Chapter 4

Aviation Security: Aspects of Integrated Security for Commercial Air Travel

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Chapter 4

Aviation Security: Aspects of Integrated Security for Commercial Air Travel

INTRODUCTION

Over the last 10 years, high-capacity international aircraft have become favorite targets of terrorists. Consequently, much research and development in counterterrorist technology has been focused on means of safeguarding this mode of transportation, in part by developing better means of detecting the small quantities of explosives believed to have caused the most recent fatal tragedies. That effort has included some attention to controlling access to the aircraft and other critical areas at airports, and to the human aspects of the security system. However, to date, the question of how best to combine technologies and people to provide maximum security is very much open.

Although most past research has looked at each concept or device as a stand-alone answer to the total problem of explosive detection, it is now generally recognized that no single detector either exists or will likely exist in the near future that can provide practical, reliable detection of explosives of the types and quantities of concern to aviation security. Recent reports by the National Academy of Sciences (NAS),[1] as well as by the Office of Technology Assessment (OTA),[2] concluded that a combination of techniques and devices is the most promising means of attaining high-confidence protection from explosive devices.

To determine how such a combination may reasonably be achieved, the performance of current and near-term technologies must be analyzed. Further, it is necessary to consider how various technologies and techniques best complement each other.

INTEGRATED SECURITY SYSTEMS

A systems approach to overall airport security is under development in a major program sponsored by the FAA Technical Center, using the Baltimore/ Washington International Airport (BWI) as a model. The development is being supported by Sandia National Laboratories, under contract to the FAA Technical Center.[3] This program is attempting to find the proper balance among risk, technology, and operational considerations for a typical airport environment, using BWI as a typical airport model. The program also will attempt to generalize the results found at BWI to other airports, by means of computer modeling. This program considers all the fictions of a security system, from detection to delaying intruders and response to intrusion.

COMBINED TECHNOLOGIES FOR AN EXPLOSIVES DETECTION SYSTEM

The explosives detection problem is one of surveying all means of bringing explosives aboard aircraft. First, this means screening passengers as well as hand-carried baggage and checked baggage that go on board. Mail and cargo must also be considered as possible pathways for introducing explosives aboard aircraft. Screening all flightcrew and service and airport contractor personnel is yet another issue, covered by the BWI program but not considered here.

[1] National Academy of Science, Committee on Commercial Aviation Security, National Materials Advisory Board, "Summary: Reducing the Risk of Explosives on Commercial Aircraft," NMAB-463, 1990.

[2] U.S. Congress, Office of Technology Assessment, *Technology Against Terrorism: The Federal Effort,* OTA-ISC-481 *(Washington,* DC: U.S. Government Printing Office, July 1991).

[3] The FAA BWI program is a multiyear systems study of security at the airport. The project began with an analysis of the airport/aircraft access problem, utilizing computer modeling and (human) expert input, new procedures, and training. It will follow with implementation, using these inputs and also encompassing hardware at the BWI airport at one of the domestic piers and the surrounding aircraft operations area.

Some general concepts must be considered in quantifying the explosives detection problem. These include the statistical parameters generally used to define the performance of detection devices, the statistics used to describe systems composed of combinations of detectors, the flow rate through the baggage checking system, and the throughput of a single device.

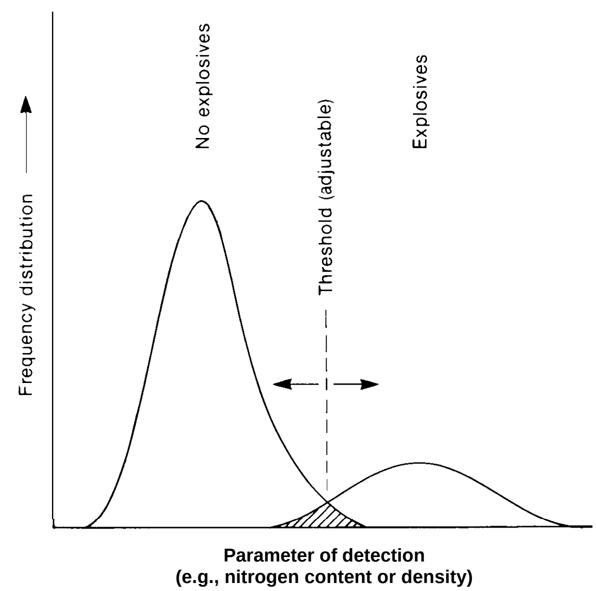
Statistics of Detection

The performance of **a** detection system can be characterized by two primary parameters: the detection probability, P_d, and the false alarm or false positive rate, F_a. A good detector has a very high detection probability (as close to 100 percent as possible), while still maintaining a very low rate of false positives or false alarms. These two parameters are coupled, primarily through the detection threshold: the more sensitive the detection threshold, the higher the false alarm rate. Unfortunately, to detect small quantities of explosives with high probability requires that the threshold for detection (the lower limit on the amount of explosives that may be reliably detected) be set as low as possible; consequently, the false alarm rate is high. This effect is shown graphically in figure 4-1. The curve on the left represents the distribution of measured nitrogen content (or other detection parameter) for bags with no explosives. The curve on the right represents the distribution of measured nitrogen content for bags with a given amount of explosives that should be detected. The shaded area of overlap represents the probability of a signal being caused by either a clean piece mistakenly identified or by a piece of contraband material.

As the threshold is moved to the left, i.e., the device is adjusted to detect lesser quantities of explosives, the detection probability for explosives increases (i.e., a greater percentage Of the total explosives population is correctly identified) but a larger area of the signals from clean items is included in the uncertain population, representing a higher false alarm rate.

Any detection scheme depends on a separation of the **two** peaks: the probability distribution of the clean items and that of the explosive. Figure 4-1 also demonstrates that as the quantity of explosive to be detected decreases, the two curves move together (i.e., the distribution of signals from bags with

Figure 4-l—Generic Frequency Distributions of Detections and False Alarms



SOURCE: Office of Technology Assessment, 1991.

explosives will be shifted **to the** left), making discrimination more difficult.

One way of increasing the effectiveness of **a** detection system is **to** combine several diverse detection techniques that make use of different phenomena. When two *independent* measurements are *both* required in order **to** produce an alarm (an "AND" gate) in **a** single detection system, the combined effectiveness in terms of overall detection probability, P_{dc}, is the product of the two individual probabilities, or $P_{dc} = P_{d1} * P_{d2}$, and the false alarm rate, F_{ac}, is the product of the two individual rates, $F_{ac} = F_{a1} * F_{a2}$. The combined probability, P_{dc}, is always smaller than the individual ones. Since detection with a high probability is the name of the game (P_d on the order of 0.90 or better is usually set as the goal), all stages of a system must individually have high detection probability. Combining two poor detectors thus does not necessarily make a better system in terms of detection probability. It is also possible to combine two detectors so that an alarm from *either* one may trigger remedial action or examination by yet another device (an "OR" gate). In this case, the resulting detection probability (and false alarm rate) combine as $P_{dc} = P_{d1} + (1 - P_{d1}) * P_{d2}$. The detection probability will increase relative to that of the individual detector, but so will the false alarm rate.

Significant gains can be made in the area of false alarm reduction by combining several detectors, each with moderate performance in the false alarm area. Two detectors each with an unacceptably high false alarm rate of, say, 20 percent would combine in an "AND' logic to produce a false alarm rate of only 4 percent, if the two measurements were truly independent. (In fact, they often will not be totally independent, so these arguments apply only to an idealized case. However, for some combinations of detectors (e.g., vapor detectors and TNA), the phenomena used are totally distinct, approximating the ideal.) A strategy of multidetector systems can be based on the goal of achieving an acceptable false alarm rate (often 5 percent or less) with acceptable detection probability. Depending on the parameters of the component devices, this may require AND gates, OR gates, or some combination of the two.

The true combined detection probabilities and false alarm rates can only be determined by measurements in an operational environment. Because of real interferants (e.g., objects that really contain large amounts of nitrogen and are dense), the combined probabilities will never be as good as the theoretical ideal. The above statistical arguments only provide an indication of possible improvements in combining systems, not a precise theoretical prediction of operational results.[4]

Detection Criteria

What actually constitutes acceptable detection probability and false alarm rate is not easily determined. The former is a question of acceptable risk while the latter is an operational problem. Setting the minimum acceptable detection probability is a subjective issue. If there were 10 attempted bombings per year (out of 40 million international enplanements), a detection probability of 0.90 would allow one expected dangerous situation (and sometimes more) to go undetected per year. If there were only one bomb attempt per year, the statistical expectation would be for one to go undetected about every 10 years. Would a terrorist be deterred by these odds and would the flying public accept them as "safe"? The operational part of the problem can be analyzed reasonably objectively, yet it, too, is difficult to specify precisely.

