLO: Bob [Heffley]?

MR. HEFFLEY: The thing is the bandwidth, that's—that can very likely, I think, be driven by the mass properties. You have got to solve that, you know.

MR. CARDULLO: If you are stuck with certain mass properties, you may not have an alternative to the mass properties, so you have got to do something, you have to use larger diameter actuators or higher pressure hydraulics, or whatever, in order to get the bandwidth.

MR. SUSSMAN: Mass properties are going to drive everything in the end, or almost everything.

MR. CARDULLO: But if you need the bandwidth, and if you increase the mass properties, it's going to reduce the bandwidth. If you specify a certain bandwidth then you, in spite of the mass properties, have to achieve it. By specifying five hertz as opposed to two hertz is it going to be a cost driver, is the question?

MR. HEFFLEY: It takes expensive components to fix it. So I guess that becomes a cost driver.

MR. BAKER: Let me stir the pot a little more.

MR. CARDULLO: I know exactly what you're going to say. More smoke and mirrors stuff.

MR. BAKER: Absolutely. If you can do it with smoke and mirrors, it's a lot cheaper than doing it with money.

I've made some comments today about doing some phase compensation or pole-zero, in some cases I have also used the motion base servo as one of the washout filters. And I think you all are thinking some things you haven't said yet. I'd be interested in your comments because you may have had different experiences than I have. You have more data than I have. I'm not in the business of running psychological test in motion platforms, sometimes I wish I were, it's an exciting business. Is that too deep a discussion for right now?

MR. CARDULLO: I think the only thing to respond quickly to that is there are things that can be done in control system design to get around that problem, basically the problem is the resonant frequency of the system. And getting around the resonant frequency of the system you have, and if you are going to try to solve it in the mechanical part of the system, you have got to make the system stiffer.

MR. BAKER: Actually—

MR. CARDULLO: But there are some control things that you can do to get around that. But I don't know what people are doing in the industry as a matter of course in production. I mean, most of what I see people doing is try to get bigger valves, larger diameter actuators, things like that. They don't try to solve the problem in the control system, they try to solve it in the mechanical design.

MR. BOOTHE: But in general we can say we have increased mass, we have to spend more money to get the desired bandwidth. So I think they are definitely cost drivers, whether Bruce [Baker] does it with smoke and mirrors instead of money.

MR. CARDULLO: His point is it's a small amount of money if you do it in the control system. It's a large amount of money if you do it in the mechanical apparatus.

MR. BOOTHE: What's the more general solution?

MR. CARDULLO: The more general solution is doing it, what I just said was my experience is most people do it in the mechanical design.

MR. BOOTHE: Then the more general case is a cost driver, then, and if Bruce [Baker] can do it cheaper, then by gosh he ought to do that.

MR. CARDULLO: Do you guys agree with that?

MR. HARRIS: I almost agree with Bruce [Baker]. The way we have improved the bandwidth is with mass—

MR. CARDULLO: That's what we are saying here. You have mass, you need to increase bandwidth to get up to five hertz to get a good motion system.

MR. HARRIS: That would normally be a server loop control, unless you run out of power, which might be transducers or valves—

MR. BAKER: Back up a minute. I have done a lot of analysis and some significant amount of testing on hexapod systems. And if you try and treat the servos on motion platforms—six axes motion platform—as conventional single axle servos, what you will discover is they don't work like that. There is an interaction between the servos that cause an instability as you start to turn up the gain and try to push the bandwidth. Typically above two and a half hertz you start to see resonance show up in the servo that is coming from the other axes, and it's essentially driven by the oil spring frequency. If you could push the oil spring frequency up, the problem would move up with it.

I worked on a project some years ago that Contraves in Pittsburgh did, the tank command wanted something like ten hertz position bandwidth out of these servos. And I've got a theoretical analysis at home that shows you can do that in theory but in actual practice it's not quite so easy. I don't think the motion platform ever achieved that performance in actual practice. Nor do I really believe it's necessary. But I think there are other ways you can achieve effectively the same thing. That was a fair sized platform, had seven and a half inch diameter actuators and you could put a seven thousand pound turret on it and shake it at two g. Three thousand horsepower pumps, that sort of thing. It was a larger system than we are normally concerned with. Yes, indeed, it cost a lot of money.

MR. BOOTHE: I think for our purposes here we can move on. It is definitely a cost driver.

MR. CARDULLO: How about hysteresis?

MR. REID: Not anymore. I think you avoid it automatically with the hexapod. If you go to some ganged systems, systems within systems, then it may be a problem.

MR. CARDULLO: You might get some position hysteresis because it's a nonlinear system, but who cares, so I wouldn't think it's a cost driver on that basis.

MR. BAKER: The hysteresis will disappear if you resolve the smoothness problem because they are closely related.

MR. CARDULLO: How about cross-talk, cross-coupling between degrees of freedom, so if you command a pure pitch, do you get a pure pitch or do you get some other degrees of freedom cross-coupled into that? The old military specification [MIL-STD-]1558 measured it on a position basis from actuator to actuator. I think the AGARD[-AR-]144 does it in degree of freedom space, which is really the way, in my opinion, it should be done. And it should be acceleration, not position, because the pilot doesn't feel position, he feels acceleration. So it's a very important parameter because it can destroy a cue, but is it a cost driver?

MR. BOOTHE: Does that fall out if we do the other things right?

MR. BAKER: No, not necessarily.

MR. CARDULLO: Not necessarily.

MR. HEFFLEY: If you have dissimilar actuators.

MR. CARDULLO: That exacerbates the problem.

MR. BLUTEAU: It's not a cost driver right now because we are not building to that spec, it's not an FAA requirement, cross-talk, so right now it's not a cost driver.

MR. CARDULLO: If we were, would it be?

MR. BLUTEAU: I don't see how that translates to any training value.

MR. CARDULLO: There is a lot—I disagree. It translates into lots of training value. Because if the pilot pulls back on the stick and expects the airplane to just to be pitching and he feels a little bit of yaw while he is doing it, he thinks he has lost an engine or something. I believe there is a lot of training.

MR. BAKER: I believe if you try and squash that number down, more than what you—well, let me back up a minute. It's an expensive thing to drive that number down real small. The main reason is that most of the cross-talk, at least in the systems that I have measured, is coming from the oil spring. Okay? You start putting high frequency large amplitude inputs in, say in a lateral on an hexapod system you will see it also gives you some roll. And it's because of the elasticity of the oil.

MR. HARRIS: But is that a problem?

MR. CARDULLO: There is another factor, the dynamic effects of the mass.

MR. BAKER: I did some tests a few years ago on an AH-1W sim for the Marines. It has a big dome on it so the CG is pretty high when you run the thing back and forth, low frequency nice and level, as you go up it starts to make a figure eight for you. It's because the CG is up so high.

MR. CARDULLO: It's the moments of inertia.

MR. BAKER: It's the moments of inertia.

MR. CARDULLO: So it's the dynamic effects of the mass.

MR. BAKER: If you want to fix that you have to stiffen the actuator. Well, putting pressure gain in there is the wrong direction, you want to take the pressure gain out. Then you have other problems that show up.

And so the only real way to stiffen the actuator that I know of that works is to make it bigger in diameter. That doesn't get you good results very fast. Flow rates go way up and servo valve sizes.

MR. CARDULLO: So on that basis it's a cost driver.

MR. BAKER: If somebody really wanted to drive that parameter down small, it gets to be expensive in a hurry.

MR. BLUTEAU: The model of the mass, it can be done.

MR. CARDULLO: That's what you can do but that's expensive the first time you do it.

MR. BLUTEAU: Still is.

MR. STOCKING: I will sell it to you.

MR. BAKER: You can achieve some performance improvement but it's a matter of degree, you may get it down by a factor of five but if you get it down by a factor of ten it's expensive.

MR. CARDULLO: I think we have agreed, so we should continue the discussion.

Platform size, this really is a mass properties issue.

Excursion.

MR. REID: Cost driver.

MR. CARDULLO: Do we all agree, excursion is a cost driver? I think that's pretty straightforward.

Payload weight, this is really a mass property, we have already defined it.

Acceleration. Cost driver, right?

Velocity.

MR. HARRIS: It is, but indirectly to achieve velocity in itself—

MR. CARDULLO: I'm sorry.

MR. HARRIS: To restrain velocity in the snubbers is expensive if you have a lot of velocity: $-mv^2$.

MR. CARDULLO: Just being able to achieve a high velocity?

MR. BLUTEAU: You need bigger valves.

MR. CARDULLO: So it's a cost driver.

MR. BOOTHE: We have already said acceleration is and we have already said excursion is, so velocity is already included. I think it's a secondary—

MR. CARDULLO: You think?

MR. BAKER: Time out.

MR. BOOTHE: I wouldn't have even marked it. Time out over here.

MR. REID: It's a different process that's causing it, though. This is a restriction like the problem of getting fluid down a pipe or through the servo valve, it's a different physical problem, so your solution has to be achieved differently from the acceleration and excursion one.

MR. BOOTHE: Okay.

MR. CARDULLO: It's a different problem.

MR. BAKER: If you run the velocity requirement up in addition to the problem with the snubbers that's been mentioned, you also have to put a larger servo valve on it and a larger pump for more flow. The downside is the larger servo valves are not going to work at low speed, the turn-around bump performance is not going to be as good. What you would like to do is have a real small valve on there because you can make it work through zero. The problem is people will object if the motion takes a week to go through a full excursion. The whiners and snivelers they are.

MR. CARDULLO: The next one is cue duration, two issues; one is excursion, on the other hand if you don't have excursion there is some things you can go do in the cuing algorithms, so whatever cost there is with cue duration personally I think is here *(indicating)*. Does anybody disagree with that?

MR. HEFFLEY: Yes, it's cue duration that kind of drives excursion more than anything, more than the inverse, isn't it?

MR. CARDULLO: Well, a couple things drive excursion. Cue duration is one thing, another thing is how large of a pitch amplitude do you need, for example, to take care of the gravity alignment?

