12

AN ASSESSMENT OF LOCAL RISK

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I will present a status report on the ORI assessment of the risk at Washington National Airport and the surrounding Washington, D.C., metropolitan area associated with commercial operations of aircraft with graphite fiber composite in their structures. Figure 1 is an outline of my presentation.

OUTLINE

- **OVERALL STRATEGY**
- **NEED FOR INDIVIDUAL AIRPORT RESULTS**
- **AIRPORT-METRO AREA MODEL**
  - **SUB MODELS**
    - **METHOD**
    - **ASSUMPTIONS**
    - **DATA**
- **PRELIMINARY RESULTS FOR NATIONAL AIRPORT — D.C. AREA**

Figure 1

First, I'd like to spend a minute discussing the overall strategy and the resulting need for individual airport analyses of the type we're going to describe. I shall then describe the actual model for assessing the risk to an airport and to the surrounding metropolitan area. Then, for that risk assessment model, I'd like to describe the set of submodels that comprise the overall model. Each one of the submodels will be described in terms of its three principal elements: the method that is used, the assumptions that are required in order to use that method, and the required data. Types, sources, and some examples of the data that are required as input to each model will be presented. Finally, we'll present preliminary results based on those data, using the methods we will have described, for the Washington, D.C. - Washington National Airport risk analysis.

The overall strategy for developing the national risk profile, that Dr. Credeur showed us in a hypothetical example earlier, is shown schematically in figure 2. The cycle in the middle tells us that we're still discussing among ourselves, and with the Project Officer and her associates, the appropriate methods to use for blending the risk profiles developed for individual airports. On the other hand, all the methods that we've discussed to date involve combining results for individual airports in order to develop the national risk profile. For this reason, we felt it was necessary to analyze at least one airport and develop methods that could be applied to any airport, given appropriate data for that locale. With that in mind, I would like to describe the model for the individual airport and, as I said earlier, we will blow that up in detail and describe all the subelements that comprise that model in terms of the methods used, assumptions made, and the necessary input data.

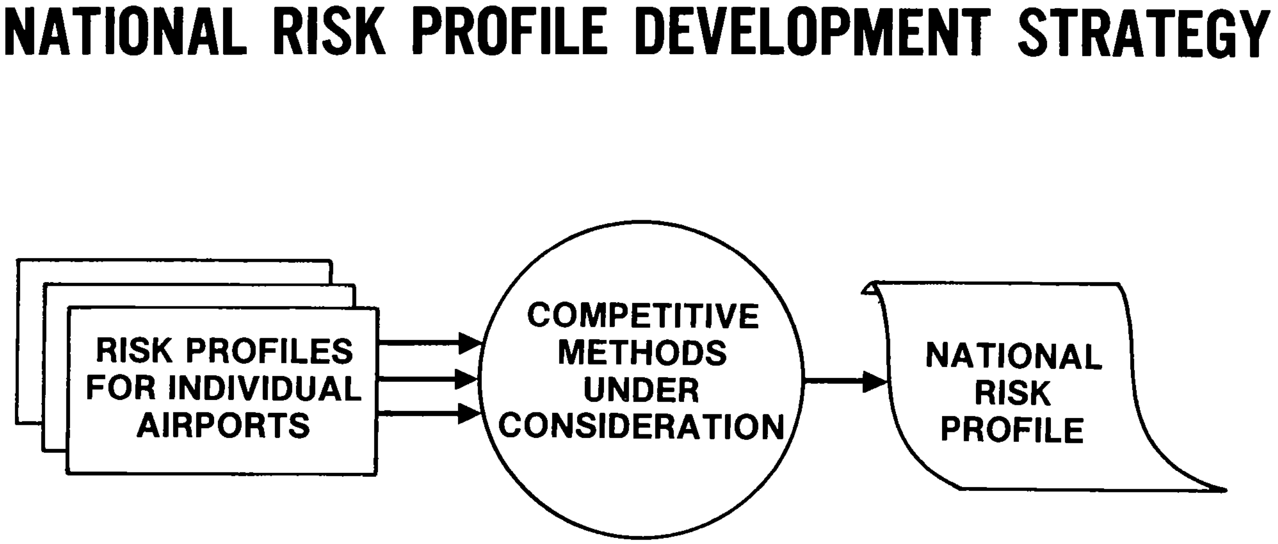


Figure 2

The airport model involves the major steps shown on figure 3. We first have to decide what time frame we're interested in and how long a time period we want to simulate. For that period, we estimate the number of accidents at this airport. Then for each

AIRPORT-METRO AREA GRAPHITE FIBER RISK ASSESSMENT MODEL

- **SELECT TIME PERIOD**
- **ESTIMATE NO. OF ACCIDENTS AT THIS AIRPORT DURING PERIOD**

  PROCESS ACCIDENT

  REPEAT FOR ALL ACCIDENTS IN PERIOD
- **COMPUTE STATISTICS OVER ALL SAMPLES**

Figure 3

accident simulated, we do something called "Process Accident", which involves computing the likelihood of damage to different facilities and estimating the resulting costs. We repeat that step for all the accidents in the time period we're modeling. We then generate more accidents for another time period and compute the statistics over all periods (or samples) to get the type of statistical distribution that Dr. Credeur showed us earlier. The statistical distribution is obtained, therefore, by the use of what is generally called a "Monte Carlo Simulation." What I'd like to do now is expand on the risk assessment model and discuss it in terms of its components.