Flow Rate or Throughput

The Air Transport Association (ATA) contracted with the Institute of Transportation Studies of the University of California at Berkeley[5] to perform an analysis of the operational problems of installing a TNA-based explosives detection system (EDS) as specified by the FAA.[6] This study focused primarily, but not exclusively, on a false alarm rate of about 5 percent, as specified by the FAA for an EDS. Among other findings, the study found that the throughput of the Xenis (TNA plus x-ray)[7] EDS had to be slowed down by 28 percent for automatic detection (from an already degraded throughput of 6 to 7 bags per minute, due to the mechanics of preventing a radiation hazard) to allow the TNA image to be maintained long enough so that it can be correlated automatically with the Xenis X-Ray image. (This is a real effect but not necessarily a permanent problem, since a storage buffer could be added to the TNA computer to maintain the image data from one object while a new object is being viewed.) The study also found that attention must be paid to the space requirement for rejected luggage for any false alarm rate, whether the alarming bags are recycled, sent to another detector, or hand searched. For a 300-bag-per-hour throughput rate, a 5-percent false alarm rate requires space for handling another 15 bags per hour. This could be a serious consideration at the much higher false alarm rates currently encountered by the Xenis EDS. Such operational issues make it difficult to set a generally applicable criterion for the throughput performance requirements of detection systems.

[4] The FAA Technical Center is planning to institute a program called X-TRIAL S, which will put a variety of detection devices (covering passengers, cargo, and other potential pathways for the introduction of explosives aboard aircraft) and other elements of an integrated security system in operating airport environments. Such operational experiments are the best way to assess the capability of the elements of a security system and the combined efficacy of parts of the system at the same time.

[5] Geoffrey D. Goslin and Mark M. Hansen, "Practicability of screening International Checked Baggage for U.S. Airlines," Institute of Transportation Studies, University of California at Berkeley, Research Report UCB-ITS-RR-90-14, July 1990.

[6] See 54 *Federal Register* 36938, (Sept. 5, 1989).

[7] The systems tested at Gatwick and Kennedy Airports combine a TNA device with an x-ray system to compare and correlate information 011 excess nitrogen density with information onhigher density objects in the bag.

The analytical model developed in the Berkeley report has some capability for investigating the impact of higher false alarm rates on the operational difficulties of the airlines and consequently could be used to set objective guidelines for the maximum acceptable false alarm rate in a given operational situation.

The FAA, both in its research and development program and in its rule making process, has arbitrarily settled on a handling rate of 600 bags per hour (or 10 per minute). Realistically, however, the throughput requirement should vary greatly, depending on where in a chain of detectors a specific instrument is being used (and where the device is located). For instance, a device used only on a small number of bags could take much more time for its inspection. If only 10 to 15 percent of the passengers were selected for detailed inspection as a result of a well-defined profiling system, the throughput of the subsequent detection system would be greatly relieved. Further, location of the instrument and detector cost also greatly influence the throughput requirement. Inexpensive systems placed at the check-in counter could certainly allow as much as 30 seconds per passenger since the check-in process takes at least that much time. The issue of throughput requirement may be left to the marketplace, where different instruments with different throughput rates could be combined by the individual purchaser.

In this context, the variability of international airports and gateways should also be emphasized. U.S.-flag international air carriers enplane international passengers at 190 different airports, the top 20 of which carry 52 percent of the 38 million enplanements (19.5 million). The largest five airports handle an average of 1.8 million passengers per year and the other 15 of the top 20 carry only an average of 700,000 passengers per year. The other 170 airports handle considerably fewer passengers, on the average only about 100,000 per year. Thus, the high-volume gateways are an exception, rather than the rule, and much of the equipment required for a national security system will need to handle only moderate rates of baggage throughput. The detection system criterion for throughput will vary greatly; the choice for any specific operation **may best be left to the users, based on operational considerations.**

RECENT DEVELOPMENTS IN DETECTION TECHNOLOGY

X-ray Systems for Bomb Detection in Baggage

X-ray technologies for airport security are developing rapidly as advanced systems used for medical and industrial imaging are adapted for screening luggage. The FAA tested some advanced commercial x-ray systems in late 1990 for specific purposes in baggage screening. The results of these tests have not yet been released.

The standard x-ray machine for airport security produces an image of the distribution of x rays that have passed through the observed object. These pictures have excellent spatial resolution-thin wires are readily seen—but the operator cannot find a lightweight object behind a denser one, nor tell whether a dark image is due to a thin sheet of a heavy material, such as steel, or a thick sheet of plastic, which can produce the same x-ray absorption. During the past few years, a number of companies, using a variety of approaches, have been trying to overcome these shortcomings.

Dual-Energy

Dual-energy x-ray inspection produces two images, each taken with a different range of x-ray energies. Comparing the images yields information on the average atomic number of the elements in the material traversed by the beam.[8] Such machines can distinguish between metals (e.g., steel) and plastics. As yet, however, no commercial machine of this type can distinguish between some plastics and explosives or books. Moreover, none can detect a lighter object behind a heavier one. This latter problem is being addressed by applying image processing and by employing multiple-view systems.

Image-Processed Dual-Energy

Dual-energy combined with automated image subtraction is being developed by several x-ray companies. The images, stored as an array of

[8] The atomic number of an element is the number of protons (or, equivalently, the number of electrons) in an atom. Atomic weight is proportional to the number of protons and neutrons in an atomic nucleus. For light elements, the atomic number is roughly proportional to atomic weight; for heavier elements, atomic number increases at a slightly lower rate than atomic weight.

numbers, are manipulated by sophisticated computer algorithms that try to identify and isolate objects from their backgrounds. The dual-energy method is then applied to the isolated objects and an alarm produced if the characteristics of the object match those of a presumed explosive. Although a clear technical advance over simple dual-energy, it remains to be proven how well such a technique will work in a real airport environment.

Vivid Technologies of Waltham, MA, starting from expertise developed in producing special purpose medical x-ray equipment, has produced a refined dual-energy, single-view x-ray machine that can, it is claimed, very precisely determine the effective atomic weight and x-ray absorption density of all items in a piece of luggage. It does this by comparing high-resolution images at two x-ray energies and then using advanced computing techniques to analyze the images. Explosives of interest are claimed to give a definite signature of well-defined effective atomic numbers and densities.

Dual-Axis, Dual-Energy

EG&G Astrophysics, of Long Beach, CA, under contract with the FAA, is developing a dual-energy, dual-view system (T-Scan™—a trademark) that may determine effective atomic numbers by comparing views at different energies. EG&G uses two perpendicular views, rather than highly sophisticated computing algorithms, to resolve confusion in the images due to overlap of objects. The system is intended to have the ability to determine average atomic numbers along the perpendicular directions of view.

X-ray Compton Scattering

American Science and Engineering (AS&E) obtains backward x-ray scattering and x-ray transmission images simultaneously. A comparison of the two images gives the atomic number of interior objects with definition comparable to that from dual-energy techniques.[9] It has the advantage in some cases, such as bombs hidden in baggage linings, of being more sensitive than other techniques. However, the backward scattered image is made by lower energy x rays that are more easily absorbed by heavy material. AS&E is also developing image processing techniques and employing different scattering strategies to improve detection capabilities and is working on an automated algorithm to alarm in the presence of explosives.

Multi-Energy Imaging

Instead of imaging at two energies, it is possible to image many energies at the same time. One company, Magal of Israel, is marketing an instrument that manipulates the information generated with pattern-recognition algorithms. A great deal of additional information is thus available for analysis. The device is purported to give automatic alarms in the presence of bomb components.

Computerized X-ray Tomography

During the past year there has been a series of FM-sponsored tests at Imatron Corp., to evaluate the current performance of an x-ray computerized tomography (CT) scanner under development there. Whereas the original development at Imatron had aimed at a stand-alone EDS system, these tests emphasized its compatibility in combination with the SAIC/TNA. A group of bags that had alarmed the TNA system were delivered to Imatron with the location of the suspected area marked on the outside of each bag. Some of them actually contained real explosives (PETN and SEMTEX). Since the TNA has only moderate spatial resolution, the marking essentially consisted only of information on which quadrant of the bag contained the suspected explosives. The Imatron CT then looked only at the suspect area by making 3 to 10 CT slices of this area to produce reconstructed images (a l-cm thick segment of the object is imaged in each slice).

The results from this series of tests, although preliminary due to the small sample size and ad hoc nature of the tests, were quite encouraging.