Were you going to say something, Ed [Martin]?

MR. MARTIN: No, I was going to agree with him.

MR. BLUTEAU: Actually velocity also affects cue duration, you saturate your velocity much quicker than you saturate position.

MR. CARDULLO: So are we saying that cue duration is taken care of by excursion and velocity requirements so we don't have to consider it independently?

MR. HEFFLEY: The reason that you might really want to consider it independently is the fact that that's one of those things you can almost relate very directly to a given task. I mean if you are really forced to a cue duration.

MR. CARDULLO: For example, a large side force?

MR. HEFFLEY: Yes.

MR. CARDULLO: A long duration side force to either cancel out roll or to take care of an engine out or something like that.

MR. HEFFLEY: Yes, yes.

MR. CARDULLO: Let's say in those kind of cases, then it would be an independent cost driver is what we are saying.

MR. BLUTEAU: Yes. There may be other examples of that.

MR. CARDULLO: Pardon me?

MR. BLUTEAU: There may be other examples as well.

MR. CARDULLO: Position accuracy, it would be a cost driver but I don't think it's important, so it's not. Everybody agree with that?

MR. BAKER: I agree with that exactly.

MR. CARDULLO: Structural stiffness.

MR. REID: Is there a spec anybody has to meet on that?

MR. BAKER: The structural stiffness requirement basically gets driven by the bandwidth requirement, does it not?

MR. CARDULLO: Not completely. You have these banjo stringing modes, right?

MR. BAKER: Yes, I know.

MR. CARDULLO: That's an independent issue.

MR. REID: The only thing I remember on that was watching an Air Canada simulator that was doing a, what was it now, it was an engine failure combined with a tire burst on takeoff. And I could see the strut on the—

MR. CARDULLO: Boing.

MR. REID: —boing on the actuator.

MR. CARDULLO: I've seen them, you guys probably have the old Link systems where you can observe out of plane motion during heave at certain frequencies.

MR. BAKER: You know what, I have put accelerometers on systems and I can't measure if that gets in the platform.

MR. BLUTEAU: It does.

MR. CARDULLO: It's a fatigue issue.

MR. BAKER: I don't know. I don't think you are going to excite that mode hard enough to cause it to be a fatigue issue.

MR. CARDULLO: As far as I know no one has ever done analysis of that.

MR. STOCKING: If you are doing PSD plots in the testing phase of a motion system, the lack of structural stiffness of your platform may induce or you can end up with resonance frequencies that show up everywhere, and you want to avoid those.

MR. CARDULLO: Speaking of Mercedes Benz, they were popping rivets on the dome because they didn't have sufficient structural stiffness.

MR. ADVANI: There are two structural stiffness issues that we have discovered. One is lateral natural frequency of the actuator in its maximum extended mode, and that affects the interloop to the motion control; and secondly, the structural natural frequency of the payload structure and we have—that in our case is a big cost driver because we have put a tremendous effort into keeping those natural frequencies above 15 hertz. So my answer is yes.

MR. CARDULLO: Yes, it's a cost driver? Does anybody object to our calling it a cost driver? Okay.

Finally, so we have got degrees of freedom, smoothness, bandwidth, particularly phase bandwidth, cross-talk, excursion, acceleration, velocity, cue duration, structural stiffness, mass properties, and environmental factors.

MR. BOOTHE: Now are those factors that we want to refer to as we address these tasks in the table directly or are they simply to have understood at this point and know that as we address these, I'm not quite sure how we are going to use these now that we have done it. I thought I knew when we started.

MR. CARDULLO: I don't know that as we go through each one of these tasks, that we then address each one of these because we would be here for an awful long time. But I think we have got to keep these things in mind when we are addressing those tasks.

MR. BOOTHE: Okay.

MR. CARDULLO: Not explicitly referencing them, but maybe implicitly.

MR. BOOTHE: On occasion—

MR. CARDULLO: You may want to raise some of these things.

MR. BOOTHE: Thank you, Frank [Cardullo], for taking that on and getting us through it.

MR. CARDULLO: No problem.

MR. LONGRIDGE: To reiterate what was said earlier, it was suggested that we identify the two or three most critical tasks that are likely to be impacted by these cost drivers. If you want to delay the discussion until we go through the table, that's fine. I think at some point you have to identify what the tasks most likely to be impacted are.

MR. BOOTHE: Yes.

MR. LONGRIDGE: Do you want to defer the discussion till the appropriate point in the tables, then?

MR. BOOTHE: What I had thought we might do is simply leaf through the tables to see what is there with the thought of working our way towards the most critical task, but if we don't already know what's there, then we can't anticipate what would be most critical. So I don't know if that makes sense, but if I know that there are takeoffs with failures in this table, then I would know that pushback and powerback are not critical. So I need to know that those other tasks are here so I don't get hung up on lesser tasks as being critical. So I think we need to leaf through the table to see what's here first.

MR. FOSTER: I think one of the things that's critical in going through the table is determining how many degrees of freedom are required. It varies in your initial estimate of—from two up to six.

MR. BOOTHE: Right. So if we—that's a good point, Bob [Foster]. You notice they are not all the same as I had listed them. Again, those are only my ideas. And not necessarily the results, probably not the result that we would come up with. Keeping in mind that currently there are only three degrees of freedom required, keeping in mind that I have said before I think that's not sufficient, but you may think that's sufficient. So I think that's up to our discussion to resolve that issue as we go.

But just to leaf through the table, we start with surface operations just as it starts in the advisory circular and I think as it is similarly stated in the practical test standards for pilot certification. And so I have just listed the task under surface operations, pushing it back from the gate or power back from the gate. Whichever the operator might do. Then taxiing, then takeoffs with various events in the takeoff, a normal one, a crosswind, and other factors associated with that. Including a windshear. Events that may occur in cruise, then there is descent, approaches, and landings.

In terms of what's critical, probably something in the takeoffs and landings is the most critical and probably also the highest gain task will come somewhere in takeoffs and landings, so I would think that's likely where we would find application for these critical parameters. But not necessarily. So we have to keep them in mind as we go through.

MR. CARDULLO: I think on ground taxiing, that's a high bandwidth task. It's a high frequency domain and that's where motion cues are critical.

MR. LONGRIDGE: That's true, but this is recurrent training and these are people that already know how to taxi and taxi on a routine basis.

MR. CARDULLO: How does that impact—

MR. RAY: There is a problem, an issue there in that they are assessed on their taxiing in a Level B. Because Level B requires a ground handling package be embedded in it. So taxiing would be an issue, I agree.

MR. ADVANI: What about landing and taxiing on contaminated runways? I would consider that important even in recurrent training.

MR. RAY: Is it important? Yes. Is it important on a Level B simulator? Probably not to the degree it is on a Level C and/or D. Not—

MR. BOOTHE: Would it be a requirement on a Level B—

MR. LONGRIDGE: Normally what we rely on is abnormal or unusual situations they don't see all the time.

MR. BOOTHE: Which points up we need to make additions to this table as we go. Bob [Foster]?

MR. FOSTER: The biggest thing we see in operation, the biggest limitation is visual for pushback and taxiing, not the motion system.

MR. CARDULLO: How do you know?

MR. FOSTER: That's where all the complaints are. "I can't find my way around the airport." The instructors are saying "can't we preset to the end of the runway." Like I said—started to say, taxiing is a nonissue to these guys.

MR. RAY: Not taxiing around the full airport environment. Because you just don't have enough peripheral vision with a 45 degrees field of view.

MR. FOSTER: Pushback is strictly procedural. What you are looking for are the people making the right calls. You don't have marshalers on a Level B sim, it's all done by the instructor saying you are clear to push back, anyhow, and making sure he sets the brakes, there you need a little cue saying the brakes are set.

MR. CARDULLO: Those aren't critical.

MR. FOSTER: They are not critical at all.

MR. BOOTHE: We have a comment over here.

MR. ADVANI: What I think you are referring to, Frank [Cardullo], what I'm saying, any time the wheels are in contact with the ground, single engine operation, crosswind operation, those are demanding situations.

MR. CARDULLO: They are. But if they are not part of the training requirement, or the recertification requirement, then they are not necessary.

MR. RAY: But in fact they are.

MR. CARDULLO: Well, if they are—

MR. RAY: Is it limited in view as far as what you can do, as far as how much taxiing you can do? Certainly. But you could not exclude taxiing from that, you have to control the aircraft on the runway, which is a taxiing maneuver, to exit the runway, et cetera.

MR. LONGRIDGE: That's true.

MR. CARDULLO: Is it mainly, as Bob [Foster] says, a visual task? Is it a navigation task or is it a handling quality task?

MR. RAY: There is a handling quality task. There are complaints about the visual from a user's perspective.

MR. CARDULLO: If it's a handling quality task, then the motion cues are extremely important because it's high frequency regime.

MR. FOSTER: In Level B? I have to question that in Level B.

MR. RAY: A lot of the complaints, the skidding on the ice complaints that you get from Level A or Level B, take your choice, is relevant to a Level B sim. The complaints you get from the pilots are about the unrealistic nature of the simulation relative to the aircraft in taxiing, whether you are decelerating after a landing or whether it's the initial acceleration, or taxiing off the runway. It is a major complaint that the pilots throw at the Level A and Level B simulators. I think to exclude that would be a mistake.

MR. BOOTHE: Bob [Heffley]?

MR. HEFFLEY: In taxiing, and ground handling, you know the dynamics, the response required is pretty high if you are going to have reasonably high fidelity. In fact higher probably than flight.

MR. CARDULLO: Yes.

MR. RAY: That's true.

MR. HEFFLEY: It seems to me this is especially a case you would like to make some sort of trade-off in terms of quality of that motion. Because that could design things very fast and I guess I would be interested in knowing how that's really handled now in terms of quality of the ground handling.

MR. FOSTER: If you don't have wide angle visual, you are wasting your time. It takes something beyond Level B to do any sort of really meaningful taxiing training and checking. I'm sorry, I think that's the truth.

