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### Session III. Reactive System Technology

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An Approach to Evaluating Reactive Airborne Wind Shear Systems  
Joe Gibson, Martin Marietta

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**AN APPROACH TO EVALUATING  
REACTIVE AIRBORNE WINDSHEAR SYSTEMS  
IN THE CONTEXT OF  
GROUND-BASED SYSTEM DEPLOYMENT STUDY**

**MARTIN MARIETTA**

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APRIL 14, 1992**

An Approach to Evaluating  
Reactive Airborne Windshear Systems  
in the Context of  
Ground-based System Deployment Study

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ABSTRACT

An approach to evaluating reactive airborne windshear detection systems was developed to support a deployment study for future FAA ground-based windshear detection systems. The deployment study methodology assesses potential future safety enhancements beyond planned capabilities. The reactive airborne systems will be an integral part of planned windshear safety enhancements.

The approach to evaluating reactive airborne systems involves separate analyses for both landing and take-off scenario. The analysis estimates the probability of effective warning considering several factors including NASA energy height loss characteristics, reactive alert timing, and a probability distribution for microburst strength.

# **AGENDA**

• **INTRODUCTION**

• **PURPOSE**

• **ANALYSIS**

• **SUMMARY**

# **PURPOSE**

## **ANALYSIS TO SUPPORT DEPLOYMENT STUDY OF FUTURE GROUND-BASED SYSTEMS**

- **TDWR OPTIONS**
- **ASR WINDSHEAR PROCESSOR**
- **LLWAS-3**

## **DEPLOYMENT STUDY METHODOLOGY ASSESSES POTENTIAL SAFETY ENHANCEMENTS BEYOND PLANNED SYSTEMS**

- **PLANNED GROUND-BASED SYSTEMS**
- **PLANNED AIRBORNE SYSTEMS**

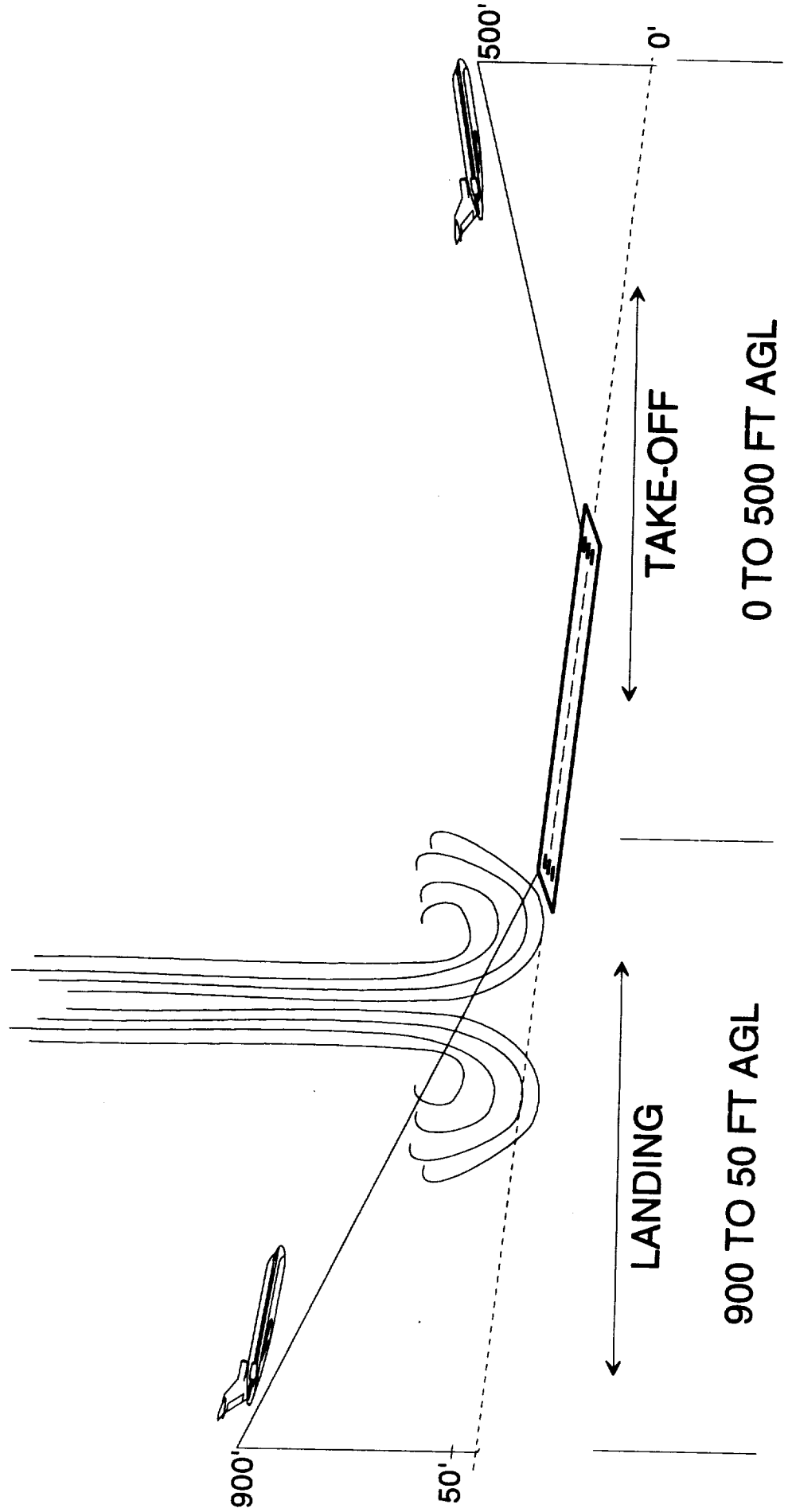
## **REACTIVE SYSTEMS ASSESSED**

- **FORWARD-LOOKING ASPECTS UNCERTAIN**

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# ANALYSIS OVERVIEW

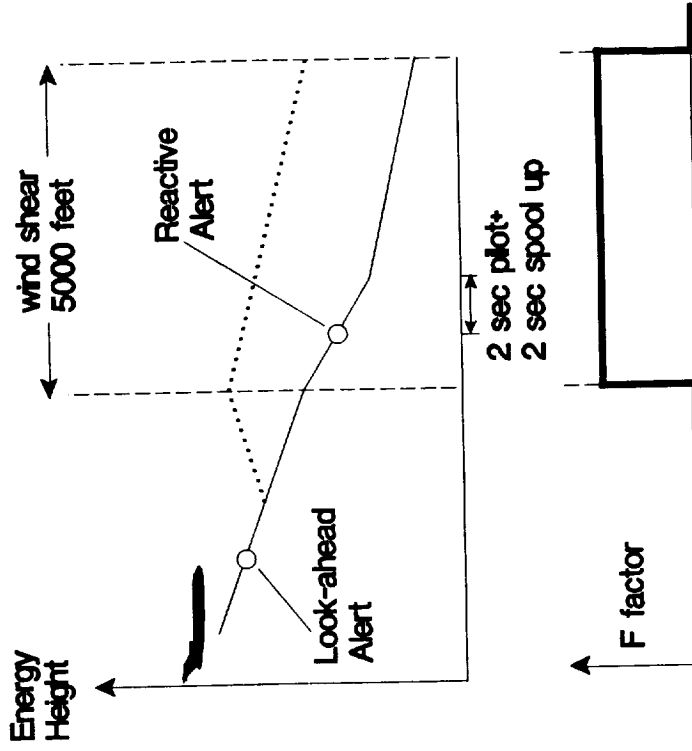
- ANALYSIS PERFORMED FOR LANDING AND TAKE-OFF SCENARIOS



# ENERGY HEIGHT ANALYSIS

- **SCENARIO FOR NASA ENERGY HEIGHT ANALYSIS**

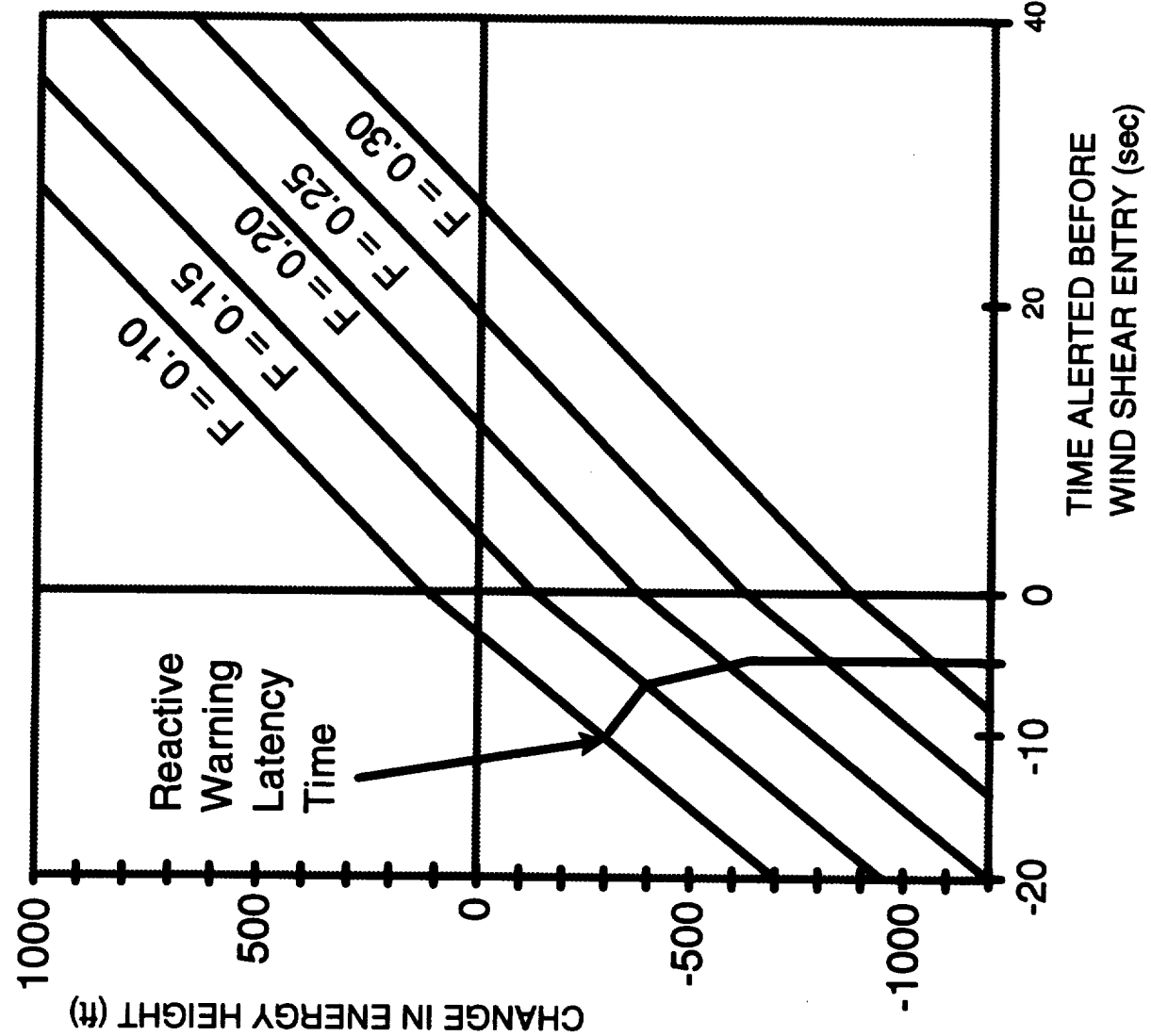
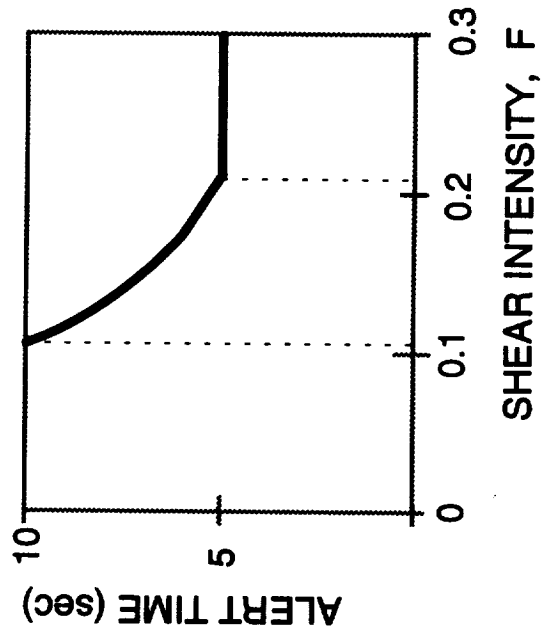
- **AVERAGE AIRCRAFT PERFORMANCE AND MICROBURST HORIZONTAL SIZE**
- **CONSTANT F FACTOR ACROSS 5000 FOOT DISTANCE**
- **PILOT INCREASES POWER AND EXECUTES RECOVERY PITCH**
- **SIMULATED FULL RANGE OF ALERT TIMES AND WIND SHEAR STRENGTHS**