The current Imatron CT seamer has a 60-cm-diameter detector ring and is not large enough to handle many common pieces of luggage. A new model with an 80-cm-diameter ring, which can handle baggage equal in size to that handled by the current SAIC/TNA, is currently under construction (under FAA contract). The biggest problem of the system is its scan speed, which is currently about 6 seconds per slice. It is claimed by the vendor, that, in the future, this scan time will be reduced to only 2 to 3 seconds in the new system. The primary issue to be resolved is the number of slices required to provide the needed detection probability (i.e., the

[9] See U.S. Congress, Office of Technology Assessment op. cit., footnote 2, pp. 78-79.

required resolution upon reconstruction). Another important issue is the eventual false alarm rate under operational conditions at an airport. At present, it cannot be ascertained whether the total detection time will be on the order of 10 seconds or a minute or more.

However, any scan time in the above range could find significant applications if the CT scanner were incorporated properly into a total detection system. With a l-minute total detection time, the CT seamer could still resolve false alarms for a system running at TNA speeds having a false alarm rate of almost 20 percent. If the time requirement were relaxed, the system could handle larger first-pass false alarm rates, greater baggage throughput, or could be used at an earlier stage of the detection cascade.

Imatron has also been developing a dual-energy CT detector. A prototype has been built and tested. It is slow, but could be used for close inspection of areas of luggage flagged by other means of screening.

Coherent X-Ray Radiography

Solid explosives are crystalline materials. Each type-PETN, RDX, dynamite, etc.—has a unique crystal structure that is different from that of other explosives and of innocuous materials. The distance between layers of atoms in the structure is revealed by using x rays in a method called Bragg scattering, after its discoverer. If the distance between the planes of atoms in a particular crystal is d, then Bragg scattering will be at a maximum (i.e., will have a peak in intensity) when x rays of energy E are scattered through an angle w, given by

$$\sin w = k/(Ed)$$

where k is a constant. Alternatively, one can send a broad energy spectrum of x rays through an object and observe the scattered x rays at a fried angle w. Bragg peaks corresponding to crystalline spacings are then looked for in the scattered energy spectrum. The method looks for the characteristic spacing of crystals of explosives that may constitute a bomb. The question to resolve is how often other crystals found in luggage or in other examined objects may have a similar characteristic spacing, resulting in false alarms. Scientists at Philips Gmbh of Hamburg, Germany, are developing the method for medical applications and have licensed Scan-Tech of New Jersey for applications in the area of security.

Scan-Tech, in collaboration with scientists at Rutgers University, has successfully completed proof-of-principle tests. These early results give some hope that coherent x-ray scattering may become useful for airline and other security applications. The next stage is to build a prototype and test it under realistic airport conditions.

Evaluation of all these new developments, both for detection probability and false alarm rates, awaits rigorous testing by outside parties.[10]

The Use of Pattern Recognition in X-Ray Images

Automated pattern recognition schemes to enhance the ability of x-ray systems to locate threat items such as guns, knives, and electronic components are under development. Such systems are not only automation schemes but are also ways to overcome the human fatigue problem ever present in a repetitive procedure such as x-ray image inspection.

One company in Canada, Array Systems Computing, Inc., has developed (under contract with Transport Canada) a neural-network based system for detecting guns, knives, and hand grenades and is in the process of extending the technique to detecting electronic components. That system uses a dedicated computer that can be added to a standard high-resolution x-ray system. In tests conducted by the company, their system was able to detect guns with over 95-percent detection probability and about a 10-percent false alarm rate. Separate, independent tests conducted by Transport Canada have confirmed these results. The use of such techniques as an operator assist, allowing the operator to concentrate only on high-threat items that alarm the automatic system, appears to be a productive approach to an important aspect of a security system.

Use of such procedures to identify bomb components is also under development. The critical questions are the eventual performance of the system and the difficulty of disguising or hiding such components from such a system. Until the technology is perfected and tested under controlled conditions, it is too early to evaluate the potential of this technique.

[10] The previous OTA study on technology and terrorism recommended that a testing agency outside the FAA should be empowered to assess explosives detectors for efficacy. See U.S. Congress, Office of Technology Assessment op. cit., footnote 2, pp. 8-10.

Early developmental work on such a technique is under way. The goal is to provide x-ray vendors with a plug-in computer card with sufficient capacity and speed that would perform the analysis of the image and make the decision. If such a system can be developed to have a high-detection probability, even with moderate false alarm rates, it may represent a very powerful add-on which could make an ordinary x-ray detection system semi-automatic.

Microdose X-Ray Images **for Examining People**

A new x-ray approach has been developed that uses extremely small doses of radiation to examine people to find if they are concealing weapons, explosives, or other contraband under their clothes. American Science and Engineering of Cambridge, MA, has adapted its x-ray backscatter technique to this end. A similar approach was developed by AGS Corp. of Hammond, IN, later acquired by IRT of San Diego, CA. The images produced by both techniques are quite clear, indicating a potential effectiveness, but immediately raising legal issues of privacy. Radiation doses are equivalent to a few minutes of natural radiation exposure, and much less than the increased level of exposure to radiation suffered on a flight. Although these are insignificant levels, there would likely be strong public resistance to the mandated use of x rays for airport security. However, this technique would protect against a principal route for bringing explosives aboard aircraft.

New *Results With TNA*

Further FAA testing of a TNA system at Gatwick Airport near London has been reported to show an improvement over its earlier performance.[11] Whereas earlier tests on goal quantities of explosives showed detection probabilities somewhat lower than desirable, the most recent tests were reported to show higher detection probabilities for quantities in the high range of estimates for the size of the Lockerbie bomb. More importantly, the false alarm rate for similar quantities was also reported to have been cut substantially. These results were said to have been obtained mainly through the development of improved detection algorithms and by the education that the neural network system has gained in observing large numbers of real passenger baggage items. However, even the improved false alarm rate is too high to allow use of the TNA device by itself as the only bomb detection mechanism. The TNA system will have to be combined with profiling (as at Gatwick) and, probably, with other technologies. Further, it may be necessary, pending a new assessment of the desired goal quantity of explosive to be detected, to reduce detection thresholds still further. This would require further improvements in the system to keep the false alarm rate to manageable proportions.

The newer results are in the process of being verified by outside consultants, and a final assessment of the capability of TNA awaits confirmation.

If TNA devices are inherently limited by false alarm rates, as some skeptics claim, one possible application could be to use the device only for close examination of individual items selected by other screening methods (e.g., x rays). As an example, if a screening device finds a suspect electronic device in a bag or carry-on item, a TNA device could be used just to inspect it for explosives content. Since electronics equipment would have a low nitrogen fraction, and the mass of the equipment would be less than that of large bags, confusing background would be reduced and the false alarm rate would be much lower.[12]

New *Results With Vapor Detectors*

Several vapor detectors were tested by the FAA in late 1990 for specific applications in screening luggage. The results of these tests have not yet been made available.

Electromagnetic Techniques for Explosives Detection

A detailed discussion of nuclear magnetic resonance (NMR) and nuclear quadruple resonance (NQR) techniques for detecting explosive compounds is given in CLASSIFIED appendix F. Both methods involve applying radiofrequency radiation to an examined object while observing the electromagnetic response of molecules contained therein. Another method, dielectrometry, measures the dielectric constant (a physical property of matter) of an object, to determine whether anomalous items are

[11] Lynne Osmus, Office of Civil Aviation Security, FAA, testimony at hearings before the Senate Governmental Affairs Committee, Feb. 26, 1991, and Ken Lauterstein, FAA, personal communication, Feb. 1991.

[12] This suggestion was made by John Baldeschwieler, Professor of Chemistry, California Institute of Technology, and Chair of the National Academy of Sciences Committee on Commercial Aviation Security, personal communication, July, 1991.

present. The latter technique does not detect explosives, just anomalies in dielectric constant. All these methods can, in principle, be defeated by wrapping the explosive in metal foil. However, it is easy to test for the presence of metal foil, for example, with standard metal detectors (see app. C). For carry-on baggage, there would be a high false alarm rate. However, for screening individual items targeted by other techniques, these methods might be useful. For screening people, NQR might become a candidate detector.

The relative values (among themselves) of NMR, NQR, and dielectrometry depends on the details of the particular application: on the explosives compound, on the nature of the objects that would be used to conceal the explosives, and on the acceptable trade-off between the probability of detection and the false alarm rate. But there are generic differences among the three techniques.

Dielectrometry is the cheapest and most portable option, and it can be very sensitive. However, the response is nonspecific: not only is there little ability to discriminate, but the false alarm rate will be high, as many materials will appear to be anomalies. Nevertheless, in some applications, such as items concealed on a person, the technique maybe useful.

NQR has high specificity, and therefore might produce the lowest false alarm rate. However, the technique may be limited in the number of explosives reliably detectable. One developer has estimated that aversion might cost about $50,000, much more than a dielectrometer, but half as much (or less) as an NMR device. In combination with a metal detector, NQR might be a very useful technique for frisking people for contraband explosives (and could be used for drugs as well).