MR. RAY: But I would add, it depends on what your definition of taxiing is. From a pilot's perspective it's the feedback of those controls, whether it's the brake pedals, rudder pedals, or nose wheel steering. The pilot focus is on whether the visual and motion cues are correct. It's just not there in many devices. If it's an exercise and it's not in just navigating around the airport, agreed, you can't do it in a Level B sim. The feedback to the pilot sitting in the seat from the brake pedals, the motion feedback you are going to get with a lurching of an aircraft, the sensitivity of the brakes in stopping the aircraft, the pitching moment that occurs, both in break-away and stopping, and the visual cuing is critical to the realism that you are trying to portray in that device.

MR. CARDULLO: I think more than the realism, it's the controllability, the handling quality.

MR. RAY: Absolutely. I got a call yesterday in the office from an operator who had received a number of complaints about his, believe it or not, Level B simulator. They discovered a major problem they had and asked "can we please fix it?" I said "by all means." They said the feedback from the pilots, even using a single channel visual, that major improvements were made in the acceptance of that device as representative of the aircraft. Was it motion directed? Probably not, according to the operator. But the key was they didn't like the way it taxied on the ground at all. It didn't feel like the airplane.

MR. HARRIS: Do you know which axes those were in?

MR. RAY: The truth of the matter was they had previously played with the main gear. The main gear positioned was too far forward. They didn't say which, where the feedback was.

MR. BOOTHE: Let's proceed under the first entry in this table, assuming it's the right position.

MR. CARDULLO: I thought that's where we were.

MR. BOOTHE: Let's look at pushback and powerback from the gate and look at the degrees of freedom listed and see if they are more or less than are needed and see if we can proceed on through here in determining what's needed for a Level B motion system to satisfy the requirements that we described earlier today. So I've listed four degrees of freedom here. As I listen to you talk I can easily change that. I'm not going to tell you which way.

MR. CARDULLO: Is powerback when they use thrust reverses to back away from the gate?

MR. BOOTHE: Yes.

MR. RAY: Yes.

MR. CARDULLO: That's really a handling quality problem, whereas pushback, the pilot is not in the loop.

MR. BOOTHE: Pushback is very procedural, but a tractor is hooked up—

MR. CARDULLO: The pilot is not driving.

MR. BOOTHE: Right.

MR. CARDULLO: So really what we are concerned about is powerback.

MR. BOOTHE: But even on a pushback there are things that happen that I think are cues to pilot.

MR. CARDULLO: They are easy.

MR. BOOTHE: But they jerk the airplane around and that sort of thing. So I think there are still motion cues to be considered. Whether or not we determine they are important to Level B is another issue, but if you sit there and feel that jerking and in fact there is some interesting sounds that go with that, there are cues. How important they are, I don't want to pass judgment on. That's you guy's job.

But I've left out pitch and I've left out roll. I left out roll because both main wheels are, or whatever number of main wheels the airplane has, are firmly planted on the pavement, so I would think roll excursions would be extremely small. But the rest of these you can't have bumps in the pavement and feelings of the airplane taxiing without some heave in the motion system.

MR. CARDULLO: Pitch for braking?

MR. BOOTHE: I was afraid you would want to add that.

MR. ADVANI: I don't know why you need yaw.

MR. IRVING: You don't need yaw. You may not need yaw.

MR. BOOTHE: Well, let's go down to this. Is there concurrence on surge?

MR. WILLMOTT: No. I would think, as Frank [Cardullo] said, pitch is better. The surge is the short-term effect, you can't do much in a motion system, anyway. The tilt that the motion has for the acceleration or deceleration I would think would be more important than that.

MR. ADVANI: On the other hand, during the pushback the acceleration levels are not very high so you just feel the sharp onset, and not the—you are not concerned with the amount because you know it will be quite small. Have we started pushback or not?

MR. BAKER: This should be one of the areas where you can do a virtually perfect job of simulating what the airplane does. He is on the ground, he is not in flight, the acceleration levels are low. If you give him the bumps and the little surge when the tractor starts, that should be almost perfect.

MR. BOOTHE: It was that tractor bump that caused me to select surge. If the tractor starts and stops the airplane and brakes are not applied, there should be no pitch. So that's why I selected surge.

MR. BAKER: There is no long-term acceleration because the acceleration is over in a matter of a second or less, probably.

MR. BOOTHE: But if there is powerback, then pitch is probably important, and it would be a trade-off, so—

MR. BAKER: I think we are going to end up with six axes before we end anyway.

MR. STOCKING: This is a six axes cue. The surge cue, if you watch the pilots during pushback you will see his head nod like this when he starts, right? You will see his head move. And that's the longitudinal axis of the motion system.

MR. HARRIS: It's an onset cue.

MR. BLUTEAU: On motion systems with six degrees of freedom we don't use very many axes, it's almost a pure surge, very brief and pure surge, for the onset at least.

MR. STOCKING: As a matter of fact, for a six axes system I would replace yaw with roll, even though it's very small, when you push back and turn, you will get a gravity line cue.

MR. HARRIS: But it is very small.

MR. STOCKING: Yes, very small, but it's there.

MR. IRVING: It's there.

MR. BOOTHE: Bob [Heffley]?

MR. HEFFLEY: I think that we have a situation developing here where we really need to maybe start to make some basic distinctions between things that the pilot is doing where he is using cues in a closed loop sense to do something that involves a basic piloting skill. And we have other things going on where the pilot is using cues only to alert the pilot. And for example, in this case here where you have got a pushback. Well, isn't this a place where you can start to talk about substitute cues? I mean, all you are really trying to do maybe is to let the pilot know what the sequence of events are and where you are in that sequence of events. And if you try to carry something as simple as what we are talking about here in this ground handling to the same point that you know you need the fidelity for a basic flight maneuver, then you might as well decide on six degrees of freedom right off the bat. No question about it. Let's go have some beer.

MR. BAKER: Two votes for beer so far.

MR. CARDULLO: I was going to say with regards to degree of freedom, maybe rather than going through every maneuver and going through this torturous thing we could abbreviate that and get to the beer sooner. We could abbreviate that by just asking a general question. Does anybody think that you can get by with fewer than six degrees of freedom and—in any maneuvers for a Level B simulator, and if so, which degrees of freedom can we get away without?

MR. HARRIS: You can get away without—

MR. FOSTER: We are doing it. We are doing it right now. We have Level B simulators with roll, pitch and heave. And they are being used only as Level B simulators. And the results to this point are very satisfactory.

MR. CARDULLO: Well, then that's the answer to the question. But on the other hand it depends on how you define satisfactory.

MR. SUSSMAN: Bob [Heffley] put the question better. We can think of two considerations, one is what do you need for a cue to alert you to an event, and the other one was what do you need for a maneuver which requires feedback to maintain control.

MR. CARDULLO: I whole-heartedly agree with that. That's why I said ground handling is important because it's a high frequency domain and not when you are being pushed but when you are actually driving the airplane on the ground, those are important. But what I was just trying to do is say, okay, we got those important tasks, can we simplify the process by saying which degrees of freedom we don't think we need or we think we do need overall rather than going through each individual task?

MR. SUSSMAN: The reason I asked is, I think he is implying that you don't need the same degree of fidelity for all cues in all degrees of freedom; am I right?

MR. HEFFLEY: Yes. But the other little step in this is that for these tasks where you don't really need the pilot in the loop, so to speak, if it's a matter of the bumps on the ramp, there are cheaper ways to get that with a cheap seat shaker or something.

MR. CARDULLO: I agree.

MR. HEFFLEY: Something artificial then to necessarily try to get that through the large amplitude motion system.

MR. RAY: Isn't that part of the bigger issue of the cost? If you dissect it too far you can drive your cost up. Let's assume that you elect a six degree system as the minimum because of the maneuvers required. With that six degree system—six degree of freedom system, I can get those same runway bumps without adding to that seat shaker. If I look at that maneuver in isolation it may be that the seat shaker could satisfy the runway bump cue. If you focus on it too long you drive the cost of your simulation up because you are embedding, or adding, that device in isolation.

That's why I think the correct thing to do is look at the most important maneuver, that maneuver which requires the most significant pilot control feedback. In my opinion, you are looking at takeoff and landing maneuvers. You focus on those and your answer becomes clear and everything else falls out.

MR. BOOTHE: Shall we proceed to takeoff and landing?

MR. RAY: My basic instincts say that's the most critical maneuvers as far as cuing requirements, everything else falls out.

MR. IRVING: If you decide that you need pushback and you say hang on, you only do this once and it really is a fairly small event, it doesn't actually add up on a cost benefit basis, so out it goes. You are looking at the asymmetric business and the axis required for those maneuvers must surely be sufficient to cover less important, less repeated maneuvers.

MR. BOOTHE: Shall we proceed to the next table, which is takeoff? I have listed normal takeoffs and abnormal/emergency takeoffs. Under normal there is the acceleration, the airplane acceleration, if you will, to takeoff speed. And of course there is steering, there is crosswind compensation, there is probably other things. But those are the three things I have listed.

Under abnormal, there are rejected takeoffs, there are takeoffs with an engine failure, possibly takeoffs with a windshear, so that's really a lumped group of considerations there and as you can see—I guess I can ask the question that Frank [Cardullo] prompted, do we need any less than what's listed there? So I pose that question to you.

MR. RAY: I'm reluctant to raise my hand.

MR. CARDULLO: So you raised a finger.

MR. RAY: I think there is a logical case that can be made to say historically we have done it with pitch, heave and roll, correct? It's only because that's what, let's face it, Link produced back when, 1960 sometime for the Level A motion systems. It doesn't—I'm sorry.

MR. WILLMOTT: Probably 1929 when he patented the simulator.