We will concentrate on the calculations we're doing for 1985 as our time period or time frame. Let's discuss the first step beyond that one in the risk assessment model for a particular airport or area. It is necessary to start with an estimate of the expected number of accidents at an airport during the simulated time period. As indicated on figure 4, the method is to allocate a fraction of the national total accidents to the combination of aircraft category and airport. The fraction is the ratio of operations for that aircraft type - aircraft combination to operations for the total U.S. Incidentally, the format we're following in figures 4 and 5 is the one I'd like to use throughout: method, assumption, and the data that is used

ESTIMATE NUMBER OF ACCIDENTS IN SAMPLE TIME PERIOD

METHOD:

- ESTIMATE NUMBER OF ACCIDENTS FOR YEAR OF INTEREST
- FOR EACH A/C CATEGORY-AIRPORT, COMPUTE RATIO OF OPERATIONS TO TOTAL U.S. OPERATIONS

ASSUMPTION:

- EXPECTED NUMBER OF ACCIDENTS IS PROPORTIONAL TO NUMBER OF OPERATIONS

Figure 4

DATA:

- NATIONAL TRANSPORTATION SAFETY BOARD:

  ESTIMATE 6 FIRE ACCIDENTS IN U.S. FOR 1985

- FAA AIRPORT EMISSIONS DATA BASE/WASHINGTON NATIONAL AIRPORT OPERATIONS IN 1985:

1. LARGE (DC-10, L1011, 747 . . .)	*18,850*
2. MEDIUM (727, 757, 767, 707, DC-8 . . .)	*124,766*
3. SMALL (737, DC-9 . . .)	*60,284*

- FAA *AVIATION FORECASTS* FY 1978-1989:

  TOTAL U.S. OPERATIONS *11,700,000*

Figure 5

as input to the calculation. Again the basic assumption in performing this calculation is that the number of accidents at a particular place is proportional to the number of operations. We've tested that relationship and it is quite good. In order to obtain the necessary data we have to go to the primary data source for aircraft accident data, we have to go to the primary data source Board. In this case we're interested in accidents involving fires in the 1985 time period. We've estimated, on the basis of historical data from the National Transportation Safety Board, that a reasonable number of accidents involving fires for commercial operations in 1985 in all the United States might be six.

In order to allocate a fraction of those six accidents to Washington National Airport, we use additional information in a data base that ORI developed and maintains under contract to FAA. These are the estimated number of operations of aircraft in the three size classes shown on figure 5. The actual aircraft designators shown with the three classes are meant to be indicative of aircraft in those size classes today - they are not necessarily the aircraft that will be operating at National Airport in 1985. In order to get the denominator - the total number of certificated air carrier operations, we use the official FAA aviation forecast: in 1985 there will be about 11,700,000 certificated air carrier operations in the United States.

The next major step in applying the risk assessment model to a particular airport is to perform a set of calculations that we call "Process Accident." Once we have an estimate of the number of accidents, we want to deal with them one by one, and in order to process the accident, we have several calculations to go through as indicated on figure 6. These are performed with considerable speed by a computer that we have programmed to do the job. In the present case the computer is an IBM 370/155. Fortunately for me, many of the steps in the complete calculation were discussed by previous speakers in considerable detail. Basically, as Dr. Credeur pointed out, we want to develop a statistical description of the risk, and to do that, we want to draw random samples from distributions of such things as the accident characteristics, including the operational phase during which the accident took place and the accident location.

We then compute the exterior exposure downwind of the accident for a series of representative locations. For each of these locations we've defined combinations of commercial, industrial, and residential units. For each point, we can then compute the interior exposure, the associated failures, and the cost of those failures. The computer then goes back, performs this routine for all the locations impacted by the accident, adds them up, and is then finished with the accident. It then goes back and looks at the next accident in this time period, finishes all

PROCESS ACCIDENT

- **SAMPLE ACCIDENT CHARACTERISTICS, A/C CATEGORY, OP PHASE, LOCATION**
- **COMPUTE DOWNWIND EXTERIOR EXPOSURE FOR REPRESENTATIVE LOCATIONS**
- **FOR EACH LOCATION, COMPUTE INTERIOR EXPOSURE FOR INDUSTRIES, DWELLING UNITS**
- **COMPUTE EXPECTED FAILURES EACH INDUSTRY, DWELLING UNIT**
- **COMPUTE COSTS OF FAILURES**
- **SUM COSTS AT EACH LOCATION**
- **SUM OVER ALL LOCATIONS, THIS ACCIDENT**

Figure 6

accidents in the time period, and then performs the next replication of the time period (or the next sample). In order to explain this in more detail, I'm in effect going to blow up the "Process Accident" routine which is the computer program that's at the heart of the calculation.

As indicated in figure 7, the first thing we have to do is to develop - by sampling from appropriate statistical distributions - information about the simulated accident. In order to develop the characteristics of the accident we're investigating, we sample from historical distributions that describe the location of accidents involving fires and the operational phase during which those accidents occurred. We calculate the fraction of the aircraft destroyed by fire from analyses of individual accidents in the NTSB files. The assumption without which the calculation should not proceed is that the aircraft accident data are statistically homogeneous -- put another way: we have to use aggregate data from all accidents recorded in recent history throughout the United States to prepare these distributions for the individual airport we're studying. Examples of the input data are shown on figure 8. The data comes from the National Transportation Safety Board files: annual accident summary reports, report of individual accidents, and finally, the actual docket for each accident. The numbers on figure 8 are examples of the data we need: the distribution of fire accidents over

ACCIDENT CHARACTERISTICS

METHOD:

- SAMPLE FROM HISTORICAL DISTRIBUTIONS FOR LOCATIONS, OP-PHASE
- FRACTION OF A/C DESTROYED BY FIRE ESTIMATED BY ANALYSIS OF INDIVIDUAL ACCIDENTS

ASSUMPTION:

- ACCIDENT DETAIL DATA ARE HOMOGENEOUS
- U.S. AGGREGATE DATA CAN BE APPLIED TO INDIVIDUAL AIRPORT

Figure 7

DATA:

FROM NATIONAL TRANSPORTATION SAFETY BOARD FILES AND ACCIDENT REPORTS

- DISTRIBUTION OF FIRE ACCIDENTS
  - 0% STATIC
  - 0% TAXI
  - 20% TAKE-OFF
  - 20% IN FLIGHT
  - 60% LANDING
- ESTIMATED FRACTION OF A/C INVOLVED IN FIRE
  - 0% STATIC
  - 0% TAXI
  - 20% TAKE-OFF
  - 30% IN FLIGHT
  - 50% LANDING

Figure 8

operational phase and then the estimated fraction of the aircraft involved in the fire for fire accidents occurring in the different operational phases for which data are tabulated. Our estimate - on the basis of an analysis of about five years' accidents in considerable detail - is that about 20 percent of the aircraft would be involved in a fire that results from a take-off accident; 30 percent for an in-flight accident; and 50 percent for a landing accident. A study by the Stanford Research Institute recently made available to us, covering a larger sample, is essentially in agreement. I want to point out that, although the numbers in the lower right of figure 8 add to one hundred percent, they do not have to.