# ENERGY HEIGHT LOSS FOR REACTIVE SYSTEMS

- ENERGY HEIGHT RESULTS
  - ALERT TIME
  - SHEAR INTENSITY, F
- DETERMINE ENERGY HEIGHT LOST FOR REACTIVE SYSTEMS

## REACTIVE ALERTING REQUIREMENTS (TSO-C117)



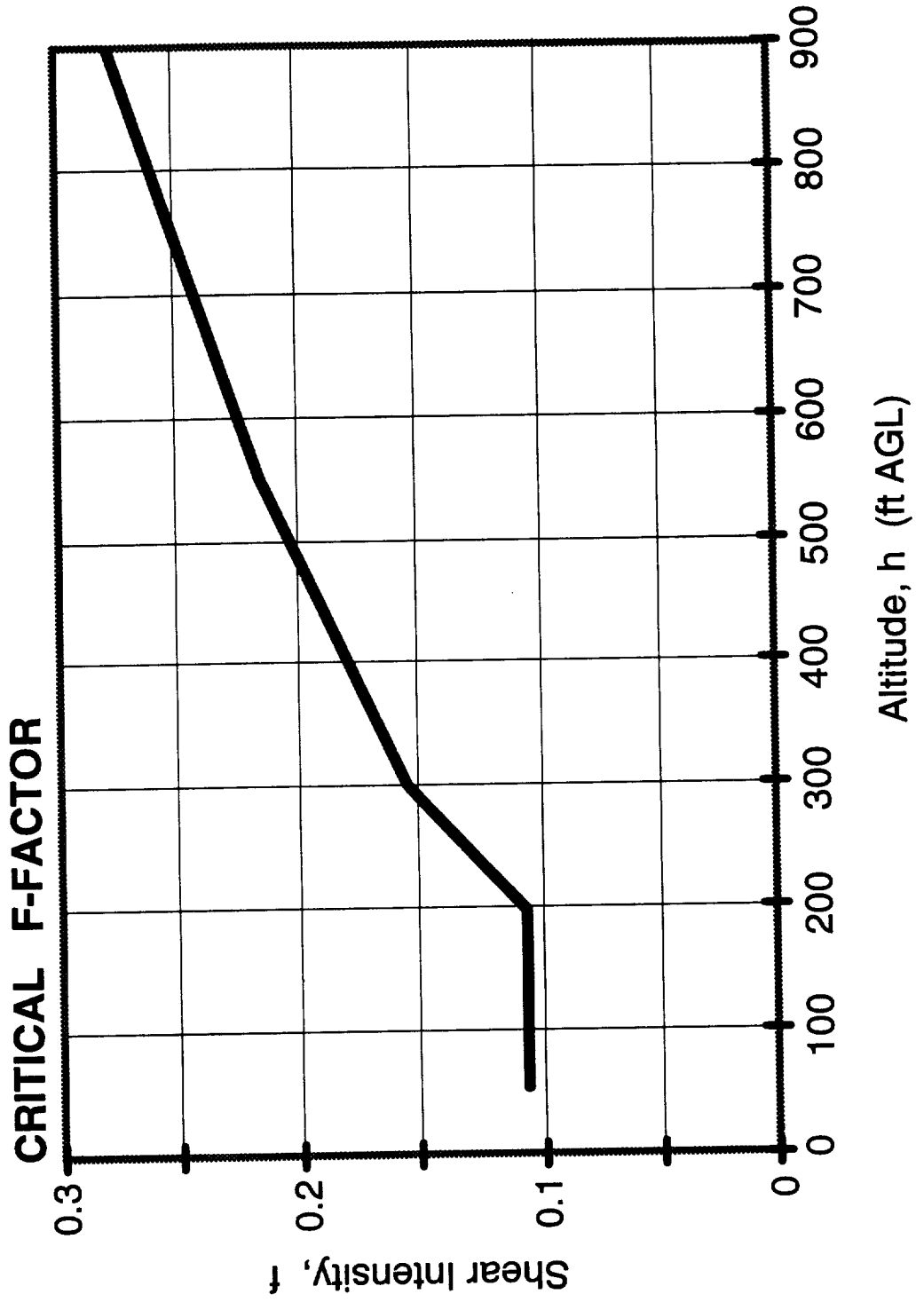
## REACTIVE ALERTING REQUIREMENTS (TSO-C117)



# DETERMINATION OF CRITICAL F FACTOR

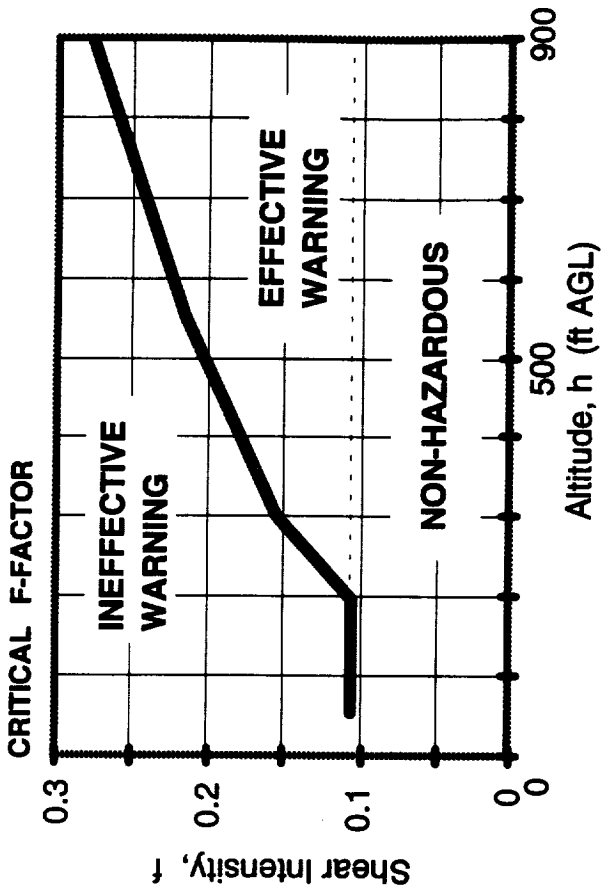
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- FROM ENERGY HEIGHT LOSS, DETERMINE ALTITUDE LOSS.
- REACTIVE ALERT TIME
- ENERGY HEIGHT OFFSET