MR. RAY: Yes, for his original simulator. I think it's very easy to come to the conclusion that that's what we have done, therefore it's correct, therefore that's what we will do in the future. I think we might cut off our nose to spite our face if we approach it that way. The reality is the pilot experience base we know that's come along through the airline history has been quite high. From military sources primarily. What's likely going to happen over the next 20, if not ten years, is the experience base is going to drop dramatically. We are probably going to end up with pilots we are required to train that have less experience than we have had in the past. We have an obligation to ensure the training of those pilots is as effective as we can reasonably make it. From what I'm hearing here from the sim manufacturers it's not going to cost any more to provide better training.

Would we be correct in the future, since [a] six degree of freedom is apparently as inexpensive as a three or four degree, should we simply continue what we did in the past? We would naturally grandfather the existing devices, we would be wrong to kill them.

MR. CARDULLO: Bob [Foster] makes a compelling argument when he says that it's been fine. And we can say well, that's all anecdotal, but nevertheless we don't have any counter-argument, any research that says anything different than what Bob [Foster] is saying. Other than the fact what we know theoretically. And what we know theoretically says that, really shouldn't be working fine. And that perhaps maybe the metrics just aren't there to identify the fact that it really isn't working. I mean, anecdotally we all hear all sorts of things, this is great, that's fine, but is it really, since we don't do transfer of training studies, we don't do much even in the way of performance studies, how do we really know it's fine? So we are stuck here. Do we just say that it appears to be fine so we do it that way? Or do we rely on our theoretical understanding of the problem to say what it should be, or do we go ahead and try to do some research to determine what really is fine. These are questions I don't know the answer to.

MR. LONGRIDGE: We are going to do both. We are going to make some decisions based on our best expert judgment. We will do some in the immediate future. We will also define promising areas of research.

MR. BOOTHE: I think we are here, you are here as a group of subject matter experts to tell us how it ought to be.

MR. CARDULLO: So theoretically I say you need six degrees of freedom. There is no question in my mind from a theoretical standpoint that you need six degrees of freedom. You get things like center of gravity movements, so you have to change the center of rotation, and in order to get different centers of rotation you need those additional degrees of freedom. You need side force cues, for engine out sorts of things, there is no question in my mind that you need six degrees of freedom.

MR. BAKER: I was going to ask if Bob [Foster] or anyone else has any anecdotal information that might shed some light on this from the standpoint of pilots that have been recertified in Level B simulator without yaw and lateral motion. And did it ever show up that they had a problem with an engine out condition, for example? Do we have any data at all that even if it's one or two cases that says, gee, this guy didn't handle an engine out situation very well and it may have been because he was getting all of his recurrent training in a Level B sim that didn't have the ability to give him a good cue for the situation?

MR. FOSTER: I'm not aware of anything. On the other hand, most of our airplanes are tail mounted engines, so there is not a—

MR. BAKER: You fly a lot of [7]37s.

MR. FOSTER: Yes, but we have all six axes simulators for the B-737 equipment. But on the other hand, look at this situation right now with the commuters, we take a relatively inexperienced pilot who has had virtually all his training in fixed base simulators or other airplanes, and now a commuter hires him and puts him through ground school and now they take him out in the airplane and do it and give him engine out conditions. They generally live through it, but that's a terrible thing to do compared to giving him a decent simulator where he can properly practice emergency procedures. There may be some limits imposed due to lack of motion in a couple axes, but I would submit I think with a good three axis simulator he is far ahead and a far safer and a far better trained pilot than the guy that that does not have the simulator at all.

MR. BOOTHE: I would agree with that. No pilots get exposure to things like engine failures in airplanes these days for training. The only people who get that exposure are the company test pilots and perhaps an FAA test pilot in the certification process. Therefore, I think it's a heavy responsibility of the simulation industry to provide the proper cues for that kind of training and that kind of pilot certification because that is the only exposure a pilot gets. And I have said that before in terms of data requirements, in terms of simulator motion cues, and even in terms of other cues a pilot receives, and I think it's, I don't want to sound too altruistic here, it's not fair to the flying public to put a guy up there who has not had the exposure to what might happen. I think Bob [Foster] probably agrees with that. But I also would have to say that a simulator that doesn't provide all the cues may be better than no simulation at all, but I don't know how to say that. Bob [Heffley]?

MR. HEFFLEY: Two points here. I guess we are really kind of talking three degrees of freedom versus six. I guess I concur with what Frank [Cardullo] says and what you just said and kind of trying to make a case for going all the way, in building a low cost simulator. If I were doing it I would still like to have the option of just going three degrees of freedom. It seems to me I could make it cheaper. But moreover, I think you all are maybe assuming that maybe you have a tacit quality, level of goodness that you are going to get with six degrees of freedom that are somehow going to give you really good engine out cues. I don't know. Given that this six degrees of freedom simulator is very expensive, one still doesn't have a very long stroke. You don't get very sustained cues, the basic quality of the motion is still pretty ragged compared to the real world. Are you really going to improve things that much more?

The bottom line is you still don't have a good solid basis for saying, well, six is really going to do the job a whole lot better. Especially in the light of people who use this three degree of freedom Level B trainer here for presumably a long time and getting what appears to be good results.

MR. RAY: I would like to add to Bob's [Heffley] comment along those lines. Looking at what's really going on, getting back to my pilot experience base again, those that are using the Level B sims, I think Bob [Heffley] would agree, are fairly highly experienced pilots. We are talking about pilots with several thousand hours of flying time. Let's look at who we are talking about if we focus on the commuter world. The vast majority of commuter pilots possess significantly less experience. Co-pilots may only possess 200 hours of actual flight time before being hired, including minimal multi-engine time or training. Are we correct in limiting motion to pitch, roll and heave only for that 200 hour pilot? Can we have the faith necessary in that the assessment of those pilots in that device is as good as the airplane? I don't think you can get there yet.

Pilots with the typical major air carriers have been through multiple engine failures both in the aircraft and [in] high fidelity simulation. The experience base that major air carriers typically have now is not going to exist in the future. Are we willing to make that step at this point to have that comfort level of proficiency assessment in simulation with three degrees versus six?

MR. HEFFLEY: Again you are assuming, though, that six sounds better than three. But those six degrees of freedom may still be just as distorted as the three except in a different way. Neither one is necessarily any closer, you know, to the real world. So it's one of those things without having something to really look at—

MR. BOOTHE: Good point. I think Frank [Cardullo] was first.

MR. CARDULLO: For the first time today I disagree with you, Bob [Heffley]. I think, you know, for example to use Ed [Boothe]'s example of the engine out on takeoff. You can't sustain that side force cue for very long, that's true. Well, but if you give a roll onset the guy is going to think the airplane is rolling, that's not going to cue him to the fact that he has an engine out. Now if you can at least provide him an onset in lateral side force and then roll it to try to sustain it for a while, I have to believe that's better than just trying to roll it. Because rolling it alone is going to give him the wrong cue. So you are right, [a] six degree of freedom system is not a perfect system because as we know it's constrained in all those degrees of freedom by its excursion.

But most of the psychophysical research with regard to how the visual system picks up after the motion, indicates that you hasten this onset of vection as long as the vestibular and somato-sensory stimulation is in the right direction. And it doesn't even have to be very long. Right? As long as it's in the right direction. And so I think that's the basis for the argument.

MR. BOOTHE: I think we are going to hopefully have time to address some of those issues about how long it has to be and what magnitude, I don't know—

MR. CARDULLO: I can't answer that one.

MR. BOOTHE: Okay.

MR. HARRIS: I will try and keep it short.

THE REPORTER: And louder.

MR. HARRIS: You are talking about cues, acceleration is obviously a prompt cue that comes from rotation. Onset is also a series of cues that comes from the linears. So if you are going to have onset with some sort of sustaining you need six axes. If you run a six axes system you can put in additional cues, like the Appendix H windshear we talked on before. The pilot may perceive a six DOF simulator as being a higher fidelity machine than a three DOF simulator. Higher fidelity. I don't know about this, but it's possible.

MR. WILLMOTT: Ed [Boothe]? Am I not right in saying that the simulator is used for training and checking? When the task of a V_1 cut or any of the tasks are done in the simulator for which the person is being checked, the check—a check airman is with him and certifies that he has done that maneuver correctly or incorrectly. Whatever the motion system is, if he does the maneuver satisfactorily, is that really what it is that you are looking for? And if it is, you know, why are you looking for other degrees of freedom in the simulator? And if by chance it's tougher to do it in the simulator, without these extra degrees of freedom, is it better for the person to be trained to do that and be more easily able to control the airplane where he has these total degrees of freedom? I mean, the argument that we are making here I think is "the closer you could make the simulator to the aircraft, the better it is." But we are looking at a device downgraded from a [Level] C and a [Level] D. We already have seven levels of flight training devices which can be used for all sorts of training for which there is no motion at all. So why do you need six degrees of freedom for motion in a Level B simulator?

MR. RAY: I would answer the question with a question, Stu [Willmott]. In that maneuver you are talking about, why do you need a visual system with it? Why do I need any motion system at all if my purpose is to see that the pilot successfully completes a maneuver? That's in essence what an examiner or check airman will be doing. They will be asked to see if a pilot can successfully control that device. If that device doesn't replicate the airplane, then how can the check airman's assessment be accurate? There's the old adage, the old Air Force adage, which was to make simulation tougher than the airplane. That was, as someone I think within this room accurately mentioned, that was the coverup for the fact that simulation at the time in the '60s could not replicate the aircraft. It was a known fact, so the Air Force accepted the adage "it's tougher, therefore it's better." But in fact what you do with improperly cuing a pilot in simulation is you include pilots who would otherwise be unsuccessful in the airplane. Similarly, we exclude some who would otherwise be successful in the aircraft. And that is, I would submit, improper.

MR. WILLMOTT: I am not suggesting that you do away with visual. I think that is a prime requirement for takeoffs and landings. But I'm not so sure that the motion is.

MR. RAY: Well, if motion is not a key player there, where would motion be a key player?

MR. WILLMOTT: For higher level devices for doing initial training.

MR. RAY: From a regulatory perspective of assessing pilot performance in flight, I'm sorry, you can't get there from here.

MR. LONGRIDGE: I think the logical conclusion, Paul [Ray], from your arguments, is we should do away with Level B simulators immediately.