The other thing we have to know about the accident is the amount of fiber liberated which is given on figure 9. Again, the aircraft types are those defined jointly by ORI, NASA, and the airframe manufacturers. The amount of graphite in the structure is based on estimates that we've mutually agreed on. We've shown on the right the amount of fiber in pounds that we estimate would be liberated in an accident for each aircraft category, for an accident in each operational phase. There are two other phases in which, on the basis of our analysis, we would not expect any fiber to be liberated because fire would not result from the accident, so we haven't shown those. The basic assumption here is that only 20 percent of the graphite involved in the accident is released in the form of the single fibers that

FIBER LIBERATED PER ACCIDENT WITH FIRE — 1985
(Pounds)

A/C CATEGORY	GRAPHITE IN STRUCTURE	OP-PHASE		
		TAKE-OFF	LANDING	IN-FLIGHT
1. LARGE DC-10, L1011, 747	1000	40	100	60
2. MEDIUM 727, 757, 767, 707, DC-8	300	12	30	18
3. SMALL 737, DC-9	200	8	20	12

NOTE: ASSUMES 20% OF INVOLVED FIBER IS RELEASED

Figure 9

the analysis is concerned with - as opposed to clumps. This is based on limited experimental data.

The next step in the "Process Accident" program is to compute the downwind exposures at representative locations, and in order to do that, the computer has to know where those locations are. So, we've developed methods for defining points that we want to look at in the geographical area. We define representative points for industrial, commercial, and residential centers for each city and county in the geographical area of interest. As indicated in figure 10, the basic assumption that we've made is that the industrial and residential units of the types we're interested in are distributed relatively uniformly over the subarea that's represented by a particular point. The kinds of data we need include population, for which we use the 1970 census. For business types, sizes, and locations, we take advantage of a scheme developed primarily by the Department of Commerce and used by many agencies: namely, the SIC (Standard Industrial Classification) code. We've limited ourselves to what is called the two-digit breakdown, some examples of which are shown at the bottom of figure 11. For example, SIC code 23 covers places that manufacture apparel and do other textile processing. Number 27 is in the manufacturing category for printing and publishing. 54 is the code number in the retail business group comprising food stores. SIC 60 is banking. Number 62 is stock brokers and so on. The

DEFINE REPRESENTATIVE LOCATIONS

METHOD:

- **DEFINE INDUSTRY AND RESIDENCE CENTERS FOR EACH CITY, COUNTY**

ASSUMPTION:

- **INDUSTRIAL UNITS AND RESIDENCES UNIFORMLY DISTRIBUTED OVER SUB AREAS**

Figure 10

DATA:

- **POPULATION — *1970 CENSUS***
- **BUSINESS TYPES, NUMBERS, PAYROLL BY 2-DIGIT SIC* CODE — *COUNTY BUSINESS PATTERNS***
- **BUSINESS LOCATIONS — LOCAL & STATE DEVELOPMENT AGENCIES**

***SIC = STANDARD INDUSTRIAL CLASSIFICATION**

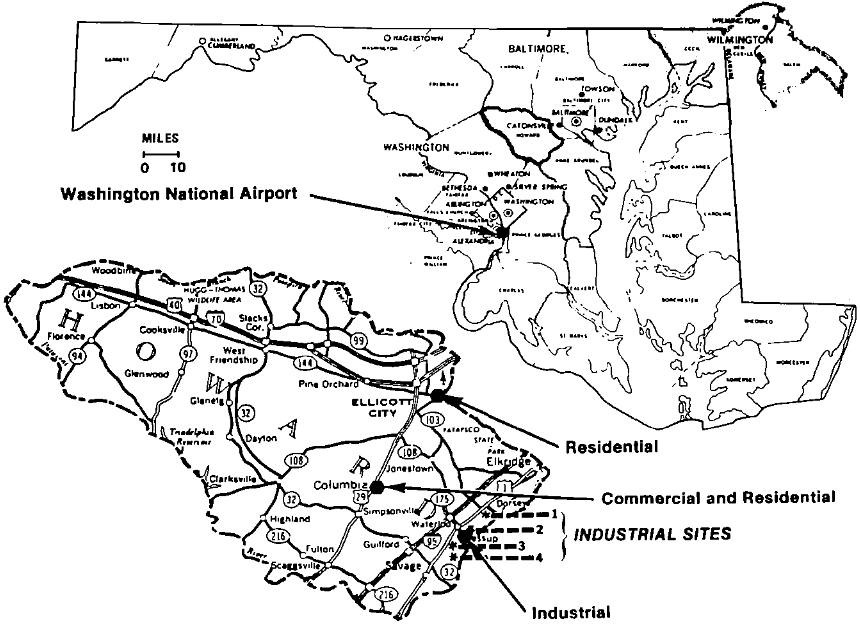
eg: 23, MANUFACTURING APPAREL
27, PRINTING & PUBLISHING
54, FOOD STORES
60, BANKING

Figure 11

County Business Patterns identifies the kinds of business performed in an individual county using this terminology. It tells us how many employees there are; there's a frequency distribution of establishments by size, as well as payroll data.