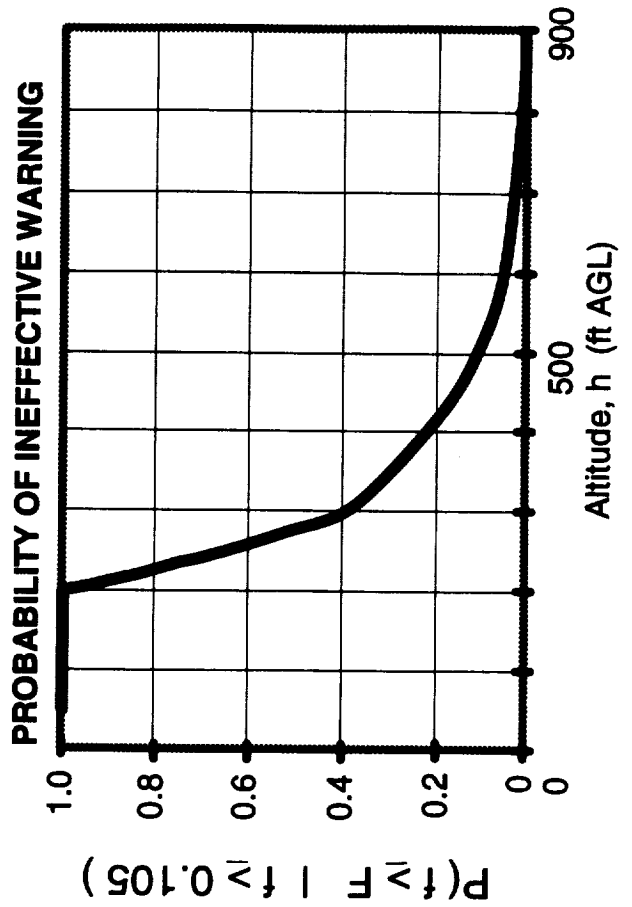
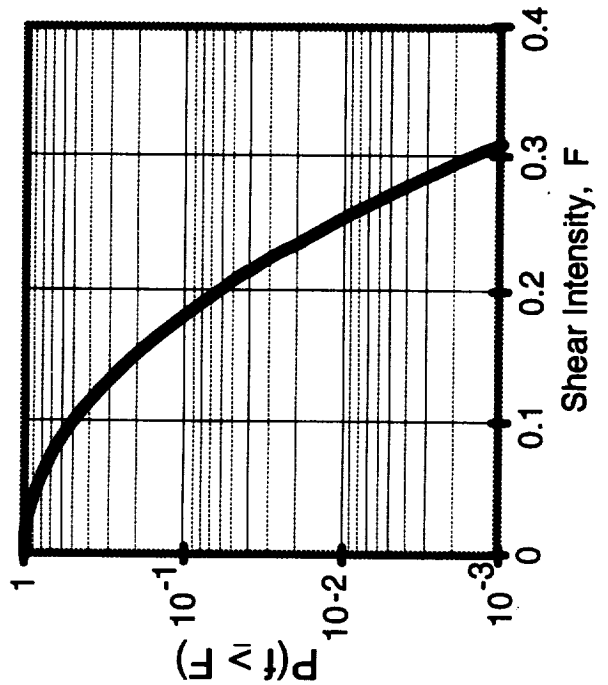


# PROBABILITY OF INEFFECTIVE WARNING

- DETERMINE PROBABILITY OF EXCEEDING CRITICAL F-FACTOR GIVEN HAZARDOUS ENCOUNTER



- EXCEEDENCE PROBABILITY,  $P(F >= F)$  BASED ON OBSERVED MICROBURSTS



## **LANDING SUMMARY**

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- **PROBABILITY OF INEFFECTIVE WARNING AVERAGED OVER ALTITUDE RANGE**
  - **= .33**
- **PROBABILITY OF EFFECTIVE WARNING IS CONVERSELY**
  - **= .67**

## **TAKE-OFF**

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- **GROUND TO 50 FT AGL**
- **REACTIVE SYSTEMS NOT REQUIRED TO PROVIDED WARNING**
- **INEFFECTIVE FOR ROLLOUT**
- **50 TO 500 FT AGL**
- **CALCULATED SIMILARLY TO LANDING.**
- **HAZARDOUS THRESHOLD HIGHER, FHAZ=.15**
- **OVERALL TAKE OFF PROBABILITY OF EFFECTIVE WARNING = 0.1**

# **OVERALL RESULTS**

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**OVERALL PROBABILITY OF EFFECTIVE WARNING DETERMINED**

• **LANDING WEIGHTED 67 % - TAKE-OFF WEIGHTED 33 %**

• **THREE POINT ESTIMATES DETERMINED**

• **OVERALL RESULTS**

• **HIGHEST 0.48**

• **MOST LIKELY 0.37**

• **LOWEST 0.24**

## **SUMMARY**

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- **REACTIVE EFFECTIVENESS DETERMINED CONSIDERING**
- **REACTIVE ALERT TIME REQUIREMENTS**
- **APPROACH/LANDING SCENARIOS**
- **AVERAGE AIR CARRIER AIRCRAFT MIX**
- **AVERAGE MICROBURST HORIZONTAL SIZE**
- **VARIED WIND SHEAR STRENGTHS**

## **An Approach to Evaluating Reactive Airborne Wind Shear Systems**

### **Questions and Answers**

**Q: Dan Stack (ALPA)** - I am curious whether or not you are including rejected landings or shall we say go-arounds in your landing criteria? Perhaps rejected landings and go-arounds should be a separate criteria.

**A: Joe Gibson (Martin Marietta)** - No I do not believe so.

**Dan Stack (ALPA)** - I can think of a couple of cases where a go-around was actually attempted. One was a US Air that ended up in the grass at Detroit, and about 15 years ago there was another one in Saudi Arabia where a go-around was attempted in a microburst and had gotten to 800 feet above the ground before they were blasted back onto the ground by a second microburst. So perhaps this rejected landing or a go-around concept should be included some place in your data.

**A: Joe Gibson (Martin Marietta)** - No we did not consider that, but it is a good point.

**Q: Unknown** - Could you expand on why you think the hazardous F-factor is higher in the takeoff configuration?

**A: Joe Gibson (Martin Marietta)** - Well, because the aircraft is up near full power, and therefore you can go through a higher strength microburst without it affecting your climb performance. When you are going in at approach airspeed you are going in slower and a microburst of comparable strength would effect you more on landing.

**Mike Lewis (NASA Langley)** - The curves that I showed in the last presentation would show just the opposite of that?

**Joe Gibson (Martin Marietta)** - Yes, I realize that. That was the assumption when I went in. I did this about six months ago.

**Q: Bud Laynor (NTSB)** - How did you consider the trade off of kinetic energy for potential energy when you were going through your studies? You talked in terms of energy height loss, but not in terms of airspeed, and yet you mentioned the pitching maneuver per the training aid?

**A: Joe Gibson (Martin Marietta)** - Yes, that energy height offset that I was talking about is basically to account for the slowing of airspeed and then losing kinetic energy to save you actual potential energy, which is the energy height, the height you are at. That was about a one hundred foot offset; considering that you could slow, you could lose some airspeed with out getting to stall.





## **Session III. Reactive System Technology**

### **Panel Discussion**

**Kirk Baker, Federal Aviation Administration**  
**Dr. Roland Bowles, NASA Langley Research Center**  
**Joe Gibson, Martin Marietta**  
**Howard Glover, Sundstrand**  
**Doug Ormiston, Boeing**  
**Rosa Oseguera, NASA Langley Research Center**  
**Dr. Paul Robinson, Lockheed Engineering & Sciences**  
**Terry Zweifel, Honeywell**

## Reactive System Technology - Panel Discussion

### Panel Members:

Kirk Baker, Los Angeles Certification Office, FAA  
Roland Bowles, NASA Wind Shear Program Office, NASA Langley  
Joe Gibson, Air Traffic Systems, Martin Marietta  
Howard Glover, Reactive Wind Shear Systems, Sundstrand  
Doug Ormiston, Reactive Wind Shear Systems, Boeing  
Rosa Oseguera, NASA Wind Shear Group, NASA Langley  
Paul Robinson, NASA Wind Shear Group, Lockheed Engineering  
Terry Zweifel, Reactive Wind Shear Systems, Honeywell

**Roland Bowles (NASA Langley)** - We composed some questions that we thought were pertinent and would fuel some discussion, and distributed them to the panel members. I will just review them briefly.