MR. RAY: I disagree. I think the potential is there for designing a Level B simulation that may have in fact less excursion than a Level C or D, reduced excursion and whatever else needs to be modified within that, you end up with a smaller motion system. You probably don't end up with a 60-inch throw system, it may be that 30 inches is satisfactory. You get a smaller building, you reduce environmental costs, as we pointed out on the board. There are all sorts of things that can be done to improve Level B without driving costs. Let's not forget Level B's origins and that they were conceived as an accommodation and bridge to Phase II and III, or [Level] C and D. We should be able to have Level B simulation that perfectly satisfactorily meets the needs of a user whose final level of simulation is Level B.

MR. SUSSMAN: At this point you get into philosophical considerations.

MR. RAY: Oh, sure.

MR. SUSSMAN: What we usually do is establish a level of safety. Then in the future when we want to buy a piece of equipment which is important to maintaining that level of safety we must ensure that it is at least as "good as" the existing equipment. That is, new equipment must at the least provide the current level of safety. There are exceptions. For instance if you expect some external change to drive safety down, for instance a change in the demography of the pilots which results in lower initial skill levels. In this case you might have to go to equipment that is "better" than the existing equipment. The question is do we want a Level B simulator which is "as good as" the current simulators but cheaper? Or do want better Level B simulators because we expect external forces to impact safety negatively?

MR. SMITH: At the same time, and I hate to say this, I mentioned this a couple times but really that Level B simulator is going to fill the role of what the Level C is doing, a lot of Level Cs are doing now.

MR. SUSSMAN: You need a better requirement then.

MR. SMITH: I'm not saying that, but like Paul [Ray] says, in order to provide a simulator that can reasonably be used for recurrent training we have to come up with a cheaper Level B, you can't cut corners everywhere.

MR. RAY: The Level B only requires a single channel visual. That keeps costs down. Expanding the visual should be an operator's choice. You are talking substantial cost differences between a Level C and a Level B simulator.

MR. LONGRIDGE: We are getting into the issue of trade-offs here. I think we need to kind of leave it up to the group to define the discussion and not define what the trade-offs would be. It may be that a three DOF system, with a wider field of view visual system would be another alternative trade-off that we might want to make that might meet our requirements. I have to think we have to keep the discussion open to all possibilities.

MR. RAY: I think defining what three DOF is. It's not necessarily the old Link system. It may have worked fine for its intended use, but three DOF may be pitch, roll, yaw, sway, pick another one, not necessarily the original three. That's the paradigm we are carrying around on our shoulders now, that three DOF means old systems.

MR. HEFFLEY: We are still with three versus six, the only argument so far here to depart from three to go to six is the initial onset of an engine out until residual tilt takes over. And that may be a big price to pay for that.

MR. CARDULLO: I don't think that's the only one. That's one example. I think handling on the ground is another. I don't know how much handling on the ground you have to do, but not navigation sorts of things, but hitting the ground and high speed control of the airplane on the ground, the side force is important. And you can't sustain it very long, true, but at least to have that onset cue and then maybe the gravity align will help. I mean, there are two camps on the gravity align issue, too. But at least you get the onset. So that's another place where side force is important.

I'm not sure in windshear, I mean a lot of things can happen to the airplane in windshear. I'm just not sure how important side force cue is in trying to fly out of windshear. And I don't know how much training you do in a Level B simulator for flying out of windshear.

MR. RAY: Quite a bit. For non-turbo prop, the regulatory structure does not presently require simulator windshear training. If you have a turbojet aircraft, yes, you are required to accomplish simulator windshear training. It can be accomplished in as low as a Level A simulator.

MR. MARTIN: If you could do without the gravity align, there is the alternative of using a dynamic seat for some of the roll and pitch cuing. I don't know that it's much good in other degrees of freedom. Of course, you could include a vibration system. We have seen that dynamic seats can be very effective for roll and pitch cuing.

MR. CARDULLO: I agree they are most effective and the work that you did points that out. But even the work that was done at NASA-Ames with the old pneumatic seat showed some value. They did some engine out things with the dynamic seat and showed some performance benefit. I am referring [to] the work of Parris and Showalter out there. And it all goes back to some of the things we stated previously, as long as you are providing some cue in the right direction, as long as it's not in the wrong direction, as long as it's not a false cue, there is going to be some performance benefit. I don't know about training benefit, but there is definitely performance benefit from that.

MR. BAKER: I wanted to mention a couple things. Degrees of freedom and the necessity for them. The phenomena that occurs in the cockpit from engine out is primarily a lateral motion as opposed to yaw. Most of the effect a pilot feels is CG, the same thing is true with pitch, that the limitation that I always had was a six axes base has to do with vertical translations caused by pitching of the aircraft. That's on an A-10 aircraft that's only got 20 feet between the CG and the pilot. So I wanted to emphasize the fact that if you leave out—if you add yaw but don't add sway, for example, you really haven't bought yourself a whole lot because the yaw motion isn't what the guy primarily feels.

MR. CARDULLO: Right.

MR. BAKER: You can buy a lot by building a motion platform that's got three axes where the pivot point is well back behind the pilot. And giving roll, pitch and yaw, put the pivot point ten feet behind him and he is a lot happier than with the pivot point beneath his feet. The degrees of freedom come up pretty well when the pivot point is behind him as opposed to underneath him.

I had another point I was going to make, and like Ed [Boothe], I forgot.

MR. CARDULLO: Two things happen when you get old, you know.

MR. BAKER: You can't remember the other one, either?

MR. CARDULLO: I have the same problem.

MR. BOOTHE: Are you suggesting, then, that if we could say use a three degree of freedom system simply by redesigning the system, forgetting about convention and perhaps having a system that's unconventional with three degrees of freedom but emulates other degrees such as sway because of design factors.

MR. BAKER: Let me say I talked to Marty Henderson at Frasca about this a couple weeks ago. They designed a motion platform like that. They are putting it under FTDs basically but they said it gives quite a good result. There is no longitudinal acceleration, no surge on it, but the other degrees of freedom seem to come in pretty well. And you know, that unfortunately increases the dimensionality of the parameters paperwork by quite a bit, so we have a whole lot of other considerations in terms of defining how the motion base might be designed.

But, you know, it's back to the question of how do you skin the cat? And, you know, back to the question about how many degrees of freedom do you have and what's the trade-off? Is six axes with a 24-inch stroke better than three axes with a larger stroke? And does it cost about the same? Once again, I don't know the answer to that. I would have to go off and do a preliminary design. There are trade-offs like that which will be very hard to get a handle on in this discussion. And, you know, would something with a foot stroke be better, six axis base with a foot stroke be better than a three axis base with a three-foot stroke? I don't know.

MR. BOOTHE: That was the question I was going to ask. If you have a small displacement, six degree of freedom synergistic system, in which you could create small pulses in the right direction, small onsets in the right direction, but yet that would limit the gravity alignment rather severely, is that something we should consider for Level B or should we consider that only with a wide angle visual system? There is so many variables that we can put in the problem it's hard. But if we for the moment confine ourselves to a single channel visual system, and look at a synergistic motion system that's capable of six degrees of freedom but only for small onset cues, is that sufficient for recurrent training in a Level B simulator?

MR. CARDULLO: How wide a field of view is that?

MR. BOOTHE: Generally 40—is it 45?

MR. RAY: Forty-five.

MR. BOOTHE: Thirty-five, 45 per pilot.

MR. CARDULLO: To get circular vection, ideally you need about 60 degrees. But all the research that I know about, that supports the fact that you need 60 degrees to get circular vection, doesn't have any motion onset with it. My guess is that with 45 degrees and a motion onset you can develop circular vection. And as far as linear vection, most of that comes from optical flow, anyway. Recent work has shown that you don't really need to stimulate the periphery, given a narrow field with sufficient optical flow, you can develop linear vection but we are mostly concerned, I think, with circular vection, anyway. So my vote would be for shortening the stroke and keeping the six degrees of freedom and you can almost shorten it to whatever you want.

MR. BAKER: One of the things, let me say—

MR. CARDULLO: To make it cheap.

MR. BAKER: To shorten the stroke you don't necessarily loose angular motion, you essentially lose linear motion. 23 degrees, right now it's not a big hexapod, you can maintain that, so the gravity vector alignment question really isn't an issue.

The other point I wanted to make a minute ago, if I could sneak that in while I have got the floor, one of the things that strikes me is that we have been searching as an industry for 20 or 30 years to try and determine what we can get by with and what we can't get by with in terms of motion cues and visual cues and so on. And there isn't a whole lot of hard data that you can hang your hat on that says this is what's enough, and anything less than this isn't enough. And you know, Bob [Foster] has been training pilots on three axis bases and as far as we know it's been satisfactory. The consensus amongst a lot of us is that "gee, you could do better if you had more degrees of freedom," we almost all intuitively believe that's true. We know if we go back to zero degrees of freedom we can create problems with training. And so we are trying to make, I would say, a judgment call here between three axes and six axes, and the concern I've got is that after a lot of years and a lot of study we still don't have any really good data that says yes, three would be good enough for all these particular types of training scenarios, and you know, I think we are in a position where it's almost not a bad idea to err on the side of conservatism and say Levels C and D are running six axes bases and we are almost convinced it's pretty good. Maybe we ought to impose that on the Level Bs. Just on the basis of consistency and the fact that, you know, to some extent the same argument holds true with motion and it holds through with a 300 millisecond time delay. That's what was available back historically when a lot of these devices were built. We had to find a way to fit them into the program.

But we are talking about new simulators now and you know, we could get into a long discussion about how much this three additional degrees of freedom cost, these guys who build the simulators think it's not a really expensive item. So if that's true, then, maybe we ought to go for it and say hey, put it in there because it's not going to drive your costs that hard.