In order to determine where clusters of these businesses are on a scale finer than the county, we deal with people at state and local economic development agencies. An example of the kind of thing we've done is illustrated on figure 12. The scale on figure 12 indicates that Howard County, at its closest point, is 15 or 20 miles from National Airport. The inset map in the lower left of figure 12 shows Howard County in more detail. In order for us to represent Howard County for the calculation of graphite fiber impact, we've located a point at Ellicott City which is residential; we have located another point at Columbia, Maryland - a so-called new town - as a center of residences and commercial interests, primarily retail establishments. The area marked by four heavy dashed lines is the part of Howard County zoned for industry. The heavy dot is where we have placed all the significant industry in Howard County and essentially assumed that the part of Howard County to the left (west) of those three points is essentially farm land and not of great interest to us from the risk-assessment point of view. The same methodology has been applied to Washington, D.C., and the

DATA:



SOURCE: STATE OF MARYLAND DEPARTMENT OF ECONOMIC AND COMMUNITY DEVELOPMENT

Figure 12

Maryland and Virginia countryside within about 50 miles of Washington National Airport to define the set of representative locations for which the computer program called "Process Accident" will calculate exterior exposures.

Once we've generated an accident with its characteristics - "drawn an accident" is the customary expression - we proceed as indicated in figure 13 to compute the downwind concentrations and the associated exposure at the set of points we're interested in. In order to do that, we use a technique similar to the turn of the roulette wheel that Dr. Credeur talked about to draw a set of weather variables from a distribution that gives the observed frequency with which different combinations of wind speed, direction, and stability categories occurred in the past. These data are made available by the National Climatic Center for major weather stations around the country--so we use the data set for Washington National Airport. This process gives us the weather conditions for the accident we are now processing. We calculate the pertinent plume rise characteristics using the so-called Briggs model that was described for us by Dr. Wolf Elber yesterday. The energy release rate is a function of the aircraft category. The assumption is that the size of the burning fuel pool, and thus the heat release rate, is proportional to the square of the wing span of the aircraft. The computer program uses inputs to the Briggs calculation based on the size of

COMPUTE DOWNWIND CONCENTRATION

METHOD:

- RANDOM DRAW OF WEATHER CONDITIONS
- FIRE PLUME BASED ON BRIGGS MODEL — ENERGY RELEASE RATE A FUNCTION OF A/C CATEGORY
- DOWNWIND TRANSPORT — GAUSSIAN MODEL
- DISPERSION, LAYER DEPTH FUNCTIONS OF STABILITY CLASS
- PARTICLES FALL OUT
- PARTIAL REFLECTION AT SURFACE

ASSUMPTION:

- FIBER RELEASED = FRACTION OF A/C DESTROYED BY FIRE X 0.2
- FIBERS MOVE WITH MEAN WIND
- DISPERSION IN VERTICAL AND LATERAL DIRECTIONS

Figure 13

typical aircraft in each category involved in the simulated accident.

The subsequent downwind transport calculation is based on a Gaussian model. The dispersion parameters that go into that calculation are based on a set of inputs from EPA. As shown on figure 14, they are from the CRSTER model that EPA makes available. The inversion height - or layer depth - is from a publication by George Holzworth. He has essentially developed a climatology of mixing depths or inversion heights and associated wind speeds for different stability classes. The model we use then takes account of dispersion, allows the particles to fall to the surface, and allows for partial reflection of the fibers at the surface and for reflection at the inversion. The basic assumption we've made is that the fraction of aircraft destroyed in the fire is used as an estimate of the fraction of the amount of fibers in the aircraft released. To be more precise, the amount of fiber released is set equal to the fraction of aircraft consumed by fire, which we have estimated from accident data, times the factor 0.2 to represent that part of the graphite that will end up as single fibers. The fibers move downwind with the mean wind, spreading by dispersion only in the vertical and lateral directions. These latter are standard assumptions in most of the Gaussian plume models used in pollution studies.

DATA:

- **WIND SPEED, DIRECTION, STABILITY CLASS FROM NATIONAL CLIMATIC CENTER**
- **DISPERSION — "CRSTER" MODEL FROM EPA/MODIFIED**
- **LAYER DEPTH — HOLZWORTH, *MIXING HEIGHTS*, *WIND SPEED* . . . EPA, 1972**

Figure 14

The particle fall rate is represented by using a "tilted" plume model, which is a variation of the basic Gaussian model.

Having computed the exterior concentration and the resulting exposure at our representative locations, the next step, as indicated in figure 15, is to compute interior exposures for the places we're interested in. To do that, we assumed that - for each one of the two-digit SIC codes - we can define a representative building. For each representative building type we defined ventilation parameters. As indicated on figure 16, the data source for most of this work is a volume put out by the Carrier Corporation for the design of air conditioning systems. That was the basic source of information for air leakage into buildings. The calculation proceeds along the lines that Mr. Israel Taback described.

For the particular building parameters we've assigned to each business and industrial category, we compute an interior exposure which is a function of the external exposure, the ventilation parameters, as well as the wind speed, and the fall rate of the particles. The basic assumption here is that these typical facilities can be defined and that all facilities associated with a given type of business or industry are similar. I should mention that, in addition to the Carrier Corporation's

COMPUTE INTERIOR EXPOSURE

METHOD:

- FOR EACH INDUSTRY CLASS, DEFINE VENTILATION PARAMETERS FOR TYPICAL FACILITY
- COMPUTE INTERIOR EXPOSURE FROM EXTERIOR EXPOSURE, BUILDING PARAMETERS, WIND SPEED, PARTICLE FALL RATE

ASSUMPTION:

- TYPICAL ENCLOSURES CAN BE DEFINED

Figure 15

DATA:

- CARRIER CORPORATION

  HANDBOOK OF AIRCONDITIONING SYSTEM DESIGN 1965

- SITE VISITS

Figure 16

handbook, we made quite a few site visits in the Washington metropolitan area. They were listed on one of the slides that Mr. Ansel Butterfield used yesterday in his talk on "Pathfinder Surveys."

At this point, we have simulated an accident, computed the downwind exterior exposure, and moved the fibers inside typical facilities at representative locations. We now need to estimate the expected failures. As indicated on figure 17, the basic method is to define typical systems for each of the two-digit industrial-commercial SIC categories that are present in Washington, D.C. and environs. For each of these systems, we computed an overall failure probability. Figure 18 illustrates the kind of data we used. As a result of digging into the journals and reports listed, we were able to develop a model of the type shown for all the industries and businesses we were concerned with. It says that, typically, power comes in from the outside through a transformer, passes through a switch panel and/or terminals on the transformer, and flows to something we call common equipment, computers or control systems for the entire facility. Power is then split into a set of parallel lines, each of which might involve a servo and a control system.