- 1) Current industry status of reactive technology.
  - Percent equipage to date in the system for those who have opted to equip with reactive system technology.
  - Operational successes that any of you may want to relate.
  - Operational problems and solutions as you see them.

We have an expert here from the FAA on equipage; his name is Frank Rock. In fact he is an expert on all of this. Frank, what is the current fleet equipage percentage now?

**Frank Rock (FAA)** - I do not have the exact number, but it was quoted at the last meeting we had and if I remember correctly it was about 50%.

**Roland Bowles (NASA Langley)** - Operational successes? You fellows who design and build and implement them, is the technology out there working for you? Is it paying off? Have you saved lives as a result of this technology?

**Howard Glover (Sundstrand)** - I guess one way of looking at it is that I have not heard of a fatal Wind Shear accident in a while. I asked around our place for some statistics, and I was surprised at what I found. I won't go into the gory details, but Sundstrand manufactures a couple of different flavors of Wind Shear detection systems. One of them contains a Wind Shear algorithm which is designed by Boeing and delivered on all new Boeing aircraft. The other is one that we have designed ourselves and is essentially intended for older aircraft, the so-called analog aircraft. There are approximately 2,500 of our systems flying, and they have probably been flying in those numbers for about a year. That is an average I would say. That is several million flight hours I believe, unless my arithmetic is totally hosed up. That is for a typical airline operation. We have only heard of a single save in that whole time, and that is the Atlanta 767 that somebody

mentioned this morning. That is amazing. So either it is happening and we are not hearing about it, or the frequency of encountering the Wind Shear is considerably less, because of the avoid factor, which all the pilots are now being trained to do, is paying off. That is the only conclusion that I can come to. I suspect that it is the correct one. I guess the conclusion that operators are not reporting events is probably true also. But on reflection, the avoidance, both by use of information from the ground and also pilot reports, is paying off.

**Unknown** - What about invalid alerts?

**Howard Glover (Sundstrand)** - Nuisances. We won't get too deep into the distinction between system failure induced alerts and nuisance alerts. Originally, they were quite frequent. The thing said wind shear and there wasn't one. Well, actually there was a wind shear, but it was not hazardous. Rosa Oseguera mentioned this morning several ways of compensating a reactive system to take care of operational factors. One of the worst operational factors that we had problems with was the down wind turn that she mentioned. When you turn from flying into the wind to down wind, the aircraft sees an effective wind shear. We had compensated for that but not enough. We found that at least one carrier during flight training operations was making forty five degree bank turns in surface wind conditions of sixty knots or more. That will do it everytime. So we had to tailor our system to that. Another factor was that pilots quite naturally tend to carry excess airspeed when they suspect wind shear might be present. To a reactive system that can look like an effective increase in the wind shear intensity. We also added compensation for that excess airspeed to reduce the unwanted warning. Since we did all of those things we have had relatively few nuisance alerts. In fact I could not find any reports, other than sensor failures, in the last six months. Sensor failures is a whole other story. Obviously, if you are depending on aircraft sensors and they fail then you can induce an apparent wind shear alert.

**Roland Bowles (NASA Langley)** - Terry, do you have any comments about your successes?

**Terry Zweifel (Honeywell)** - We have been out in the industry now since about 1985 or so and have had on the order of 10 valid alerts by pilots. In some cases they were apparently quite critical wind shears that the pilot was able to get out of and wrote us a nice report. I tend to agree with the idea that having these devices coupled with the training in avoidance has made a major impact on the number of alerts that has occurred, even possible accidents.

**Paul Robinson (Lockheed)** - Can I ask Howard Glover how you compensate for the wind shear alert going off in the down wind turn?

**Howard Glover (Sundstrand)** - In the down wind turn we have bank angle as an input. We assume that if a bank angle above a certain threshold is sustained for a while, the pilot or the flight control system is doing it and the aircraft is in an intentional turn. Now I have heard it argued that we know that the kind of turbulence you get in a wind shear encounter induces bank angles of that order, I say yes, but the wind shear warning has gone off before that, in our simulations anyway.

**Paul Robinson (Lockheed)** - So you are effectively reducing the gain on the system?

**Howard Glover (Sundstrand)** - Exactly, yes.

**Roland Bowles (NASA Langley)** - I think that introduces the next question. Is there design space remaining to improve reactive system technology? Is it possible to look at perhaps better performance at lower cost? Is the gust rejection or turbulence problem solved? Are the time to alert performance of these systems optimized? And the last one relates exactly to Paul's question; do you need three axis implementation? You can let the physics do the walking through the yellow pages for you there, rather than degaining the system as a function of bank angle. Would that be a worth while improvement or would it be considered excessive cost? Any comments along those lines?

**Paul Robinson (Lockheed)** - I would like to present something which backs up what Mike Lewis presented this morning. This deals with the gust rejection filters, the time to alert, and the parameter on which the system should alert. Mike mentioned that the hazard is defined as a one kilometer averaged F-factor. I would like to show you this chart here. The red line is the F-factor that was experienced by the In Situ system while penetrating Event 143. It is filtered using a second order filter. If we take the raw unfiltered data and calculate the backward one kilometer average of the F-factor we get the black line. As you can see it is a lot noisier than the In Situ F-factor we are using, but it illustrates two points. One is that if you are going to work on an average F-factor of 0.105 or more you require some filtering in order to get the alert at the correct time and of the correct volume. The other point is that the filter does a lot better job at noise suppression. So you are really gaining two things here, noise suppression, and you are actually calculating an averaged F-factor on which to alert. This might put up a new spin on the gust rejection filter problem.

**Roland Bowles (NASA Langley)** - We are asking this question from the perspective of the technologist. Let me ask this, is there any drivers on the airline side to improve performance, or are they perfectly happy with the product they have? Do they want improved performance, perhaps even at lower costs? Or is the customer clambering for something better? Any other comments about design space remaining for this technology to improve situations?

**Howard Glover (Sundstrand)** - I think I would get fired if I said there was no design space left. Yes, of course, there is. But you hit it right on the head a moment ago. Are the improvements necessary? No, the customers are not beating on us for that. They are beating on us for all the usual things that customers do. More reliability of the equipment, etc.

**Terry Zweifel (Honeywell)** - I would like to make a few comments relative to the turbulence rejection and time to alert. The real problem with reactive systems is that you have to have the heavy filtering. The filter that Paul just showed is not a light filter, it is a very heavy filter, and you have to have that for the turbulence suppression. Conversely, that filter is the very thing that keeps it from alerting faster. A lot of studies that we have done at Honeywell and I know that others have done throughout the industry show, that unfortunately, with the simple type filters that we are looking at this is apparently as good as we can do. There are other concepts that we have looked at, but have not really got to the point of production readiness. Smart filters for example, using some of the atmospheric parameters that Kelvin Droegemeier was talking about. Maybe you can make those filters a little less heavy in certain conditions. So I think there is some

room to grow in that area. But right now as I see it that is about the only area you are going to get a faster detection time out of.