MR. CARDULLO: I'd like to make one comment about what you can train with. Ed Link trained thousand of pilots in World War II with a blue box and trained them, as everyone would say at that time, trained them successfully, and that blue box was a relatively low fidelity simulator. So you can accomplish a certain amount of training with any kind of a training device. But when we want to talk about some of these more sophisticated maneuvers, and actually training them in some of the things we have been talking about here, that's when I think we need the additional fidelity or the additional capability. So you can get by with very little, but trying to do as much as possible with as little as possible I think there are trade-offs and I think, as I said before, I would err in the direction of six.

MR. BOOTHE: Ed Link didn't certify pilots to go and fly in revenue service. He prepared them to go and train in airplanes.

MR. CARDULLO: But they got some training, that was my only point.

MR. ELDREDGE: Can we take a five or ten minute break for Allison [The Reporter]? We are expected to go another half hour.

MR. STOCKING: Just one quickie I wanted to bring up. Signs of the times. There is also product liability that's going to come in the future. We need to think about that, also, in terms of cost of this device.

MR. BAKER: Would you elaborate on that?

MR. STOCKING: Somebody suing us after an accident saying our training equipment was not satisfactory.

MR. BAKER: You would like to face the situation and say we did the best we possibly could.

MR. BOOTHE: No, what they will say is the FAA approved it.

MR. BAKER: You guys will pay the bill?

MR. BOOTHE: That is a good thought. I think a few minutes break, five to ten minutes is a wonderful idea, and I had been waiting for an opportunity.

(Break taken.)

MR. BOOTHE: Did everybody that gave me a ticket get it back?

If anybody did not give me a copy of their ticket, would you please remember to do that tomorrow?

I think the consensus was that if we all had what's best, we would have six degrees of freedom for the takeoff task or various takeoff tasks. The question that I have, is that the minimum we can have and still meet the requirements for Level B simulator which are, which you heard before the break are now being met with three degrees of freedom. Or should we try to define a system of less than six degrees of freedom and decide what are the most important ones and can we build a lesser system reasonably or cheaper to satisfy those requirements, or should we say we need the six degrees of freedom and start working on how small can we make it in terms of those critical parameters?

MR. ADVANI: As far as I'm concerned, it all comes down to the acceleration and the amounts of false cues that are presented. The elimination of false cues and the negative effects on training of those, as far as I'm concerned, are the most critical parameters.

MR. BOOTHE: Do we introduce more false cues by reducing the size of the system?

MR. BAKER: Yes. It's a trade-off between washout rate and level of input cue. If I wanted to have the same level of acceleration cue in a small system versus a large system, then I've got to wash it out faster to keep from bottoming out the actuator.

MR. BOOTHE: But if we accept a smaller system, can we accept less acceleration cue as long as it's in the right direction? Assuming that we then generate, more quickly generate vection in the correct direction?

MR. BAKER: I think Frank's [Cardullo] position is we can do that, if we have a cue in the right direction even though it's reduced amplitude, that's a very good thing. I've got data that says the same thing. We ran a sim at 20 percent gain and got very good motion acceptance by the pilots. They were getting a fifth of what they would have gotten in the airplane with the same maneuvers, yet they were happy with the result.

MR. BOOTHE: They were happy in what respect?

MR. BAKER: They were happy in the sense they could do a rather difficult task, they had very complimentary things to say about the motion cues and its effect on flying. The tasks they were doing was manual terrain avoidance on a simulated night vision system which had a very restricted field of view. And at the same time they were asked to do a task of looking at a head down display on a missile guidance system, they were busy. They were busier than just about anybody would ever get in an aircraft. They had very good things to say about, for example, looking at the head down display, how fast it took them to mentally figure out what the airplane was doing when they went back out the window, for example.

Basically the problem is, one of the problems that you get into with that particular environment, the guy has been looking at the head down display for maybe as long as a few seconds, he wants to check that the airplane is still airborne and isn't about to run into the mountain or getting too low to the ground. He wants to be able to acquire in the essentially out the window visual or his flying visual scene, he wants to acquire very quickly what the airplane is doing. And the comments from the pilots were that it's much easier to do with motion on them than no motion. We didn't try it with three degrees of freedom as opposed to six, just the point was that even the 20 percent cues they were getting were a huge advantage for the problem of acquiring, rapidly acquiring what the airplane was actually doing.

MR. BOOTHE: This was strictly pilot opinion, you didn't measure performance or workload?

MR. BAKER: The only measurements on workload was 29 out of 30 pilots said they couldn't fly the mission without the motion on it. The other guy was some anomalous character that said it didn't matter. He can do it with motion or without motion. 29 out of 30, the most frequent comment was "gee, now I can fly it," when we turned the motion base on for it. We instruct him by a guy sitting by the side of the cockpit with the motion off, we instructed them on exactly what the task was and they would try to do it with the motion off, generally not do it very well. As soon as we turned the motion base on every one did well. So that's my anecdotal story about motion. It's an intense task, okay, it's like a carrier landing in bad weather, very, very intense.

MR. CARDULLO: I think we should ask Ed [Martin] to tell the group about the experiments that they did with very little motion system and the very favorable results they got.

MR. MARTIN: You are speaking about the dynamic seat stuff?

MR. CARDULLO: Right.

MR. MARTIN: We were looking only at roll axis, that was supposed to be just an initial look into the effectiveness of seat cuing. We had plus or minus 12 degrees capability in roll. Of that, we used just a couple degrees. But we were able to elicit operator performance with just seat cues that was indistinguishable from operator performance observed in a one-to-one full body motion device.

In addition, we measured frequency domain characteristics that allowed us to essentially characterize the pilot as a filter—and in this way look at operator control strategy. We were able to elicit the same operator control strategy as observed in the full-motion environment, with just a small amount of seat motion. This was accomplished with essentially plus or minus two degrees or so of platform motion that was providing tactual cues. There wasn't any vestibular information that we could detect coming through. We did some tests with a bite board to check this out.

MR. BOOTHE: You mean the motion drive was just on the seat itself?

MR. MARTIN: Just on the seat. The information was just coming through the seat of the pants.

MR. BOOTHE: So you had roll—just roll.

MR. MARTIN: Roll was all I looked at initially. Some follow-on stuff was done with pitch. They seemed to be getting similar results in pitch.

MR. CARDULLO: It's a single axis tracking task he was doing. With a very narrow field of view visual that was really nothing more than an instrument display, an artificial horizon.

MR. MARTIN: The visual display mimicked an ADI. As I recall it subtended a visual angle of about 12 degrees.

MR. CARDULLO: You weren't really getting a lot of motion information out of the visual.

MR. BOOTHE: All I need is a little six degree kick in the pants?

MR. CARDULLO: The question you asked was how small can you get?

MR. BOOTHE: Right.

MR. CARDULLO: So this indicated that you could get quite small. No washouts, you've just got to be careful as Sunjoo [Advani] has said several times, not to give any false cues. Now, this was a limited experiment, but nevertheless I think it's quite encouraging, the results were all published so you can read them.

MR. SUSSMAN: Ed [Martin], you said one thing, you were sure they were having no vestibular cues, the head was fixed basically?

MR. MARTIN: Pardon?

MR. SUSSMAN: The head was fixed?

MR. MARTIN: Yes.

MR. SUSSMAN: Just seat of the pants.

MR. MARTIN: But still with tactual seat motion.

MR. SUSSMAN: Yes.

MR. ADVANI: We have done work in our group also using a very limited display, artificial horizon in a tracking task where the only, let's say motion cues, are coming through an active side stick, so you can see that the very high frequency proprioceptive feedback gets you a lead [and] that you can stabilize a highly unstable task just through that cue only. Which tells you something about the muscle, joint and proprioceptive sensors as opposed to the full vestibular system.

MR. CARDULLO: I'm not advocating we go to a dynamic seat at this point. I think it would be problematic from a pilot acceptance standpoint, and maybe probably from the FAA. But nevertheless, it does give you some idea that you can get performance equivalent to the criterion device. That was key, I don't know if everybody caught that but they actually transferred and measured in a full motion simulator—they didn't transfer to an airplane, but they transferred to the RATS, the roll axis tracking simulator, which gave full roll motion.

Do you have pictures?

MR. MARTIN: Yes, I think I do. Yes.

MR. CARDULLO: So that's a quasi transfer study, so it's essentially the same thing as transferring to the airplane. You get as much motion out of that in that roll axis as you would out of the airplane.

MR. MARTIN: Basically what we had for a criterion device was a roll axis tracking simulator that was capable of full 360 degree roll. We included the dynamics of this device in the simulation for the dynamic seat. For training we used this dynamic seat in the enclosure shown here, with the same ADI-like display as in the full motion device, and performing the same task—but with just the limited amount of seat roll motion. We trained subjects in this device, then transitioned them to the full-motion device. We actually had four groups of subjects. One group started off in the full motion device as the control group. One group trained with no motion cuing. Two groups trained with two different dynamic seat drive laws.

MR. SUSSMAN: Let me ask a question, you are saying people who trained in this device did as well in the RATS as people who trained in a full motion device?

MR. CARDULLO: No, we didn't say that. That's the other shoe.

MR. MARTIN: No. Once subjects were trained to proficiency, task performance using the dynamic seat cues was indistinguishable from task performance in the full motion environment.

MR. SUSSMAN: Okay. That doesn't demonstrate that this was good training for flying airplanes. It means that you can get the same cues. That's different.

MR. MARTIN: Training transfer was disappointing, because when we took groups that trained on the seat and put them into the full-motion device, they regressed and required a few sessions to get back to previous performance levels. However, they didn't start out as badly as the control group starting out in the full motion device with no previous training.

MR. SUSSMAN: That's very important, though.

MR. MARTIN: Oh, yes.

MR. CARDULLO: The point is that you can elicit the same performance, whether that transfers or not is another question. And that is a very difficult question to answer.

MR. SUSSMAN: Isn't that the most important question?

MR. CARDULLO: It may be.