COMPUTE FAILURES

METHOD:

- DEFINE TYPICAL SYSTEMS FOR EACH INDUSTRIAL CLASS, RESIDENCE
- COMPUTE OVERALL FAILURE PROBABILITY FOR EACH TYPICAL FACILITY USING INDIVIDUAL COMPONENT FAILURE PROBABILITY, COMPUTED EXPOSURE

ASSUMPTION:

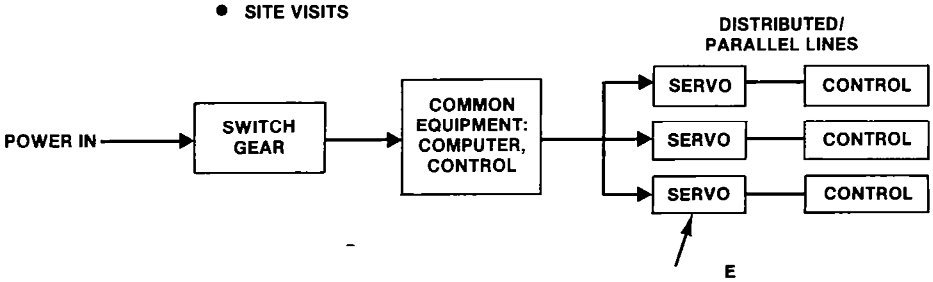
- TYPICAL SYSTEMS CAN BE DEFINED
- EXPONENTIAL FAILURE MODEL FOR INDIVIDUAL EQUIPMENTS

Figure 17

DATA:

FACILITY MODELS FROM

- IEEE *SPECTRUM*
- *INSTRUMENT & CONTROL SYSTEMS*
- *AUTOMATION/INDUSTRIAL ENGINEERING*
- *MACHINE DESIGN*
- *STANDARD HANDBOOK OF MECH. ENG.*
- *CONTROL ENGINEERS HANDBOOK*
- SITE VISITS



$P_F = 1 - e^{-\frac{E}{\bar{E}}}$

$\bar{E}$ FROM TEST DATA

COLOR TV: 10^7 FIBER-SECONDS/m^3
COMPUTER: 10^6
HIFI AMP: 10^5

Figure 18

The probability of failure for each individual element in the system obeys an exponential law. As shown on figure 18 the probability of failure is 1 - exp(-E/E), where $\bar{E}$ is a number we get from test data of the type described by Mr. Taback in his lecture on vulnerability. From the available experimental data we matched the tested equipment to actual industrial and commercial equipment as closely as possible to obtain the appropriate $\bar{E}$. With the computed interior exposures E, and $\bar{E}$, we compute the failure probabilities for individual equipment. With these individual probabilities properly hooked together, we obtain - for the computed interior exposure - an estimate of the probability that a plant or facility of a particular industrial-commercial category will fail. A basic assumption is that such typical systems can indeed be defined and that the exponential failure model is appropriate for the individual equipment. Once we've computed these expected failures, we have to estimate the cost impact. That is the next step in our "Process Accident" calculation.

To compute the costs of failures, the basic method, as indicated on figure 19, considers that the fraction of the industry down or the fraction of production lost is equal to the probability that an industrial unit of that class has failed. The residential unit cost is estimated by looking at the costs of repairing equipment in the household that has failed. The data

COST OUT FAILURES

METHOD:

- **FRACTION OF INDUSTRY DOWN = PROBABILITY OF INDUSTRIAL UNIT FAILING**
- **COST OF OUTAGE IS FRACTION OF LOCAL GDP, BY SIC**
- **RESIDENTIAL UNIT COST IS COST OF REPAIRING FAILED EQUIPMENTS**

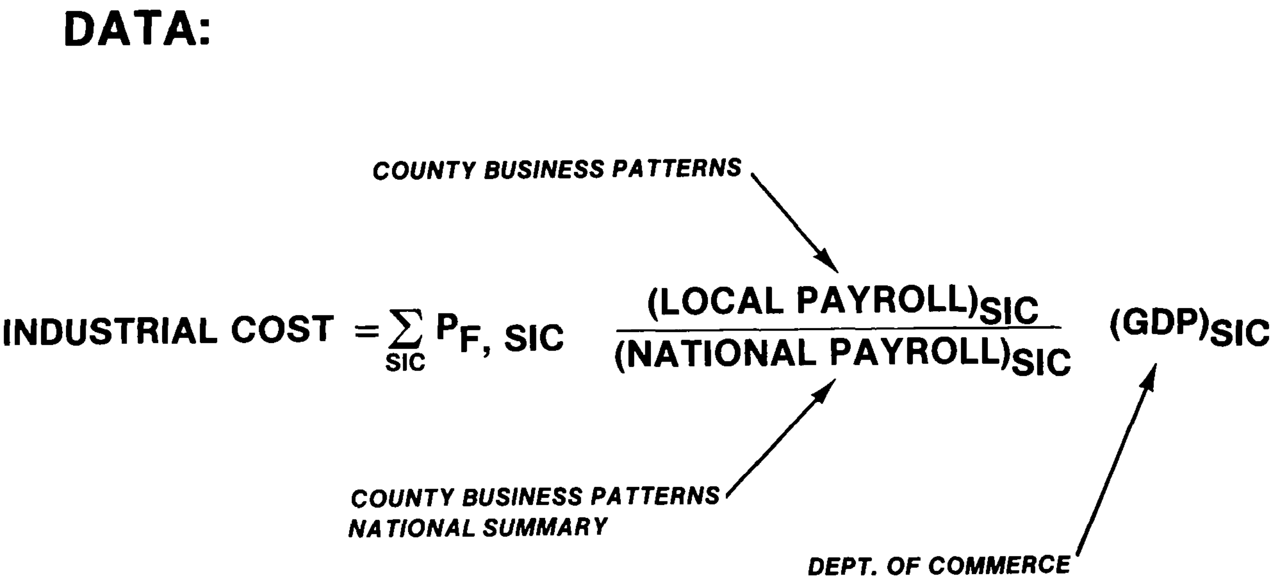
ASSUMPTION:

- **INDUSTRIAL IMPACT MEASURABLE BY GDP**
- **NATIONAL PRODUCTIVITY VALUES CAN BE APPLIED LOCALLY**

Figure 19

and the actual formula or algorithm for industrial cost estimating are shown on figure 20. It says that for a particular SIC classification, we can estimate local productivity by looking at the Gross Domestic Product (a term that is closely related to what everyone calls the GNP (Gross National Product, the sum of all goods and services produced in a year)).