For baggage inspection, NMR would probably not be as specific as NQR, but it might be effective for a greater number of explosive species. NMR would require the imposition of a strong magnetic field on the baggage, presenting other operational problems (data on magnetic disks carried in baggage would be destroyed, etc.).

Throughputs for all three techniques might eventually be as high as a few seconds per bag.

Associated Particle Production

This technique has been looked at for a number of years, and some researchers have received FAA funding to examine its feasibility for a number of applications.[13] It utilizes a nuclear reaction between two kinds of hydrogen that produces helium nuclei and neutrons at a well-defined energy. Characteristic garoma rays are produced by each element when neutrons strike their nuclei. It is, in principle, possible to measure the relative amounts and locations of nitrogen, carbon, and oxygen in a sample using this method. This technique would greatly reduce false alarm rates because all important elements that constitute explosives could be measured.

However, problems with this approach in the past have included limited accelerator tube lifetimes and slow measurement times. If the reaction is made more intense to produce more neutrons, the tube tends to burnout earlier and a requirement for a large amount of unwieldy shielding is generated.

Nuclear Diagnostic Systems, Inc., of Springfield, VA, asserts that it can produce a useful system based on this technique within a few months. The company claims that it has a tube that lasts sufficiently long to be practical for a number of applications, including airport security, and that needs to function at such a low level of neutron production that no shielding would be required. The researchers have received support from private sources for this development. Again, testing by outside parties will be needed for a proper evaluation of the claims.

PASSENGER/BAGGAGE MATCHING

In June 1985, an Air India flight enroute from Montreal to London was destroyed by an explosion over the North Atlantic; Sikh terrorists claimed responsibility. Investigators believe that an unaccompanied checked piece of luggage contained the bomb that caused the explosion. Since most terrorists are not suicidal (despite press attention to the contrary),[14] ensuring that all checked luggage belongs to passengers who have actually enplaned is an effective frost line of defense against this threat.

[13] U.S. Congress, Office of Technology Assessment, op.cit., footnote 2, pp. 74-75.

[14] Thomas Strentz, FBI/FAA profiling contractor, personal communication, Nov. 9, 1990.

Effective December 1990, the FAA required all U.S. carriers to ensure that all personal baggage carried on international flights of U.S. airlines be positively matched to passengers who board the flight. Unaccompanied baggage can be transported only after "close scrutiny."[15] These FAA requirements are similar to current International Civil Aviation Organization guidelines. FAA does not mandate a specific technology to accomplish this task; airlines are free to choose the approach that suits their traffic levels and organizational structure.

Most airlines use a manual approach, especially where traffic levels are low, by inspecting each passenger's baggage claim tickets at the aircraft gate and coordinating the loading of the corresponding bags. For example, American Airlines baggage tags have peel-off sections that the baggage handlers attach to the cargo containers when the bags are loaded; a telephone or radio link is maintained between the gate and the loading area and the handlers annotate the corresponding tags and a master list as the passengers board the aircraft.[16] Some airlines are testing bar-code-reading equipment to speed the matching process and are using information systems to track where each bag is placed, permitting quick baggage retrieval when necessary. On aircraft that are not wide-bodied, such as the Boeing 727, baggage cannot easily be containerized, making the retrieval process more time consuming. Northwest Airlines has installed bar-code-reading and data-communication equipment at all stations, and uses it for all international (and some domestic) flights.[17] Trans World Airlines has also begun applying bar-code technology.

For domestic travel, airlines cite the volume of traffic and the use of smaller aircraft as reasons making passenger/baggage matching difficult (without enormous delays and drastically altered current flight schedules). However, in the domestic case, it would be possible at least to apply matching on a limited basis: using profiling information to select a subset of passengers and bags for close scrutiny, or giving priority to matching interline baggage, **for example.**

In spite of these disparate efforts, there has been no standard defined nor has there been a demonstration of generally available equipment that makes this process operationally practical. A key problem is the difficulty of interline and intraline baggage checking. Further, it is essential to check that baggage introduced as interline transfers be matched to an enplaned passenger or subject to careful examination.[18] The transfer of baggage between connecting flights at the points of departure to or from the United States must be controlled, whether the same or a different airline is used. This is a much more formidable problem for outbound international flights because of the U.S. system of airline hub cities. A simple solution would be not to allow through checking, but this would be unacceptable to the airlines and, probably, to the flying public. Straight-through checking is very important to U.S. airlines as a major selling point. One solution to the problem of controlling baggage checked through to international destinations presents airlines with the difficulty of checking baggage to international standards at additional airports that by themselves do not handle any international traffic. Current practice for most airlines appears to be the use of modern x-ray equipment at the first check-in point. This is not currently a very good detection scheme for explosives.

However, it appears that all the technological elements of an effective automated (or at least semi-automatic) positive baggage matching system are available. For instance, one might use bar codes or magnetic tape, scanners, and dedicated local area computer networks. Bar codes on the baggage tag as well as on the passenger ticket already identify all baggage in some airlines. These bar codes on the baggage could also track the baggage from the check-in counter to the aircraft. The attendant checking tickets at the airplane gate could scan the code while taking the ticket, thereby releasing that bag to be placed on the aircraft. The scanner would be networked to a terminal on the apron that relays the information to the baggage handlers. Each baggage container could have a manifest, listing each bag in the container (either with bar codes or in

[15] Close scrutiny'' is language from the guidelines developed by the International Civil Aviation Organization. Lynne Osmus, Office Of Aviation Security, FAA, personal communication, Feb. 22, 1991.

[16] Homer Boynton, Chief of Security, American Airlines, personal communication and site visit, Dec. 3, 1990.

[17] Douglas R. r&d, Director of Security, Northwest Airlines, personal communication, Feb. 22, 1991.

[18] It appears that the luggage containing the bomb that destroyed Pan Am 103 was introduced as interline baggage at Frankfurt.

the apron computer terminal) and baggage could be held out from loading until the passengers owning the listed baggage had boarded.[19] A key operational problem is how to handle the bags awaiting the passenger's arrival. Since aircraft are commonly loaded by seat numbers, it has been suggested that the baggage could be loaded into containers in similar order. Missing or last-minute passengers could present problems, and some containers may have to be held out until the last passenger shows. Another alternative would be to load passengers by paging, with the roster correlated to containers. All these procedures could be foiled by last-minute arrivals, but these passengers do not usually have their checked baggage placed in containers anyway. Interline passengers, often late, also sometimes fall into this category. If the bar-code systems are made sufficiently uniform between airlines, application of these techniques could solve the interline baggage problem.

Finally, positive matching of baggage with passengers is useful only insofar as the baggage handlers are trustworthy. If suborned, they could subvert any mechanical system. As in many other aspects of security, the human element is essential (see further discussion on background checks for airline and airport employees under section on access control, below).

Research and Development

A few years ago, FAA considered conducting R&D for passenger/baggage matching technologies, but the airline industry position was that the airlines could handle it themselves (and they did). However, the FAA Aviation Security Research and Development Service has recently issued a contract for ongoing R&D to develop further refinements of the technology for future systems.

AIRCRAFT HARDENING

The difficulty of developing explosives detectors for currently accepted minimum threat levels for aircraft has focused new attention on the possibility of hardening either the aircraft or the baggage containers so that they could withstand a threat substantially in excess of this minimum. Both the President's Commission on Aviation Security and Terrorism[20] and the study of the Committee on Commercial Aviation Security of the National Academy of Science[21] recommended serious efforts to evaluate the potential of this approach. Success at such an effort could greatly simplify the detection problem. Of the two, aircraft or container hardening, the latter seems to be a more feasible approach since any change to the aircraft structure would require significant airworthiness recertification efforts and costs.

The susceptibility of modern aircraft to fatal damage by explosives has been under study at the FAA for some time. However, this effort has so far been primarily an empirical approach. In particular, aircraft have been tested by exploding various quantities of explosives in diverse locations to attempt to determine a least-damage location on board the aircraft, as well as to find the minimum quantity of explosive that could cause catastrophic damage in flight. Unfortunately, such tests are usually nonflying, static tests and they involve many variables (location of bomb, types of surrounding baggage, etc.). Exploring the effects of all these variables would take an inordinate amount of tests and would thus be impractical.

In 1990, the FAA Technical Center conducted a 3-day meeting to discuss and plan a new program to evaluate the potential of these techniques. The result of this meeting has been the development of a multiyear plan of attack on the problem of aircraft hardening to resist in-flight explosions.[22] The report has been submitted to the administrator for approval. A key ingredient of this new program is a strong analytical effort to adapt and apply currently existing computer codes, both for the effect of the explosion (e.g., several DOD-developed codes or DOE's LASNIX) and for the structural response (e.g., NASA's NASTRAN) to the problem. Use of such numerical simulation is a vital addition to the

[19] Some airlines, notably Northwest and Trans World, are now implementing such systems.