MR. MARTIN: In the case for the Level B simulator, we have got people that already know how to fly the airplane. We did look at reverse transfer with pilots (rather than naive college-student subjects) where the pilots were trained in the full-motion device and then transitioned to the dynamic seat. That turned out to be pretty straight transfer. Forward transfer (from the seat to the full-motion device) showed statistically significant benefit of seat training when experienced pilots were used as subjects. However, naive college-student subjects that were trained in the seat and then transitioned into the full-motion environment still had a lot to learn about that motion environment. There was a lot of difference in the motion environment with whole-body motion versus just having tactual stimulation. Naive subjects just weren't able to learn how to use that motion information with the seat cues alone.

MR. CARDULLO: There is probably only one study out there that shows significant transfer of training of motion to the airplane. And that's that helicopter study that was done by—

MR. HEFFLEY: Jeff Schroeder?

MR. CARDULLO: No. Who was the guy? I think it was a Navy guy, wasn't it?

MR. MARTIN: Galloway, are you talking about somebody down at the Naval Air Warfare Center's Training System Division?

MR. CARDULLO: I don't remember. Grant often quotes that work. Other than that, any transfer of training studies that have been done with motion show virtually no transfer. But almost all the transfer of training studies, if not all, were done with inferior motion systems. And recently with the stuff that's been done with good motion systems there haven't been transfer of training studies, they have been performance studies. And does performance in the simulator improve with motion? And the answer to that question is always yes. Does that mean anything? It means something, but it's not clear whether it means it transfers training. But if you compare behavior or performance, it seems to me if you are getting the same behavior in the simulator as you would get in the airplane, then that should be indicative of transfer. Because what are you trying to train? Well, you may be shaking your head no, but what are you trying to do in a simulator? You are trying to teach behavior. And so if you are getting the same behavior, I don't know why it doesn't seem to transfer.

MR. SUSSMAN: I would argue in a simulator you are trying to teach appropriate responses to cues which indicate emergencies or flying difficult situations, you are not trying to teach how to fly a simulator.

MR. BOOTHE: The question I have, you said you are getting—you are studying performance and performance improves if you have motion. And then you switched to behavior. Now, my question is—

MR. CARDULLO: What's the difference between performance and behavior?

MR. BOOTHE: My question is, which are we really getting? You can get the same performance with a lot of pilot compensation.

MR. CARDULLO: That's right.

MR. BOOTHE: That's different than—

MR. CARDULLO: Depends on how you measure performance. That's why performance and behavior sort of overlap.

During the break I was talking about some things that we did just fooling around where you saw, when you turned the motion system off, that the pilot went from very small control in station keeping for air refueling, to after the motion system was turned off really jerking the stick all over the place. But nevertheless maintaining the same error, so behavior changed but the performance, as measured by the error with respect to the tanker aircraft, remained the same.

MR. BOOTHE: My whole point.

MR. CARDULLO: That's your point?

MR. BOOTHE: Exactly. Performance alone—

MR. CARDULLO: It depends. If you call performance in a general sense behavior, where workload goes up or down, so it depends on how you define it.

MR. BAKER: I think from a scientific/analytical perspective what we are trying to accomplish with training, at least in a lot of the situations, is that the man's mental controller that he uses for the particular task is the same in a simulator that it is in an airplane.

MR. BOOTHE: That's close.

MR. BAKER: If we had a way to measure that, we would be home free.

MR. BOOTHE: You never know how hard I'm working.

MR. BAKER: You can measure how hard somebody is working a lot of times by looking at amplitude of motions.

MR. BOOTHE: You can get indicators, I think. But we are interested in more than training. We are interested in pilot certification. What we want a device to do for pilot certification is to permit that pilot using the behavior he would use in the airplane to achieve the same performance he would achieve in an airplane. And in fact there is only one set of performance standards and it doesn't matter whether you take a check in an airplane or a simulator, you still get graded on the same performance standards. So if the device doesn't stimulate the same behavior for any given task that the airplane would, then we aren't really certifying the person for the same airplane.

MR. BAKER: That's basically what I was trying to say.

MR. BOOTHE: So when we talk about small motion systems, that's the question that I'm concerned about, will they stimulate their behavior that the airplane will stimulate? And how can we decide that here? Has somebody got an answer?

MR. CARDULLO: You can do experiments. Not here.

MR. ADVANI: We need to do research.

MR. SUSSMAN: The research is transfer of training research.

MR. CARDULLO: I don't think you can do transfer of training research. I think it's impossible to do transfer of training research.

MS. BÜRKI-COHEN: Perhaps you can do quasi.

MR. CARDULLO: Perhaps you can do quasi transfer of training. For example, how do you do transfer of training for negotiating windshear? Are you going to take the guy up and fly around and look for some windshear and try to fly through it?

MR. MARTIN: You could probably do that in a variable stability aircraft.

MR. REID: I can simulate windshear.

MR. LONGRIDGE: Certainly we can do transfer performance from a redefined Level B to a Level D sim.

MR. CARDULLO: Sure. Those kinds of things you could do quite easily.

MR. LONGRIDGE: We could do some transfer to aircraft for tasks that routinely occur in aircraft.

MR. CARDULLO: That's still tough and expensive to get.

MR. LONGRIDGE: Money is no object.

MR. CARDULLO: Performance studies are easy, performance studies are more reasonable to do than transfer of training.

MR. LONGRIDGE: Of course. Yes. I mean we are concerned really with transfer performance, we are not concerned so much with transfer of training in that we want the same level of performance whether we are talking about the aircraft or a simulator, we are talking about terminal performance.

MR. BOOTHE: But as I understand it, you have two objectives here: A very short-term objective of trying to define a Level B simulator that's lower cost and can do the job, and a longer term objective with some research—

MR. LONGRIDGE: Right.

MR. BOOTHE: —involved to maybe validate what we do in the short term, I don't know.

MR. LONGRIDGE: Yes, by all means.

MR. BOOTHE: So I think it's our job here in the day remaining to see if we can identify something for the short term that we think—I mean, we have the data that you know about, but we are still stuck with our expert opinion to identify a device that we think will satisfy the short-term purpose of certifying pilots, recurrent certification in a Level B device, and what's that minimum device? And would motion be in the pertinent subject for this group? I think we have already come to two preliminary conclusions, I say preliminary because we have another day and what we say today may change by tomorrow. And that is we seem to agree that six degrees of freedom is necessary. And we also seem to agree that six degrees of freedom with very limited envelope is acceptable. Is there any—am I wrong on that?

MR. LONGRIDGE: Can we take a show of hands how many people concur with that position?

MR. BAKER: I agree with that conclusion.

MR. BOOTHE: I certainly do. I shouldn't be able to vote. Well, let me just ask, who does not think six degrees of freedom are necessary for the critical tasks that we identified in takeoff and landing, is there anybody that thinks we do not need six degrees? We have—

MR. HEFFLEY: About the question, I guess you are just asking for an opinion.

MR. BOOTHE: Expert opinion, that's what I'm asking. So we have Bob [Foster] and Stu [Willmott] and you [Heffley] and Tom [Longridge]. We have four people who say that we do not need six degrees of freedom.

MR. LONGRIDGE: Maybe a better way of phrasing it is at least I'm not convinced, I'm not convinced that we need six degrees of freedom for a Level B device.

MR. HEFFLEY: It seems like there must be some burden of proof here to make the step that we are talking about. It seems reasonable, seems nice. But there is this fundamental trade-off between cost and effectiveness that maybe is a flip of the coin. And we have got this basic experience of existing simulators that keeps bothering me.

MR. RAY: I just pose a question to you, Bob [Heffley]. I'm not trying to convince you. I guess my answer would be do I agree that more than three is required, and that's a yes. The options were three or six. I think more than three certainly are required. But would you agree or disagree that some standard should be applied to what those three degrees should be capable of doing?

MR. HEFFLEY: Yes.

MR. LONGRIDGE: Of course.

MR. HEFFLEY: Yes. And likewise with six, you know. Six doesn't buy you the world. You can have six really poor degrees of freedom.

MR. CARDULLO: Which six are the poor six?

MR. HEFFLEY: The other thing that bothers me about it is the same question is going to maybe pop up here with some of these other characteristics. Seems nice to eliminate all cross-talk, but it's a matter of degree, and engineering time alone to handle some of these questions can be horrendous. And it's trying to make these kinds of judgments or decisions simply based on—well, not casual, this isn't casual discussion, but I understand we are all coming from a lot of different places and experiences here. But ultimately it's not having any real good rational basis other than just some kind of logic that sounds, you know, sounds about right. Six sounds better than three.

But it troubles me that there is still, still might be some very good reasons for allowing some latitude as to stick with three here.

MR. IRVING: I just want to make a point, I think six is a comfortable decision. I don't think that it's necessarily a valid or logical decision. I think we might be doing a disservice to the community if we say six. Three or four, four and a half, four and a quarter, I don't know. Remember, Ed [Boothe] and I worked on the Level A working group and we agreed that counting the level of axes was too difficult, so we didn't count them.

The industry hasn't taken up the issue because we don't have Level A simulators. I think there is a disservice in saying [that] six is comfortable, and [that] six must be better than four axes.

How you quantify or define as good or not so good in a regulatory document I think is probably nearly impossible.

MR. LONGRIDGE: Did you include any specifications regarding what would be sufficient for the task?

MR. IRVING: No.

MR. LONGRIDGE: You left that wide open.

MR. IRVING: We said it had to be sufficient.

MR. LONGRIDGE: This is kind of a subjective decision on CAA's part.

MR. IRVING: The FAA was present. But I think the point there is that we couldn't sensibly conclude what was or was not necessary and we felt that there are wiser people and we shouldn't constrain their creativity. Remember the ultimate—the less you specify, the more risk you are passing on to the doers and owners downstream.

MR. LONGRIDGE: That's great. How does the regulatory body qualify the device in the absence of qualifications?

MR. IRVING: Because three axis and six axis doesn't help to qualify the device. The subjective tests are really the arbiter in our view.

MR. LONGRIDGE: The six.

MR. IRVING: The six. I remember sitting there being told you can't have at Level C, why not, it can't move forward and backwards, it only has five, not six. Ridiculous observation. Well, make it move back and forward. I think it has to be left subjective. I think we are bright enough to define collectively how good or bad motion must be when it's totally integrated with the training device, simulator.