The Gross Domestic Product is the Gross National Product with all production in the United States by foreign manufacturers added and all production by American manufacturers overseas taken away. The basic approach is to say that the productivity per payroll dollar can be estimated by looking at the amount of Gross Domestic Product assigned to each economic sector on the national level. We take the Gross Domestic Product associated with each type of industry and divide it by the national payroll for the same type of industry - that, in effect, gives us the impact of a payroll dollar on Gross Domestic Product. We then multiply that result by the local payroll for the same industrial category obtained from a document called County Business Patterns for each county (as opposed to the County Business Patterns, National Summary.) We then multiply that result by the probability of failure for that class of industry that we just computed at the particular location. We have assumed that the impact lasts one day - so we have divided the annual GDP by 365 in estimating failure impacts. We add these costs up over all SIC categories - all



$$\text{INDUSTRIAL COST} = \sum_{\text{SIC}} P_{\text{F, SIC}} \frac{(\text{LOCAL PAYROLL})_{\text{SIC}}}{(\text{NATIONAL PAYROLL})_{\text{SIC}}} (\text{GDP})_{\text{SIC}}$$

Figure 20

industries or kinds of commerce represented at this location. That is the way we estimate the industrial and commercial impact of a failure at the local level.

The basic assumption is that industrial impact can be measured this way and that the national productivity estimate obtained by dividing Gross Domestic Product by the national payroll for a particular industrial sector can be applied locally. In other words, it says that the workers, say in printing or publishing at Time-Life Books in Alexandria, are as efficient as the "national average workers" in the same industry.

The next calculation, as indicated on figure 21, is to estimate the impact on individual households. Again, as described by Mr. Taback yesterday, we have estimated some fraction of households as being air-conditioned, some not air-conditioned, where the fraction that is air-conditioned decreases with distance away from the metropolitan area - assuming that farmers in Talbott County do not have air-conditioned farmhouses. We assume, on the other hand, that everybody in Montgomery County is air-conditioned. We've estimated the number of TV's and Hi-Fi's per household, again assuming that although the national average is one TV per household, the number will be a little higher in more affluent communities and lower in less affluent communities. With those

HOUSEHOLD COST MODEL

METHOD:

- VENTILATION PARAMETERS DEFINED FOR A-C, NON A-C HOUSEHOLDS
- ESTIMATE NUMBERS OF TVs, HIFIs PER HOUSEHOLD FOR EACH GEOGRAPHICAL AREA
- COMPUTE NUMBER OF TV, HIFI FAILURES EACH AREA
- COMPUTE TOTAL REPAIR COSTS

ASSUMPTION:

- HOUSEHOLDS UNIFORMLY DISTRIBUTED OVER GEOGRAPHICAL AREAS

Figure 21

numbers we were able to compute the estimated number of TV and Hi-Fi failures for each one of our residential units. We estimated the total repair costs based on a gross cut: it costs 50 dollars to fix a TV set and $75 for a Hi-Fi, if it failed as a result of the graphite fiber problem. Again, the basic assumption is that the households are uniformly distributed in the neighborhood of the representative points we've selected.

We find that we have now more or less worked our way painstakingly through the calculation. The next step is one that doesn't need any technical explanation - we add up the costs for everything at each location and then add up the costs for all locations for this accident.

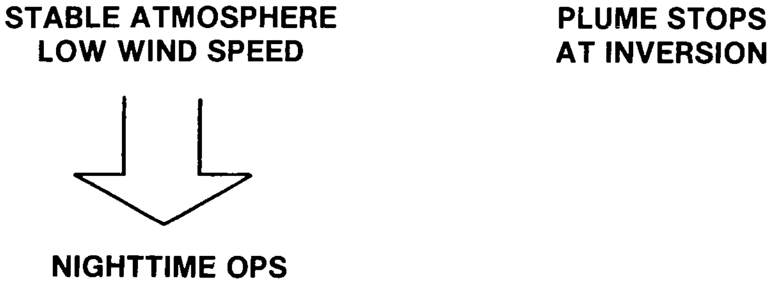
That takes us through the "Process Accident" routine, and if we look back at the Airport-Metropolitan Area model we find that once we have finished the "Process Accident" routine we repeat it for every accident in the simulated time period. We then repeat the time period over and over again to develop statistics over many sample time periods. I feel that I have now described the strategy - why we need the individual airport results - and I have described the Airport-Metropolitan Area model in some detail. I would like to stick to our original outline and show you several preliminary results for the Washington National Airport - Washington Metropolitan Area risk assessment. The map we looked at (figure 12) showed that the area we needed to consider included the Baltimore SMSA (Standard Metropolitan Statistical Area), the Washington, D.C., SMSA, and the Wilmington, Delaware, SMSA. So, when we say Washington, D.C., we're really talking about Washington, D.C., Baltimore, and Frederick, Maryland, as well as large parts of Virginia.