**Roland Bowles (NASA Langley)** - You are really beating your head against a vicious trade off. The physics is compelling. You are either going to get a lot of false alerts and good response time, or a lot of delay?

**Terry Zweifel (Honeywell)** - The filter itself determines how many nuisance alerts you are going to have.

**Roland Bowles (NASA Langley)** - To what extent do you think the application of reactive system technology can be made aircraft independent or aircraft non specific. In other words, can one box work for all airplanes? Would that be useful? Are there manufacturers that are thinking along those lines?

**Howard Glover (Sundstrand)** - I think all of the reactive system manufacturers have essentially one system, for all transport category aircraft anyway. In fact, I think inherent in the reactive system is an independence from the aircraft performance; as far as wind shear detection is concerned anyway. As far as recovery guidance is concerned, obviously it has to be somewhat specific to the aircraft. Terry, do you disagree with that?

**Terry Zweifel (Honeywell)** - I agree one hundred percent. In fact, we have done studies on that and have actually submitted a report to the FAA comparing L-1011's, DC-9's, 727's, 737's, the whole gambit, and the detection times just do to the algorithms are virtually identical. There are of course differences in what sensors they have, how the boxes are mounted on the airplane, that sort of thing. The basic detection algorithms have not changed for any of the airplanes so naturally you would hope that it would detect the same. So yes, I would agree with that. There is physically no reason that they should be different, given roughly the same long period frequencies and that sort of thing. It is not necessarily true, as you mentioned, on the lighter airplanes, the Gulf Streams perhaps, and some of those.

**Roland Bowles (NASA Langley)** - I think for heavy airplanes, 100,000 pound category or heavier, you are in good shape. I think the light ones could pose a challenge. I guess that leads us into the one that I think a lot of people are about ready to engage in, and that is, the industry view of the FAA certification criteria as exemplified in the TSO C-117. Is the TSO a useful standard? Is the TSO content technically sound? What are the current problems in applying the TSO? And, are industry and government willing to modify the TSO where appropriate? If that is a reasonable thing to do, what kind of process would you have to go through to do that?

**Kirk Baker (FAA)** - Right now the requirement documents that we use to certify reactive systems are AC 25-12, AC 120-41, and TSO C-117. The minimum performance requirements for the system are referenced in TSO C-117. One of the problems that we have seen is a discontinuity between AC 25-12 and TSO C-117. AC 25-12 brings out the way you demonstrate the system, but it does not specifically have hard requirements like the TSO does. Today we've only had one application for TSO C-117 that we are considering in the Long Beach Office. What we have looked at so far has demonstrated to us that there is a definite lack of interpretation of

what the TSO really says, and how you interpret the performance requirements. This is our goal: that all applications for type certificate or type certificate and supplemental type certificate STC's will be required to meet the minimum performance standards of the TSO. No one has demonstrated that to us yet. I think this is because of the complexity of the TSO. I think the FAA has an obligation to make this happen; to clearly define the FAA policies for reactive systems and approval under TSO C-117. One of the ways that Roland had indicated, was possibly amending the TSO. If we can't use it and we can't seem to implement it then maybe we need to change it. Well, I am doing something right now, in the ACO, to try and better provide the FAA's interpretation of what the TSO requirements are. I have sent that document out and I believe some of you have received that document already. If you haven't I do have copies here and you are welcome to take some. This policy statement is in a draft form right now and we have coordinated it through all the ACO's. It specifically spells out our interpretation of the requirements, and how you should meet the requirements in performance and guidance. We are soliciting your comments right now on our interpretation. I think that is one way of determining whether we need to change the TSO. What I would propose is to come to an agreement on what those policies and interpretations should be. Then I would like to amend AC 25-12 to include a statements which references the TSO as the minimum performance standard. But, in order to do this we need your comments as soon as possible. That is basically, I think, the FAA's position right now on certifying and approving systems under the TSO. We will need those comments in by April 30, 1992.

**Terry Zweifel (Honeywell)** - One obvious comment there would be on your statement to amend AC 25-12 to include a statement which references the TSO. That kind of makes the TSO an advisory circular, doesn't it? What if I have this wonderful box and I want to go certify it are you going to certify it under AC 25-12? If so, do I have to go out and run the whole TSO? For those of you who may not be familiar with it, the TSO is not a small test. It takes approximately four weeks to run this set of tests. So if you are trying to build boxes for all kinds of airplanes you are getting into some very involved testing. Obviously we as manufacturers would just as soon not do that unless we had to. That is my concern. In essence the TSO is just becoming a part of an AC and there is no TSO.

**Kirk Baker (FAA)** - Well the AC is one way to certify a system. I don't think you are creating an AC out of the TSO. The TSO has minimum performance requirements listed in it, times to detect. That is something that the AC doesn't have. There shouldn't be a disconnection there. What I see happening in the industry, is everybody wants to continue to certify their systems under the AC 25-12 to establish practices with various ACO's. One thing that promotes is non standardization and ACO shopping. Because one ACO does not treat an applicant the same as another. That is one of the reasons that I think the TSO is a valuable document. It could create some standardization. It is a minimum performance standard. I think that goes right along with a generic type, airplane independent system. I know the industry feels that they are generic, but they have never demonstrated it. We have always gone and demonstrated on the type airplane that needed it.

**Terry Zweifel (Honeywell)** - My concern is that if you continue doing it that way, what you end up with is that we AC every possible type of airplane. There is no longer any need for the TSO. It doesn't accomplish anything. If you take that approach, you think why TSO to begin with.

**Howard Glover (Sundstrand)** - I would invert that. Our experience is that we had to do the same amount of testing to certify, in addition to TSO certification, whether or not meet we the TSO. In other words, when we go to the certification office, they still want to see it on the simulator specific to the type of aircraft were going on. We still have to ground and flight test on the aircraft that we are applying for the supplementary type certificate for. The biggest potential factor in variation of performance from installation to installation, is the sensors on the aircraft, and that is not addressed by the TSO at all.

**Kirk Baker (FAA)** - Those are installation specific requirements.

**Terry Zweifel (Honeywell)** - That is why you need the AC.

**Kirk Baker (FAA)** - Exactly, I was going to add that point. That is why I think, if we can somehow be convinced in the FAA that the systems are generic detection wise, than the TSO could become a useful document. Because once you demonstrated your performance and function of detection then again you would still have to go out and demonstrate installation specifics like sensor combinations and guidance requirements. But the detection portion would be taken care of under the TSO. That is one advantage I see of the TSO. I am not a real fan of the TSO myself, but it is with us and we have to try and use it. That is why I am trying to disseminate and get the FAA to make some interpretations of what the requirements are of the TSO and standardize those. Then disseminate them to industry for your review and comment. If we can live with our interpretation, then we will go ahead and publish that as a memorandum policy letter to all of the ACO's along with probably some guidance on the installation specifics. Again, just because you have the TSO doesn't mean you can just go stick it on an airplane.