[20] The White House, Report *of the President's Commission on Aviation Security and Terrorism, (Washington* DC: The White House, May 15, 1990), p. 66, recommendation 5: "The FAA should conduct research to develop the means of minimizing airframe damage that may be caused by small amounts of explosives."

[21] National Academy of Sciences, Committee on Commercial Aviation Security, op. cit., footnote 1, pp. 3-5.

[22] Department of Transportation, Federal Aviation Administration Technical Center, *Aviation Security* Research *and Development Plan for Aircraft Hardening* (Washington, DC: Federal Aviation Administration, August 1990).

FAA program. Such codes, combined with carefully designed calibration tests to anchor them to reality, will be of use in defining the problem and synthesizing possible countermeasures.

The last line of defense against an airline terrorist is the aircraft itself. Although the design and operating environment of a passenger airliner (lightweight structure, sensitive controls, pressurized fuselage) make it very vulnerable to internal detonations, there are potential ways to limit explosive damage. Possibilities include the containing, controlled venting, or the absorption of explosive shock waves and gas pressures. By raising the minimum quantity of explosives needed to destroy an aircraft, hardening could complement airport-based passenger and baggage screening technologies, since the detection probability of all devices increases with the amount of target explosive, and the concomitant use of higher detection thresholds would also reduce the false alarm rate.

The British Department of Transport, following its investigation of the Lockerbie incident, recommended that government authorities, aircraft manufacturers, and other interested parties "undertake a systematic study with a view to identifying measures that might mitigate the effects of explosive devices and improve the tolerance of aircraft structure and systems to explosive damage."[23]

This report was able to rely on an unusually complete analysis, because the accident occurred over land and a large fraction of all the parts involved in the explosion were recovered and reconstructed. The investigation found that there were at least three separate effects that contributed to the loss of the aircraft. First, the direct or blast damage, resulting in a relatively small hole (the shattered region was only 45 to 50 centimeters) through the skin of the fuselage; second, the propagation of cracks emanating from this jagged hole to distances as large as 12 meters, which were driven both by the blast pressure and by the aerodynamic forces on the peeled back skin; and finally, further skin ruptures, driven by overpressure from the blast and from gas dynamic shock propagation through open passages between the skin and the baggage containers (and other ducts), which occurred at large distances away from the hole. These latter shock waves finally met obstructions that created local areas of high overpressure due to shock reflections. According to the British analysis, it was the combined phenomena of these forces that led to the disintegration of the aircraft. Other investigators, however, remain skeptical as to the importance of distant shock wave propagation within the fuselage and feel that static pressure was the principal cause of the catastrophic failure. The issue may be resolvable by further testing. The British report indicated that the failure was a complex process and was specific to the local geometry.

Explosive devices of the size used in airline terrorist events to date are deadly not because they directly cause catastrophic failure (i.e., blow the aircraft to pieces) but because they start a domino effect where the aircraft destroys itself. Possible scenarios include:

- the explosion blows several holes in the skin, as described above, in such a way that they are opened further by pressurization or aerodynamic forces until the aircraft structure fails;
- the explosion destroys critical components causing safe control to be lost; and
- material ejected from a hole caused by an explosion damages critical aircraft components.

Some technological options discussed in the U.K. report (and elsewhere) include:

- modifying cargo containers to absorb shock waves, prevent fragmentation, and vent overpressures to prescribed pathways;
- adding cargo bay liners to keep fragments from penetrating the cabin floor or fuselage;
- incorporating blow-out panels on the fuselage at container vent positions to control skin ruptures and limit skin tearing;
- closing cavities and pathways that exist between cargo containers and inside aircraft structures (e.g., between floor beams); such cavities can serve as conduits for shock waves and supersonic gas flows, permitting damage at aircraft locations far removed from the explosion site; the U.K. investigation decided that cavities played a role in the Lockerbie incident; and

[23] Department of Transport (United Kingdom), Air Accidents Investigation Branch, Aircraft Accident Report, February 1990: *Report on the Accident to Boeing 747-121, N739PA at Lockerbie, Dumfriesshire, Scotland on 21 December 1988*, p. 58.

- using energy-absorbing material (e.g., in the cavities) to attenuate shock waves.

These options entail numerous cost and engineering problems, including design difficulties stemming from the potential variations in charge size, location within the aircraft, and the nature of the materials in the immediate vicinity of the charge.[24] The combination of engineering and recertification efforts required to structurally modify a commercial transport would likely make most of these options prohibitively expensive. Moreover, some of these options would add to the aircraft weight or reduce cargo and passenger loads, in either case reducing profits by cutting revenue or increasing fuel costs. These options will be more practical in the distant future, if they can be incorporated in aircraft during the design process. The FAA is examining this option.

RESEARCH AND DEVELOPMENT

The FAA has researched the effects of explosives on aircraft in the past, with the focus on where to place an explosive device discovered onboard an aircraft during flight to minimize the catastrophic potential. Also, tests were done on baggage containers to estimate the size of the explosive charge used on Pan Am 103. Recently, FAA held a conference to discuss R&D into examining the aircraft hardening issue. A program along these lines has been implemented at the FAA Technical Center. The following points emphasize the cooperation with outside experts that can be brought to bear in the problem:

- Coordination with military researchers and engineers is valuable (survivability studies have been done on virtually all military aircraft—data on transports would be applicable to airlines). FAA is proceeding to investigate the issue of aircraft vulnerability and hardening in cooperation with the Air Force's Wright Aeronautical Laboratories, the Naval Surface Weapons Center, and the Defense Advanced Research Projects Agency. Experimentation with explosives tests is continuing.
- Aircraft manufacturers also have expertise and technology to address explosive decompression problems, although they are reluctant to discuss it; FAA issued contracts during the 1980s to aircraft manufacturers to analyze the optimal on-board location to place a discovered bomb (to minimize potential damage) for each aircraft type flown by U.S. airlines.
- Coordination with FAA aircraft certification officials and airline maintenance and engineering people would be advisable in attacking this problem, so that the R&D efforts focus on concepts that have the hope of economic feasibility.

The FAA is currently assembling its research and development program in aircraft hardening and survivability and is cooperating with aircraft manufacturers in applying computer codes on structural failure to the problem of on-board explosions.[25]

BIOLOGICAL AND CHEMICAL DEFENSES

The confined space and recirculated airflow within airliners could increase the effectiveness of chemical or biological agents. Many (although not all) biological agents take many hours to produce symptoms. However, chemical attacks as well as attacks with very fast-working biological agents could well be a terrorist option. Few possibilities exist for dealing with this problem beyond attempting to detect the agents when being brought on board-and this would be difficult to do. For aerosols, a separate air system for the flight deck to insulate the flying crew from the effects of the gas would be one tactic. Controlled, but rapid, depressurization in the cabin, to be followed by repressurization, might mitigate effects on the passengers.

ACCESS CONTROL AND EMPLOYEE SECURITY AT AIRPORTS

Access Control

On December 7, 1987, a recently dismissed Pacific Southwest Airlines employee used an ID badge (which was not collected upon his dismissal) to circumvent security checkpoints and board a flight. While the flight was enroute he shot both the pilot and copilot, resulting in a crash and the death of all 43 people on board. One Federal response was

[24]Ibid., p. 54.

[25]Lyle Malotky, FAA, personal communication, April 1991.

a rule[26] **that** emphasizes technological solutions to the problem of unauthorized access. Each commercial airport operator is required to implement a "system, method, or procedure' that ensures that only authorized persons have access to secured areas of the airport. While the rule does not specify the technology choice, FAA's intent was that airports install computer-controlled card access systems.

Airports and airlines have found fault with this rule since its initial proposal in March 1988. The main concern of the airports is *avoiding FAA enforcement penalties.* Institutional problems (coordiation between FAA and other Federal agencies that must operate at airports-Customs, INS, Agriculture; FAA regional differences; state and local employment and privacy laws) cause many of the security management difficulties for airports. Airline management and pilots are concerned that the hodgepodge of airport access/control systems being deployed in response to the rule will hamper operations and raise the fees airlines must pay for airport services. Issues include how to deal with itinerant aircrews (single access card for whole crew used at some airports, escorts used at others-airline control of airport badges); overlap of some airline ''exclusive use areas"; need for some form of a national system-one proposal was a $15 million communication system to handle transient aircrews for all domestic airports but this was rejected because airports are unwilling to pay for transient benefits.