We are still working on the processing of the statistics to develop risk profiles. Figure 22 shows some sample results garnered from the simulation of 2,000 accidents processed by the computer in exactly the way I described. Over the 2000 accidents - using the best estimates we could get for our 1985 scenario - preliminary results indicate that expected cost, or average cost per accident, is on the order of 5,000 dollars. If one looks at the accident rate and asks for the numbers per year - the expected cost per year is on the order of a little more than 100 dollars; because, the likelihood of an accident at the Washington National Airport involving fire in an aircraft with graphite fiber is quite small. If you remember, we started off with an estimate of 6 fire accidents per year in the country and that number is then degraded by the share of operations at Washington National Airport, further degraded by the fact that about 20 percent of the 1985 aircraft fleet will be using graphite fiber. We can also look at the distribution of accidents. We've estimated that - at the relatively high end of the spectrum - .005,

1985 RESULTS
2000 SIMULATED ACCIDENTS

- **EXPECTED COST PER ACCIDENT ≈ \$5000**
- **EXPECTED COST PER YEAR ≈ \$110**
- **FRACTION OF ACCIDENTS WITH COSTS > \$200,000 = 0.005**

CONDITIONS ASSOCIATED WITH THESE ACCIDENTS:



STABLE ATMOSPHERE
LOW WIND SPEED

PLUME STOPS
AT INVERSION

NIGHTTIME OPS

Figure 22

or half a percent, of the 2,000 accidents we simulated ran up costs greater than 200,000 dollars.

Now, I'd like to describe one of the advantages of our method. Although Dr. Credeur concentrated on statistics in her talk and our goal is clearly to develop statistical results, one has the option when using this computer program of asking for what I call almost "infinite detail." We have several options with regard to computer output, starting with the "De-Bug Print" which prints out every calculation the computer made--all the way up to gross statistics summarized over many replications. In between, we can ask for certain results for every accident that was simulated in the program.

What we've done in figure 23 for the 1985 scenario is to show key items that the computer drew from the random distributions described earlier - associated with the results computed for each accident. Of interest is the fact that all of these relatively high cost accidents, in our sample of 2,000, occurred in the most stable meteorological conditions. All but one of the accidents took place in the landing phase. The stability conditions correspond to what Dr. Elber defined as Class E and Class F, the most stable Pasquill-Gifford categories. Associated with them were low wind speeds, but different wind directions. A sample from the statistics for the Washington National Airport shows that all directions are not equally likely, but these

HIGHEST COST ACCIDENTS
1985: BASE CASE

AIRCRAFT CATEGORY	OP PHASE	STAB CLASS	WIND		GRAPHITE RELEASED (POUNDS)	TOTAL COST ($$10^3$)
			SPEED (M/SEC)	DIR.		
MED	LAND	6	2	166°	30	844
LARGE	LAND	5	2	226	100	537
MED	LAND	6	2	174	30	490
MED	LAND	5	2	171	30	387
MED	LAND	6	2	341	30	303
SMALL	TAKE-OFF	6	2	165	80	299
MED	LAND	6	2	177	30	250
MED	LAND	6	2	189	30	250
MED	LAND	5	2	342	30	234
MED	LAND	6	2	162	30	227

Figure 23

are the directions associated with these particular accidents. These stable meteorological conditions, incidentally, might occur with fog or generally reduced visibility. Further, the stable atmosphere and low wind speeds are typical of nighttime conditions. This implies - again, this is a preliminary result based on the analysis of these 2,000 simulated accidents - that if a relatively bad accident of this type were to occur it would appear most likely to occur during nighttime operations. Now, for safety purposes, night ends an hour after sunrise and begins an hour before sunset. So even though a commercial airport typically closes at night, closing time might be ten or eleven PM, which includes a few hours of what Pasquill-Gifford call nighttime. In addition, in these cases the Briggs model is used to estimate the height of the fire plume, and if the plume height provided by the equation is above the inversion, we stop it at the inversion. This is by far the most frequently observed situation. We've shown that, when the amount of fibers increases by a factor of 10, the expected cost per accident increases by a little less than a factor of 10. So that, if the estimated costs for other scenarios are high enough to worry about, these results say that we should probably take a closer look at the meteorology of this situation.

Now beyond these results, we have made some runs for the 1993 time frame using the information shown on figure 24. For

1993 SIMULATION PARAMETERS

	AIRCRAFT CATEGORY	FRACTION WITH GRAPHITE	GRAPHITE PER A/C	AIRPORT OPS	
1985	1	.33	1000	18,850	TOTAL U.S. OPS 11,700,000
	2	.20	300	124,766	
	3	.20	200	60,284	
1993	1	.50	4500	29,621*	TOTAL U.S. OPS 13,800,000*
	2	.60	1500	143,669*	
	3	.50	1000	24,710*	

*1995 FAA PROJECTIONS

Figure 24

1993, the rough situation is that the amount of composite per aircraft with composite structure is expected to increase by about a factor of 5. The number of aircraft with composite in their structures is expected to go up roughly by a factor of 2 to 3. The charts identify the time frame as 1993 although the FAA air traffic projections are for 1995, the closest date for which they are available. With those changes to the basic inputs, the results for 1993 are as shown on figure 25. Assuming that population and industry stay the same, the average cost associated with these accidents on a per-year basis is estimated to be about a thousand dollars and the average cost per accident, on the order of $20,000. This is based on an analysis of about 2,500 simulated accidents. Using the same $200,000 dollar cutoff we used for the 1985 scenario, it is estimated that about 2 percent of the accidents involving fires aboard aircraft with graphite fibers in their structures would incur costs greater than $200,000.