**Terry Zweifel (Honeywell)** - No, admittedly. The problem from the manufacturers point of view is that building simulators to certify all these systems on is a very expensive proposition. Where do you find DC-8 simulators that you can try your reactive system on. They are very hard to come by and you end up struggling with that. The idea of the TSO, I thought, would be that you could take this box which was TSO'd and I wouldn't need to build that DC-8 simulator. I know the detection laws are OK. That to us was the big advantage. I was afraid you were trying to tell me, "that is nice but we won't do that, you are still going to have build the DC-8 simulator."

**Kirk Baker (FAA)** - No, I think we can tackle the detection issue. Guidance is another question altogether, obviously. The rule has been changed. Guidance is not a requirement on older airplanes. DC-8 being one of them.

**Howard Glover (Sundstrand)** - Kirk, if you are willing to revisit AC 25-12 are you willing to revisit TSO C-117, and reconvene the committee for one session?

**Kirk Baker (FAA)** - Certainly, if the comments from industry strongly oppose our interpretation and convey to us that there is a need to amend the TSO then that is what we will do. That is a lengthy process.

**Terry Zweifel (Honeywell)** - That is the concern I have. If it will take 50 years then it is going to be of no value to anyone.

**Kirk Baker (FAA)** - That is why I am trying to promote this other way. That is, by coming to an agreement on the interpretation of the requirements in the TSO. With that knowledge base, then amend the AC 25-12. We want to enforce the idea that any certification of a reactive system has to meet the minimum performance standards of the TSO. That is standard FAA policy. Right now that is not happening.

**Terry Zweifel (Honeywell)** - I am not sure what you are referring to. We, by the way, happen to be an applicant for the TSO, in case you haven't deduced that?

**Kirk Baker (FAA)** - We haven't seen that yet and you may convince us otherwise. From the data that I have looked at so far, I don't think you demonstrated the system the way we interpreted it. For instance, the wind axis separately as opposed to in combination.

**Terry Zweifel (Honeywell)** - I don't know if you want to get into the details of the TSO?

**Kirk Baker (FAA)** - I don't think we really do.

**Roland Bowles (NASA Langley)** - I don't think we have time today. The intent here is to expose a willingness on the FAA's part to sit back and garner comments from the industry, look at what your comments are, and if appropriate, put a process in place to alter or at least amend the TSO. In terms of you who have actually used it. What are the areas that are sensitive to you? What is most difficult? If it takes four weeks, what are the stumbling blocks in the TSO?

**Terry Zweifel (Honeywell)** - One thing is this running the turbulence test.

**Roland Bowles (NASA Langley)** - I totally disagree with the whole turbulence approach. That is one we are going to purpose.

**Howard Glover (Sundstrand)** - It isn't just the time taken for the turbulence test, Roland, which is excessive. I think it is 250 hours, something like that. It is the fact that each run of the turbulence test is, for example done at constant altitude. We have to have a system which takes into account aircraft performance instantaneously. If the aircraft is in takeoff configuration it should be climbing. If it is in an approach configuration it should be descending at 700 feet per minute, roughly. None of that is taken into account by the turbulence model. In fact it is totally artificial for our system to fly level at 500 feet above the ground. That does not make sense, and yet here you are doing it as a test.

**Terry Zweifel (Honeywell)** - I don't argue that. It does give you an indication of what your turbulence sensitivity is.

**Paul Robinson (Lockheed)** - But it doesn't have to be done like that. The turbulence testing process can be simplified based on the work that Roland has been doing at NASA. A follow onto that is the inputs for Wind Shear detection, using actual microburst F-factor inputs or windfields. There doesn't seem to be too much representative of what we saw in the field in 1991, that goes through the system in terms of predicting time to alert, and missed alerts in the TSO. That would be another problem, the weather inputs.



**Terry Zweifel (Honeywell)** - Are you saying that the wave forms are not realistic?

**Kirk Baker (FAA)** - They are not realistic.

**Terry Zweifel (Honeywell)** - The problem is you would have to come up with an infinite number to represent every conceivable microburst thing. How do you say this five is representative and this five isn't?

**Roland Bowles (NASA Langley)** - What we would like to contribute to your process is to suggest a significant revision, though not complicated or more complex, turbulence realization for consideration in the TSO. And then also, to consider the applicant complying with the nuisance criteria by a direct calculation of a performance number compared to a curve. Is he above it or below it? This ability to predict what the nuisance rate or level exceedance rate may be is based on well founded scientific and accepted aviation computational principles. Let me put it another way. I think it makes no sense to sit there and run at one constant altitude an airplane simulation for 2500 hours with a fixed RMS turbulence, and count an exceedance. What I think we want to do is ask the question, "how often will you get a nuisance due to operational turbulence based on well founded available data, per operation." Use three minute approaches and three minute departures, and Monte Carlo that. That is the operational number you want. Not whether or not one turbulence realization run for 2500 hours will give you an exceedance. Howard, do you see what I am suggesting?

**Howard Glover (Sundstrand)** - I agree with you entirely.

**Roland Bowles (NASA Langley)** - And, we can do that problem by calculation, rather than simulation. We would like to lay this out for you Kurt, and see how the industry responds to it. Here is some data that shows how well we predicted it as compared to measurements. The measurements are based on data that was provided courtesy of Boeing in their Southwest program. Our problem is getting this kind of operational data to compare the predictions to. This is what our system looked like, and notice in both cases, the measurements are falling under the tail of the calculation. Which says if we had a higher population or a higher statistical sample we are likely to pull this up and they would agree even more closely. We can't pursue it here because of the complexity of it. But this is the approach we will recommend to you. It could really cut down on the cost of complying with that nuisance demonstration that you have in the TSO.

**Terry Zweifel (Honeywell)** - Why do you need actual operational data? That is really just a mathematical exercise of running through the process?

**Roland Bowles (NASA Langley)** - Strictly to convince us that the prediction is true.

**Terry Zweifel (Honeywell)** - How do you get that? How do you gather all that data operationally, turbulence levels and all that?

**Roland Bowles (NASA Langley)** - That will be embodied in the turbulence model and we base that on literally 3000 hours of low altitude turbulence measurements by the whole B-52 fleet. About 7000 hours of data out of Canadian and US turbulence measurements in different terrain

and different atmospheric stability at low altitude. That statistical model has been put together.

**Terry Zweifel (Honeywell)** - Is that the one in the TSO?

**Roland Bowles (NASA Langley)** - No. It came out of Slick's deck.

**Terry Zweifel (Honeywell)** - I guess what I was trying to get at is that once you define what the turbulence is then all you have to do is sit down and run it through the filters.

**Roland Bowles (NASA Langley)** - Precisely, you define the turbulence realization, you define your gust rejection filter network and by calculation show that with that stochastic input across that ensemble of statistics you fall either above or below the exceedance line. I think it could cut the cost considerably, and it would be actually more valid than what we are doing now. This is the way we prove that the wings won't come off of airplanes due to extreme gust loads. The TSO may be useful but it could be more useful, and less costly to apply. I think there is some room for improvement, or maybe it's clarification, of the technical content in the TSO. So, we will respond as will the industry and we will see where we go.