Some sections of the FAA recognized that problems could arise from incompatible access systems used at multiple airports-in an early version of the rule, FAA inspectors (who travel to many different airports as part of their duties) would have been allowed to circumvent computer-card security systems. Vehement airport and airline protests caused the FAA to drop this provision.

Passenger airlines already accomplish a significant access control function-passenger and baggage screening. But cargo airlines are not covered under the same security rules as passenger carriers (14 CFR 108) and consequently cannot be given security authority like the passenger carriers. Therefore the airport must remain responsible for security at cargo facilities, increasing the difficulties in meeting 14 CFR 107.14 access control requirements, a problem for both the airport and the airline.

Background Checks

An additional problem lies in the difficulties associated with checking on the backgrounds of airport employees with access to sensitive areas. The Aviation Security Improvement Act of 1990 permits airport authorities or airlines to check on the backgrounds of prospective employees, who would have access to aircraft. However, authorization is given only to receive information on convictions for certain serious felonies, such as murder, robbery, and rape, that transpired during the previous 10 years. Records of convictions for other crimes or earlier convictions would not be available to the employer.

Currently, up to 90 days are needed for this information to arrive from the Federal Bureau of Investigation. A prospective job applicant may not always be willing to wait this long before accepting a job, which makes it harder to hire. If the applicant were hired in the interim, dismissal after 90 days on receipt of a bad record might induce the individual to use the knowledge acquired to sabotage airport operations. Further, the records are sometimes up to 2 years out of date. Such delays can, in principle, be remedied. For instance, new hires at Baltimore/ Washington International Airport have their records in the State of Maryland checked in a matter of minutes. It would be possible to improve on the current nationwide system, at least for a subset of reporting States.

A further problem is the question of current employees. If someone has worked at an airport for years and proved reliable, should a past conviction require termination? Currently, all present employees must be investigated. If nothing else, this will create an enormous backlog in background checks. Some decisions may need to be made on circumstances in which employees of long and good standing might be permitted to remain without undergoing such checks.

To improve airline security and implement an integrated security system, it would be desirable to check in a better fashion on the trustworthiness of employees with access to aircraft. This might mean checking for more than just serious felony

[26] 14 CFR 107.14.

convictions (although complete background investigations, such as now done for those with jobs that require access to national security information, would probably be impractical). For example, other felony convictions or serious misdemeanor convictions could be relevant. Even if a person has no violent history, past dishonesty could raise questions of susceptibility to bribery or blackmail. This situation could be used by terrorists as part of a plan to sabotage aircraft.

To reduce negative impacts on individual privacy, a clearinghouse might be established to receive information on individuals, with only the minimum necessary data passed on to the employer.

Finally, steps must be taken to speed the process for accomplishing the checks.

THE ROLE OF HUMANS IN PROFILING AND SCREENING

Chapter 5 contains a detailed description of human factors and their role in airline security. This section presents a summary of some contributions that this field can make in the specific areas of security profiling and screening at airports.

According to the Presidential Commission on Aviation Security and Terrorism, human factors in the implementation of an airline security system have not received the attention that they deserve.[27] OTA concurs with this observation. A major application of human factors concerns the type of personnel (and their responsibilities and training) utilized in the security system. In the United States, they are often minimally trained, unmotivated, minimum wage personnel, usually working for a contract security services firm, performing boring and repetitive work in a very low-threat-frequency environment. On the other hand, the Israeli model relies heavily on maximum human involvement by a highly trained and motivated force. It is generally agreed from the investigations of the Pan Am 103 accident that better use of security personnel is in order.[28]

The most controversial use of security personnel is in the screening or profiling process that is used to determine which passengers constitute a potential threat and therefore should be given greater scrutiny. However, human factors are also a major factor in the selection and even the design of detection systems (i.e., whether they should be totally automatic, as required by the current FAA EDS rule) and in specifying the degree of automation and human interaction desired. Techniques currently under development, such as the pattern recognition discussed above, can sharpen the attention of screeners in the x-ray image observation process.

When it comes to screening or profiling passengers, the techniques employed by the security division at Ben Gurion Airport in Israel are probably the most stringent. In fact, selection criteria for extended interviews used in Israel could probably not be used in the United States. At this airport, which has just under 20 percent of the international enplanements that occur at Kennedy Airport in New York, a highly motivated and well-trained security force of mostly college-age personnel perform a personal, in-depth interview and profile evaluation. The profiling depends on the travel documents (the airline tickets and passports) plus responses to a set of questions, but most importantly, the integrity of the security system depends on the observations and the personal initiative of the highly trained staff. The aim of this process is to eliminate a large fraction of the passengers, who do not appear to represent any possible threat, from the time-consuming, thorough search process and to select only that small segment of the passengers who for any reason present some suspicions for such a search. The other passengers are allowed to proceed through security with a minimum of surveillance and only a few questions about their checked baggage. However, there is a further, last-minute positive baggage match of all passengers and all checked luggage at the entry point to the aircraft. No flight leaves with a piece of unaccompanied baggage that has not been thoroughly searched for weapons, explosives, or other contraband.

A number of U.S. airlines (e.g., American, Trans World, and Pan American) have employed Israeli consultants with knowledge of these techniques to devise similar programs, tailored for their operations, as well as to train their personnel. The standard

[27] The White House, the President's Commission on Aviation Security and Terrorism, op. cit., footnote 21, p. 122: "The FAA must take the lead in stressing the role of human factors in the security equation; training must be improved."

[28] See, for example, the White House, the President's Commission on Aviation Security and Terrorism, op. cit., footnote 21.

argument against the Israeli approach is that it is too expensive (22 percent of the Ben Gurion Airport operating budget goes to security), that it is too time-consuming (passengers are requested to be at the airport 2 to 3 hours prior to departure time), and that it is too disruptive. Most of the consultants are attempting to devise systems that will overcome these shortcomings without compromising the quality of security.

The FAA has been experimenting with a semi-automated profiling system, the Comprehensive Passenger Screening Profile (CPSP), in which the security person keys the answers (yes/no only) to a set of 7 questions into a portable computer terminal, which then compares the answers against a database and produces a risk assessment. The operator uses the results to dispose of the case. The system constantly adds new data to an original, intelligence-based, database of the profiles of threatening passengers for future use by both the airlines and the FAA. The FAA is considering making the CPSP mandatory for all U.S. airlines, and, as an incentive to the airlines, the FAA has offered to assume liability for failure to detect: airlines can blame the FAA if the system fails to detect an actual security threat. However, some airlines have objected to sharing their passenger profile data with the FAA.

The incorporation of an effective profiling system into an overall security system could eliminate a large number of passengers from further screening. To date, the FAA has considered profiling apart from the overall security process and has not included it in considering the performance requirements of detection equipment. In fact, the definition of the screening system has been handled by the FAA Aviation Security Division intelligence group, quite separate from those responsible for security R&D. Profiling makes slower, more complex detection systems more interesting in high-traffic situations, where they could not possibly handle all the items arriving at the check-in counter. Incorporation of profiling is another argument against setting throughput standards for detection equipment at the R&D stage. The Xenis EDS at Gatwick Airport near London, has been used with a profiling system that requires only a small fraction of the baggage to be viewed by the TNA.

Human-factors design has also proven useful in the process of heightening the attention of security personnel operating repetitive and boring tasks such as viewing the x-ray images. One vendor (EG&G-Astrophysics) has produced a false alarm data package (a cassette or disk) that randomly superimposes various threat objects on the images of luggage on the viewing screen.[29] The operator can attempt to clear the threat by pressing a key if he/she recognizes it (the program clears the threat unless it is real). An operator who fails to do so can be disciplined. This technique can also be used as a positive reward system for all threats "caught."

The degree of automation that is demanded of a detection system is another human engineering consideration that must be considered at the design or even system conception stage. The human brain can often be the most powerful discriminator, especially when well-trained personnel are involved. The use of an automatic system to alert the human operator of a suspicious situation is a powerful tool. This is actually the way in which the Xenis was used in the tests at Kennedy Airport. There was always an operator who made the decision whether to call the passenger to open the bag when the Xenis signals showed an alarm. In this way the automatic system is used to counter a major human fallibility, lack of attentiveness, rather than replacing the humans. At the Gatwick tests, however, if the machine alarms, the operator cannot overrule it, and the bag is automatically given careful scrutiny by security personnel, usually including a hand search.

COMBINED USE OF SEVERAL DETECTORS WITH PROFILING

Choosing a practical architecture of detectors to provide the best possible security system is an important challenge. Such an analysis should be performed for various levels of detector technology: current state-of-the-art, likely near-term capability, and long-term potential.

A problem with such an effort is that the necessary performance data on various candidate sensors is not available, and consequently any such effort must, at this time, depend on guesswork and conjecture. However, even an attempt to perform such an analysis would be informative.