MR. BAKER: I think the danger of doing that is you get quite a variety of reactions from pilots. One guy will say "well, I can't fly this thing in this particular maneuver because the cues are missing." And another guy will do it just fine, he won't even care. And, you know—

MR. BOOTHE: That's a good point. But you see, Bruce [Baker], I think it's even more serious than that in terms of a recurrent check. Maybe Bob [Foster] can help me out here, but in an airline where you have pilots whose career is at jeopardy when they take a check, and should they fail that check, and that the device is in their opinion insufficient to support the task they failed, there are—that there are means for them to get checks in other devices, even airplanes and all sorts of things. I say you might have to help me out including union policies to save their jobs. So we can't be in a position of specifying something that won't support the task, in fact rather than minimize a specification and have some fears of it not supporting the task I would, as I did, go with Don's [Irving] position of something sufficient for the task. Not knowing what that is. And so we are back where we started from. But we can't afford to specify something that sets a guy up or a woman up for failure. So that's a tough problem. Right?

MR. CARDULLO: If you go through this taxonomy of tasks that you have listed here, if you say which tasks can be done with a three degree of freedom of motion system, the standard I think which is pitch, roll and heave, it's none.

MR. BAKER: That's the cues missing. You have missing cues in every one of those tasks.

MR. CARDULLO: Right. And the only ones, the only maneuvers that include pitch, roll and heave are the ones that include all six. So—

MR. BOOTHE: My guess is—

MR. CARDULLO: So what that says, if you are going to have less than six, presuming this is reasonably accurate and you certainly have as good a sense as any one of us as to what the dynamics are and what information you need to do the various tasks, what that says is if you are going to do with fewer than six degrees of freedom, you have to design a new three degree of freedom or four degree of freedom motion system.

MR. LONGRIDGE: There is nothing that says we can't do that.

MR. CARDULLO: No. But I'm just making that point.

MR. BAKER: Let me say something about that.

MR. CARDULLO: Is that really cost effective? I think the sense I got was that the people who were favoring the three degree of freedom were favoring from the standpoint something already exists, and we can work with what already exists. That may not have been your point of view but I think it was Bob's and Bob's [Foster and Heffley].

MR. BOOTHE: No, I think that's not the case.

MR. CARDULLO: Is that not the case?

MR. BOOTHE: We think there are four important degrees of freedom that will support this task. I think we ought to say what they are.

MR. CARDULLO: Oh, yes.

MR. BOOTHE: And then, as Don [Irving] so aptly points out, it's the industry's problem to figure out how to get them.

MR. BAKER: Let me make a comment about making motion platforms that have less than six axes and other than roll, pitch and yaw. Roll, pitch and heave I mean. Roll, pitch and heave are probably the three easiest to get and it's easiest to constrain x, y and yaw. All right? There have been motion platforms built in the entertainment industry that I'm aware of that do x, y and z. And there is a lot of iron in there to keep the thing from doing roll, pitch and yaw when you don't want it to. And I think for most of those configurations, with the possible exception of one that I mentioned that did roll, pitch and yaw, it's probably true that you are not going to save a lot of money by taking degrees of freedom out. Because the constraint mechanism gets to be very, very hard to build. And believe me, we have looked at a lot of different situations where guys have asked funny questions about two axis or three axis, like an x, y motion platform. It's a hard thing to build, okay? Compared to pitch and roll. Pitch and roll is very easy to build.

So I think that if we are going to constrain—if we are going to allow or constrain the thing to three degrees of freedom we better have a reasonably good idea of how we are going to—what three degrees of freedom we are going to use and exactly how a guy might build that.

MR. LONGRIDGE: I think there is an improper phrasing, there was never an intent or suggestion to constrain it to three. All you are doing is specifying a minimum requirement. That doesn't preclude people from using six.

MR. BAKER: The guy can go beyond the requirement, yes.

MR. FOSTER: One thing I would like to say, I don't think you can judge a three axis motion system that would be built today with the experience that most of us have had with three axis motion systems that were built in the late '60s, early '70s. I think if we were to allow, still allow use of the three axis level motion for the Level B, there has to be performance specifications, serious ones about turn-around bumps, smoothness and that kind of thing. I don't think you would find a lot of comparison about the pilot sensed end performance in a hydrostatic three axis motion system that had some serious analysis done of proper drive algorithms to it. If you remember, most of those were attached to PDP-11s and GP-4s, the motion drives in them were so simple, it's hard to believe. There is no compensation for hardly anything. And the servo valves were very bad on them by today's standards. If somebody was to start from scratch to build a three axis system with roll, pitch, heave and had minimum performance specifications to meet, I think you would end up with a much different three axis motion system than what people were used to in the old 727, DC-9 and that kind of thing.

MR. CARDULLO: It would still be missing degrees of freedom.

MR. FOSTER: But I think it would take a lot more advantage of the ones that are there. Most of the three axis systems out there now are so toned down, a lot of them have a frequency range of one cycle every two hours, you turn it on, it goes up, two hours later you turn it off and it comes down. And it wiggles.

MR. CARDULLO: That's true of some of the old six, too.

MR. FOSTER: We have to tie some performance specifications to it. Particularly, the friction on those cylinders was so high, and so variable depending on, you know, whether it was first thing in the morning or you overhauled the o-rings, the seals last week or last month. So consequently they were all severely detuned and in fact most of the time people turned on servo—

MR. CARDULLO: I think what we are talking is equivalent servo performance and actuator design and all of that whether it's three or six degrees of freedom, the question that's germane is can you get away without some of these degrees of freedom?

MR. FOSTER: And I think—

MR. CARDULLO: And which ones?

MR. FOSTER: Right. What drives that for me as a user is the overall size of the device. I wouldn't probably have—if there wasn't a lot of economic or cost difference between the three axis and a six axis and it fit in the same envelope, and I could put it in the same building.

MR. CARDULLO: You could do that.

MR. FOSTER: Nobody has proposed it and I haven't seen any. Nobody proposed it when we looked at some of the regional people trying to go for—to try in the last few years trying to set up regional carriers with it. Maybe somebody can do that. But the problem you get into is the life cycle cost of the simulator. If you now all of a sudden have to go to something with a 32-foot ceiling or a 24-foot ceiling instead of a 19-foot ceiling, it's a huge difference in initial cost which you have got to fund out over ten, 15 years, and it becomes a prohibitive cost rather than possible.

MR. CARDULLO: I agree.

MR. STOCKING: I was going to say there is a fellow in Binghamton that makes a good three degree system. It's about the same size and stroke as the old ones. He still ends up with cues subdued, part of the reason is you are not getting all the cues. They have to subdue the cues, you do have to hide or mask the false cues. So you still end up with the same problem.

MR. HEFFLEY: Well, so, you know, it's sounding more appealing to me to focus on the cues that you want as opposed to how you get them. And the idea here that, I think Don [Irving] was really right on, you lay out the task, you lay out the relevant cuing, and whether that cuing comes as a result of a direct axis of actual motion or whether maybe it's substituted very cleverly by something in your seat, if in the end it does the job, that's what you want. And it's kind of like the problem over the years that airplane designers had versus the people who were specifying airplane designs, you know? In the end you really wanted to lay out what you wanted the airplane to do, then you let the designer do it and do it to design the aircraft, to do this job in whatever way really made sense. And you didn't say "well, we have got to have spoilers and flaps and all kinds of augmentation systems," you do what's required to get the end result. So you lay out what you want first.

MR. BOOTHE: If you are lucky you get a P-51. So seriously, that's the kind of thing I think you are talking about. I think we have got a set of directions for tomorrow and I appreciate Bob [Heffley] bringing to the day a bit of humor near the end on a one cycle system. But I think we have done lots of discussing of what we know about motion systems or what we don't know about motion systems, as the case may be. I would like to leave here tomorrow, though, with something tangible that we can use to pose to the FAA to propose to regional airlines and I don't know whether at this point it should go through this table and try to forget what I have written here, just look at the task and say what are the minimum degrees of freedom or whether we should abandon the table and do what Bob [Heffley] has said and look at these tasks and say what are the cues you need? And is there a big difference?

MR. HEFFLEY: I don't think there is any difference, that's what I was thinking.

MR. CARDULLO: The table has the cues.

MR. HEFFLEY: It has the cues.

MR. BOOTHE: So is that a direction for tomorrow morning, to go to the table and minimize those cues to get a minimum system to serve our purpose, and not be concerned about whether it's a six degree of freedom system or whether it's a four degree of freedom system? Let's just look at the task and try to minimize the requirement. Is that a possibility for a starting point tomorrow? I can't think of another direction to go.

MR. WILLMOTT: I was going to say if you have one maneuver in there that required all six degrees of freedom, then why do you go to the rest of them?

MR. BOOTHE: I don't know which one that is.

MR. HEFFLEY: You might think of other ways.

MR. BOOTHE: Maybe we can start with what we think are the more complex ones and work our way down to the less complex. That might be a good approach.

MR. CARDULLO: Maybe we could give everybody a homework assignment tonight to go through the list and check off the degrees of freedom that you think you need for each of these maneuvers. And see how that comes out tomorrow. It won't take very long for each of us to do that this evening. And then we come prepared with that tomorrow morning and I think everyone will have a good idea of what they think they can eliminate, which degree of freedom they think they can eliminate.

MR. BOOTHE: I would be delighted if you would take that assignment. So we can proceed in that direction in the morning. For the rest of today, there is, what little bit is left, there is the cash bar that was supposed, does begin at 6:00. And—

MR. LONGRIDGE: That's in the grand ballroom number three right through the double doors.

MR. BOOTHE: And dinner will also be there at 7:00.

MR. LONGRIDGE: Yes.

MR. BOOTHE: So hope to see you all there. We will start here again in the morning at 8:00 for the continental breakfast. Thank you for today. It was interesting and I look forward to tomorrow.