**Kirk Baker (FAA)** - Yes, I think that is very important.

**Roland Bowles (NASA Langley)** - The final subject. How does industry view hybrid systems technology based on the integration of reactive and predictive technology? What are the expected problems, expected improvements in safety, and perhaps cost? I have heard people say that reactive system technology is non throw away. I have said it. I think that is where I heard it, actually. I do believe it is non throw away technology. So, is there some industry sense that hybrid devices may be useful if the cost can be controlled. Would that not get us out of some of the dilemmas on certifying predictive systems as a stand alone device. Any comments along that line?

**Howard Glover (Sundstrand)** - I think one of the keys to convincing airlines to put money into anything other than the reactive system is the benefit to cost ratio. If you can make the predictive system do something other than detect this Wind Shear event, which is going down in frequency as far as encounters are concerned, then that is the best way to do it. Things such as was mentioned today like clear air turbulence detection, wake vortex detection, perhaps even terrain detection. If you can do that and demonstrate it, then I think it is probably something that the industry would go for. If you can't do that then I don't believe that they will. Except in rare occasion.

**Sam Shirck (Continental Airlines)** - I think I would be remiss if I left anyone with the impression that our airline in particular, and I think American and Northwest also, are really enamored with the reactive systems. I think it was the best technology that we were able to produce at the time, but I don't think it is the answer at all. Joe Gibson presented some facts there that would indicate that on takeoff we have only got one chance out of ten of survival in the right type of shear. That is what I got out of what you said. As a pilot, I can tell you I am not wild about those odds. And I think I can speak for the airline, that I don't think we would stay in business with those type of odds. So we are hoping that we can get certification of a predictive

type system that is stand alone for at least the retrofit aircraft. The better of all worlds would be to back it up with a reactive system. In the future I don't think you will be able to buy an airplane without a reactive system that is embedded in the flight control laws of the aircraft. I don't think it is going to be possible to do it. But a predictive system is something that we are definitely striving for and I think we are very close. One of the things that kind of bothers me, I guess it is a comment more than a question, I heard just a few minutes ago that we were using a two second pilot response time and a two second engine spool time. I think accepted pilot response time in the past on RTOs which is a critical situation, has been 2 1/2 seconds. I would like to see at least some recognition that we stick with the same ground rules. And, for those that think that the engines on the ground loving 727 are going to spool in two seconds have got another thought coming. That won't happen.

**Roland Bowles (NASA Langley)** - Your point is well taken Sam. We have had some successes out there with this technology, but there is one around the corner where we may dig a whole and have to go back to the drawing board.

**Russell Targ (Lockheed)** - I was worried about the exact thing that Sam just spoke to and that is the data that Mr. Gibson just presented. In the pilot's wind shear handbook we learn that a average wind shear encountered in the JAWS study had an F-factor of about 0.2 and they warned that a heavy weight jet encountering such an average wind shear had about a 50% chance of experiencing undesirable contact with the ground. Now that is three year old analyses, and we have a whole panel of experienced reactive investigators here. I wondered, if you consider this F-factor of 0.2 to be an average wind shear that one might encounter, what is the likelihood of having an accident even after you have enunciated a wind shear occurrence that you are flying into.

**Roland Bowles (NASA Langley)** - Well, this is a rare opportunity for me, this is a time I get to challenge Russell. No statistic came out of the JAWS program with regard to an average F-factor of 0.2 at all. What we do have is a statement based on a 498 microburst sample with a lot of data provided by Lincoln and the NCAR guys, using the same algorithm that we were using to uplink the F this past summer, that suggest that this is the probability of equaling or exceeding a given level of F. So, about half of them are greater than 0.12. A 0.2 or bigger, based on this data, would occur at a frequency of one in one hundred, roughly. I don't know where you got that number but it was clearly not true.

**Russell Targ (Lockheed)** - Where I got the number was from the histogram that appears in the JAWS study where they say that an average Denver-Stapleton dry microburst would correspond to a 40 or 50 knot headwind change.

**Roland Bowles (NASA Langley)** - That is not an F-factor, that has nothing to do with airplane energy loss.

**Russell Targ (Lockheed)** - If you say that you lose that over a kilometer.

**Roland Bowles (NASA Langley)** - But that was not the case. Some of them were five kilometers wide.

**Kim Elmore (NCAR)** - I am trying to remember what the numbers were, but I think a typical size was a little over three kilometers and typical intensity was something on the order of 14 meters per second, or something like that. Of course, we did not know what F-factor was back then. 0.2 would be far bigger than what we saw on the average.

**Russell Targ (Lockheed)** - I have no desire to quarrel over what the average F-factor in the universe is. What I would like to know is if I encounter such an average F-factor as is indicated here, what is my likelihood of surviving?

**Roland Bowles (NASA Langley)** - I think Joe gave you the answer to that in terms of a system effectiveness number. Again effectiveness of a system is not the ability to detect it, it is the ability to prevent an accident. Let's face it, there are some events in this world that I don't care if you get the reactive system alert in two seconds or four seconds or a millisecond, if you are in it you may not survive. There are some out there that big. But these tend to be relatively rare.

**Joe Gordan (Safe Flight)** - I think everybody is missing something here and that is what the accident studies have shown. The fact is that given all the accident studies, any reactive system would have saved that accident. You can pick numbers out, Mother Nature does some funny things, but that is not what the evidence has shown.

**Roland Bowles (NASA Langley)** - You can make a compelling case that for the vigil pilot who is right on top of it, knowing what is coming, he can survive. The point is, nobody knows what the effectiveness of the system is. As we heard, we have only gotten a few alerts out there in the system and we sort of know what the false alert problems are.

**Terry Zweifel (Honeywell)** - I will just make a few more comments relating to that. When you say it is a 0.2 F-factor shear, the question is not is it in a 0.2 F-factor shear, the question is for how long? There is another assumption that is being made and that is, if you are in a shear and the shear is 50 knots that you will lose 50 knots of airspeed. That does not happen in reality. You do lose airspeed, but you will not lose the entire amount of the shear. So that means your kinetic energy relative to the air is not as bad as it appears in some of these studies.

**Roland Bowles (NASA Langley)** - That's right, and that is why we need to change that curve in the TSO from wind speed change to something more meaningful in terms of performance impact on airplanes.

**Terry Zweifel (Honeywell)** - One more comment on the accident models. What Joe said is exactly true. There is not an accident case that anyone's reactive system can't detect and fly out of. In fact, in many cases we ran them 2 and 2 1/2 times the actual value and you still could fly out. So if there was a conception somehow that the reactive systems are just totally ineffective, it clearly is not true. They are not the final answer, I don't think anyone is promoting that. But they also can do a lot more than seemed to be coming out in some of the papers here.

## **Session IV. Airborne Doppler Radar / Industry**