[29] This was funded under the FAA Small Business Innovative Research program.

Appendix C of the National Academy of Sciences study presented a hypothetical example of a detector system architecture for illustration. It focused on the cost of the overall system but left out the connection to possible solutions that may meet the requirements of the various stages.

The following discussion is not meant to provide an optimal architecture for a combined explosives detector system. It is only an example presented for purposes of illustration.

From a systems point of view, the sensitivity always gets worse in any cascade of detectors and only the false alarm problem can be improved by the repeated use of AND gates (see discussion in section on statistics, above). It has been generally accepted that the overall detection probability of any chosen system should be high (at least 0.85, or so). This means that the individual detector P_d's must be very high, higher than 0.90, in order to yield this overall system performance. Three stages, each of $P_d = 0.90$ would result in an overall P_{dc} of only 0.73, which might not be considered acceptable.

It follows that, for several stages operated as an AND gate, it would be desirable to use individual detectors with detection probabilities that are close to perfect, on the order of 0.98 to 0.99. There is currently nothing known that can claim such sensitivity, the R&D programs are not even directed at achieving such a high value, and current test protocols are not capable of determiningg whether such a value has actually been achieved. On the false alarm side, the objective of a combined system should be to bring the need for final hand search down to a number of bags that can be handled by one or several security personnel per given station. Allowing for 5 minutes per hand search, one should thus look for systems that would not require more than 12 to 24 bags per hour to be hand searched per station. In a situation with very high throughput, such as exists at some of the major international airlines at Kennedy Airport where the throughput can be as high as 4,000 bags per hour, this would require an overall false alarm rate of about 0.5 percent. It is interesting to note that three independent stages, each operating at a false alarm rate of about 20 percent would almost be able to meet this requirement (0.8 percent v. 0.5 percent).

A possible system might thus *theoretically* consist of three different stages of detection equipment all operating with P_d approximately 0.97 and F_a about 0.20. The first would be a high-throughput stage (this stage may have to be a number of parallel inexpensive detectors), the second stage could be of more moderate speed and possibly somewhat more expensive, and the last stage could be quite slow and possibly expensive, since a single unit should suffice due to the smaller number of bags handled. It is worth repeating that the multiple detector approach puts the strain on achieving very high sensitivity (high P_d) at each stage, while allowing for much more relaxed false alarm criteria than if a single stage of detection is utilized. It is not clear how close this ideal will be approached in the foreseeable future.

The characteristics of the frost-stage screening detector are very critical since it must handle the largest throughput of luggage. In a high-throughput situation, such as encountered by some of the major airlines at the major gateways, this is a demanding requirement. The candidate detectors for this use should be as inexpensive as possible, since it is likely that many or several parallel detectors maybe required to handle the traffic. For instance, the FAA requirement of a throughput of 600 bags per hour for the EDS still would demand as many as 5 to 10 systems in high traffic. This strongly argues against the use of expensive systems such as the SAIC/TNA as a first stage.

Probably the primary candidate for a first-stage screen is a well-designed, thorough, profiling system operated by motivated, well-trained security personnel. Profiling systems typically identify a few percent of the sample as potentially threatening and requiring further investigation (the actual percentage is very situation- and process-sensitive). It is extremely difficult to identify a quantitative detection probability and false alarm rate for a profiling system.

Another measure, which is not specifically a detection stage but should be a part of any overall system, is a foolproof, positive, passenger/baggage match for all boarded passengers to prevent the shipment of any unaccompanied baggage (unless baggage separated from passengers-e. g., by airline error-is subject to specific stringent security measures). Such a system would raise the stakes for any terrorist group, by isolating the potential threat to dupes who do not realize that they are carrying a bomb, or suicidal terrorists who are willing to sacrifice their own lives.

When it comes to existing detection hardware, advanced x-ray imaging systems will probably be a significant component of any integrated security detection system. Included among the advanced x-ray concepts for consideration should probably be the T-Scan™(dual-energy, dual-view), Z-Scan™ (backscatter) systems, and probably other similar systems including those that emphasize pattern recognition. These systems all have some ability to detect masses of materials with low atomic number that could be explosives but could also be many other common materials. They should be effective in identifying electronic hardware, which have been popular hiding places for explosives in the past. A recent assessment of the capability of certain of these systems for this specific purpose has been conducted by the FAA Technical Center.[30]

Currently, the performance of these systems when used in realistic environments is not known. It is quite possible that the specificity of these systems is quite high, but the false alarm rate is a completely unknown factor. How many suitcases contain some sort of electronic equipment that would require the security inspectors to take a second look? How many other objects with low atomic number would be mistaken as explosives? Could the false alarm rate of such a system be kept in the 20-percent range?

Some advanced x-ray systems, such as the American Science and Engineering (AS&E) Z-Scan™ concept, could be particularly sensitive to the popular terrorist technique of lining a standard suitcase with a thin layer of Detasheet-like explosives inside the normal lining. The Z-Scan™ has somewhat limited penetration capability but is very effective at or near the surface facing the x-ray source, and consequently, with its double-sided illumination, it should be especially sensitive to explosives hidden in the lining.

There has been some recent interest in coupling vapor detection sniffers with advanced x-ray systems used in the above manner to detect electronics and other threatening masses. In this coupling, the sniffer is used only on those items identified by the x-ray system as presenting a potential threat. Thus the vapor sniffer has the specific role of detecting explosive particles or vapors on electronic components and of differentiating low-Z (low atomic weight) masses that are made of harmless materials. Any vapor detector, no matter how good, is always susceptible to the technique of sealing the explosives in impervious wrappers; however, there has been great controversy about the practicability for terrorists to achieve this level of cleanliness.

A candidate for the final detection screen could be the x-ray CT scanner currently being developed by Imatron. With the CT scheme, it is possible to determine the mass density of each volume element due to the many cuts being taken through the same element. This knowledge, combined with the excellent spatial resolution inherent in the CT system, allows for a automated identification of masses that have both the correct density and a suspicious shape. Further, the suspect region identified automatically can be viewed by the operator in a three-dimensional reconstruction from various aspects. Although the ability of this scheme to identify unambiguously the various candidate explosives has not yet been demonstrated quantitatively, the primary shortcoming of this scheme is the questionable speed of the system. The speed is a function of the time required to achieve one slice through the suspect object as well as the number of slices required to achieve the needed resolution for three-dimensional reconstruction.

Currently, the prototype system at Imatron requires about 6 seconds per viewed slice of l-cm thickness, with the promise of being able to reduce this to 2 to 3 seconds. The number of slices required is a more subjective issue and depends also on what information is available before the CT scanner is utilized. In one current scenario, an advanced x-ray system might indicate the presence of a suspicious mass in one quadrant of a luggage piece, thus allowing the search to be conducted over a restricted predetermined area. If one then assumes that 6 to 10 slices are required (there are no published data on this question), it follows that current technology might require about 1 minute per bag, while there is hope for reducing this time to 10 to 15 seconds. In a third stage detection application, where the flow of baggage may have been reduced to roughly 4 percent of the total throughput, one device may be able to handle the high-throughput requirement of most of the high-traffic airports (i.e., operate at about 1 or 2

[30]At this writing the results of this assessment have not been publicly released by the FAA, but it is understood that the vendors have been informed as to the FAA assessment of the performance of their hardware.

bags per minute). Such a system may leave very few bags to be opened for hand inspection.

It is also possible that the current SAIC/TNA system could serve the purpose of the third stage detector in a multistage detection system. Since the throughput of a third-stage system could be relatively modest even for highest traffic use, it maybe possible to achieve somewhat better performance by slowing down the SAIC/TNA system from its current 6-seconds-per-bag goal.

From the above discussion, it maybe possible to synthesize a multistage explosives detection system, based on current or near-term technology, by guessing reasonable performance values for the systems used where the data are not available. First, the system should have a positive passenger/baggage match for each flight segment, which, however, does not affect the performance. The first detection stage could be profiling with a false alarm rate of 0.05. The main shortcoming of the use of profiling at this position in the system is that it is not the ideal, cheap stage, since the personnel requirements, and consequently cost, for this process are high. Furthermore, its detection probability is unknown.

In addition, the first stage could contain an advanced x-ray system, automated to respond to low-Z masses and electronic hardware. It is possible that such a system might operate with high detection probability, but would have a significant false alarm rate, perhaps 0.20. The cost of the x-ray system could be between $50,000 and $200,000 each. For the purposes of this analysis, the assumption of a 0.90 P_d is used.