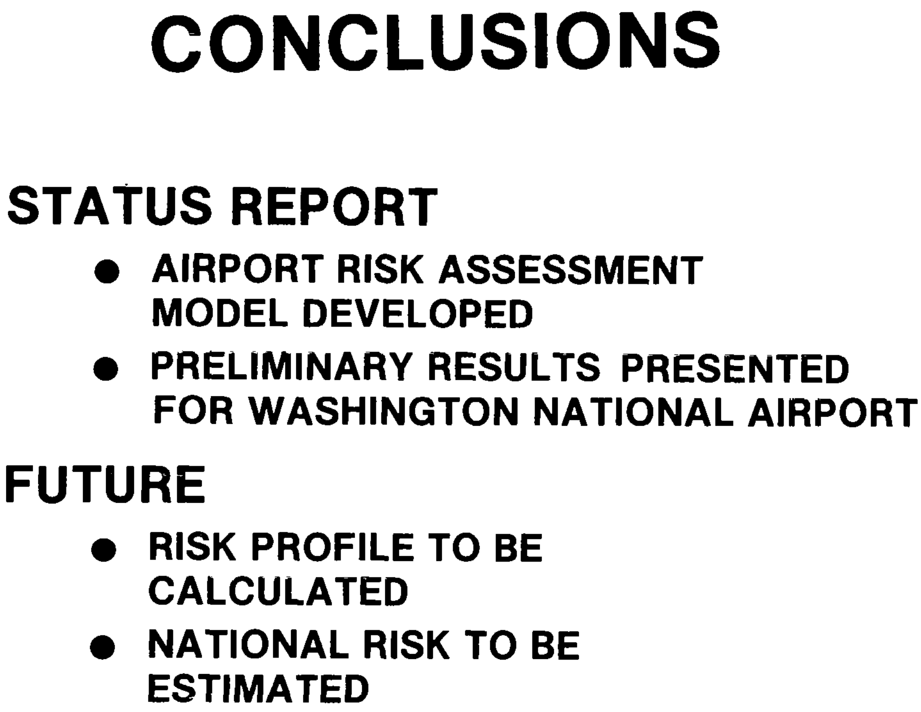
1993 RESULTS

2500 SIMULATED ACCIDENTS

- **EXPECTED COST PER ACCIDENT ≈ $20,000**
- **EXPECTED COST PER YEAR ≈ $1000**
- **FRACTION OF ACCIDENTS WITH COSTS > $200,000 = 0.02**
- **FRACTION OF ACCIDENTS WITH COSTS > $1,000,000 = .0036**
- **ONE ACCIDENT WITH COST > $4,000,000**

Figure 25

To wind things up, I would like to summarize our current status, which is shown on figure 26. We have developed a viable airport risk assessment model. In the lingo of computer experts, it is an input-driven model. We have some preliminary results for the Washington National Airport risk for 1985 and 1993. We plan to combine those results appropriately to develop risk profiles for the Washington National Airport and Washington-



CONCLUSIONS

STATUS REPORT

- AIRPORT RISK ASSESSMENT MODEL DEVELOPED
- PRELIMINARY RESULTS PRESENTED FOR WASHINGTON NATIONAL AIRPORT

FUTURE

- RISK PROFILE TO BE CALCULATED
- NATIONAL RISK TO BE ESTIMATED

Figure 26

Baltimore metropolitan area and to go on from that to develop a national risk estimate. That completes the formal presentation.

Question: Do you have the standard deviation for the accident costs as well as the expected value?

Answer: I don't have that right now. We haven't calculated it yet.

Question: When you talk about 6 airplanes a year being involved in fire, you projected that for 1985 . . Is that 6 airplanes with composite fibers?

Answer: No, six altogether. For fire accidents with composite onboard, it's actually lower than that. It's about 20 percent of that number (6).

Question: All your results are for stable meteorological conditions?

Answer: Well, I'm sorry if you drew that conclusion, because that means I really didn't get my message across very well. The major point of our whole approach has been the sampling of conditions from the appropriate statistical distributions The meteorology is drawn from a distribution that gives wind speed, wind direction, and stability class for Washington National Airport. The likelihood that the stability for the particular accident will be an unstable case is based on the historical record of weather as observed at National Airport over a long period of time.

The cases on the last figure were the conditions associated with the ten worst accidents out of 2,000, so it happened that the highest cost accidents according to the model we've developed seem to be those that occurred when stable conditions existed.

We ran 2,000 accidents for 1985. Each time there's an accident the computer asks: "What's the weather for this accident?" It looks at a table, structured by sixteen wind directions, five wind speed ranges, and six stability classes, so there's a box for every one of those combinations. In each box is the fraction of weather observations at Washington National Airport in which that combination was observed. Now the computer makes a random draw, generates a random number, turns the roulette wheel that Dr. Credeur told us about, and picks the weather condition.

Question: (Continues) But we know that accidents tend to occur when the weather is bad.

Answer: Well, that's a problem that we recognized early in the game and addressed with the Project Officer. A decision was made to draw the weather from this random distribution. Now, it's true that one would have expected some bias in accidents toward bad weather, likewise towards cases when there's rain falling. Frankly, for the degree of precision with which we know all the inputs that go into this calculation I feel that that problem is one that we can neglect for the time being.

Dr. Credeur responds: Your point is correct with respect to foul weather. Roughly 40 percent of the accidents that involve fire occur in foul weather; that is, weather involving precipitation. There are two problems with that though. "What is the effect of weather downstream?" You may have rain at an accident site for a very short time or over only a very small portion of the dispersion area. So one of the problems was how to handle the rain factor. The other was that, even if we incorporate it, the greatest impact it would have upon the answer was at most a factor of 2.

The other errors involved in this problem are much greater than that, so for the time being, we're not including it.

Question: Can you report on the results of sensitivity analyses?

Answer: Well, let's put it this way. One of the reasons we developed this approach was to be able to do the kind of things you asked about. We haven't done them yet. The one thing we can say is that the average cost per accident, at least in the range we're dealing with, is roughly linear with the amount of composite. Increase the amount of composite per aircraft by a factor of 10 and the average cost goes up by a little less than a factor of 10.

Question: What about sensitivity of results to the modeling method itself?

Answer: Well, hopefully, we're going to get some of that by comparing results from people who've used other models for the same kind of calculation. One of the big things that our industrial impact calculation leaves out is the cost of repair of equipment that may fail. In making the decision to use this approach - which I must admit is very attractive on the basis of data availability - we argued that the cost of a plant being closed down might roughly be equal to the cost of cleaning up any equipment. At most we thought we might be off by a factor of 2. We've made the assumption here that if a plant is down, it's down for a day. There's a one over 365 factor applied to the GNP numbers. That's our intuitive feel for that part of the problem.

Question: Have you neglected costs due to lawsuits following accidents?

Answer: The honest answer to that is: yes, we are neglecting that part of the problem.