All items alarming the first stage would be passed to a second stage, which could be a vapor detector. The vapor detectors could be collocated with the x-ray system or could take the luggage from several such stations. Vapor detectors might operate at a relatively high P_d and a false alarm rate of 0.20, provided that the luggage had been previously screened by the x-ray system. Again, for the sake of the argument, the optimistic assumption of a P_d of 0.95 is made. Vapor detectors that show some promise are on the market now. There is considerable variation in their cost: $50,000 to $150,000 per station is an approximate range.

The final stage could be an Imatron CT scanner. If enough time were available and enough cuts are taken, the detection probability of this system might be very high, say 0.95 to 0.98, while the false alarm rate could be quite moderate. An estimate for this discussion is 0.10. The CT scanner would probably cost about $500,000 to $700,000.

In a high-traffic situation (like TWA at Kennedy Airport) of about 3,000-4,000 bags per hour, such a system might consist of one to three Imatron CTs (depending on whether they can process one or two bags per minute), which would result in about 10-15 bags per hour being hand searched. The second-stage devices would need to handle 150 to 800 bags per hour (depending on whether the first stage is a profile or an x-ray system). If we assume that a vapor detector requires 30 seconds per bag, three to seven such detectors would be required.

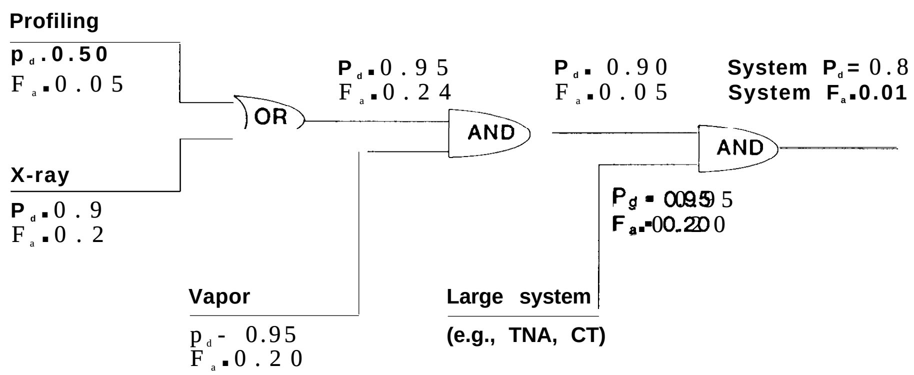
The first-stage x-ray detectors have a fairly high throughput. Current systems can easily handle 600 bags per hour. If we assume that the data processing will not slow down the systems, it might take about six of these systems to handle the high traffic.

As far as cost is concerned, using the lower range figures, this complete station would cost about $1,00,000 in equipment, while the upper end might be as high as about $4,000,000. This would be less than the cost for 19 TNA machines (probably over $20 million for capital costs), thought necessary for Kennedy Airport in the absence of other technologies for explosives detection. The overall detection probability, P_{dc}, would be 0.81 to 0.84. The false alarm rate would be 0.004 (if all devices were statistically uncorrelated, which is probably not strictly true). Although we have had to assume the performance values used in this example, it does give hope that respectable detection performance might be achieved with near-term hardware.

An improvement on this technique (see figure 4-2) would be to begin with an OR gate, combining profiling and the first x-ray screen. An alarm on either technique (or both) would send the bag on to the more sophisticated detectors. That way, failure by either profiling or x-ray alone would not cause the system to fail as a whole. The x-ray device might be a backscatter machine, or a refined dual-energy system. Both types of detectors react to high-density items of low atomic weight, like high explosives. The advantage of x-ray systems over TNA for a first stage is in the cost, which is a factor of 5 to 10 less.

The detection probability for profiling is unknown; it is certainly greater than zero. The Murphy

Figure 4-2—Notional System Combining Different Explosives Detection Technologies



SOURCE: Office of Technology Assessment, 1991.

case in London-among others-where an El Al security agent discovered, through interviewing and then examination, a bomb placed in an unsuspecting woman's carry-on luggage by her terrorist boyfriend, attests to that. It is certainly less than 1.0, evident through common sense and through some experiences that have indicated the rare passage of bombs through a careful profiling system. By using an "OR" gate between profiling and a good mechanical system, the system would scrutinize a bag that fails *either* technique, resulting in a detection probability greater than that of either alone.

As an example, if the x-ray system had a detection probability of 0.90 and the profiling one of 0.50, the combined system would have a probability of 0.95 = (0.90+ 0.50– 0.90 * 0.50);[31] if the profile has a better detection probability, say 0.80, the overall probability is better, too-O.98; and if the profiling doesn't work at all, the system still retains a 0.90-detection probability. The false alarm rate of the profiling is set by the user, generally at 0.02 to 0.05. If the false alarm rate of the x-ray device were high (say, 0.20) the combined false alarm rate would be 0.22 to 0.24. This would mean that 22 to 24 percent of the luggage would proceed to the next level of scrutiny.

Following this stage, one could add another stage with a totally different technology, say, a vapor detector, which would be especially appropriate for carry-on baggage. In this context, assume, again optimistically, that the vapor detector had a detection probability as high as 0.95 with a false alarm rate of 0.20. Finally, one might add a TNA or a computerized tomography system. Assume for this system as well a detection probability of 0.95 and a false alarm rate of 0.20. These numbers are consistent with or more conservative than earlier proposed FAA criteria for acceptability of single explosives detection systems. The combined detection probability of the system is relatively high (0.86, assuming only 50 percent effectiveness of profiling and the false alarm rate is low (about 1 percent). Excessive reliance on one technology (the first-stage x-ray) would be reduced using OR gates with profiling.[32]

CARGO AND AIRMAIL

To be complete, a security system would have to protect against bombs being brought aboard aircraft through the cargo route. At least two countries, Switzerland and Israel, currently employ a variety of techniques to counter this eventuality. These include delaying shipment of packages and exposing them to the altitude profile of the flight by subjecting them to depressurization, extra use of x-ray equipment for examining packages with care, and special equipment for probing packages that are suspect. Switzerland also has special equipment for examining mail

[31] This assumes *that* there is no correlation between the two techniques, profiling and x-rays, as app

[32] Again, this assumes a perfect situation in which there is no correlation among the different detection systems This will not be true, although the correlation will often be quite small, so the combined probabilities and false alarm rates should be close to the theoretical ones cited in the text.

bound for "high-risk" destinations, such as the United States and other Gulf War Coalition countries. Special x-ray equipment and other means of examining packages are used.

In the United States, where the volume of air traffic is much larger than in the above two countries, the FAA is considering several possibilities for increasing security of air cargo. One approach would be to require forwarders to open and inspect shipments from sources unfamiliar to them. In addition, FAA now requires that international shipments to the United States handled by on-board couriers be x-rayed before the couriers board the aircraft. During the Gulf War, the U.S. Postal Service shifted all mail, except for the smallest parcels, to all-freight flights. In another development, British Airways is planning to install x-ray machines at U.S. gateway airports to check small and express shipments for explosive devices.

SUMMARY AND COMMENTS

The fundamental problem in explosives detection is to design an EDS that has acceptable detection probability and false alarms rate but does not unduly inconvenience travelers. One approach is to combine detectors based on different phenomenologies to provide independent assessments of whether items boarding an aircraft contain explosives. A suggestion for such a system has been presented. The need for a detailed systems study to optimize such a system has been recognized by the FAA Technical Center and a research program to this end is underway.

An approach synergistic with the first is to harden aircraft, raising the amount of explosives needed by the terrorist, and making detection correspondingly easier for counterterrorist systems. Research in this direction is being pursued; first indications of the promise of this line of work will not be known for at least a year or two.

In addition to detecting explosives brought aboard by passengers in checked or carry-on baggage, a complete system would have to prevent passengers from carrying explosives on their persons and to prevent explosives from being hidden among cargo or secreted on the aircraft by personnel with unescorted access to aircraft. Some vapor detectors, x-ray microdose, or radiofrequency methods of explosives detection may solve the problem of explosives carried by passengers. As for mail and cargo, the bulk methods of detection (x-ray and nuclear) could be engineered for this application at current levels of technology. Also, delay and depressurization of cargo (as done in Switzerland and Israel—following the altitude and time profile of the specified flight) could be used to detonate cargo bombs in bunkers on the ground. Wider systems studies, such as those being done at Baltimore/Washington International Airport, would also help in solving these problems.

Finally, in designing security systems, it would be advisable to "red team" individual devices and entire systems. That is, the FAA might arrange for outside experts to consider how a device or system might be circumvented, to assess the ease of doing so, and to consider countermeasures against circumvention. This information would be helpful both for the FAA and any outside testing evaluators[33] in deciding what kinds of systems are acceptable, and for airport operators and airlines to understand better their security capabilities.

[33] See again finding 4 regarding outside testing in chapter 1 of U.S. Congress, Office of Technology Assessment, op. cit., footnote 2, pp. 8-10.