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Abstract

Until the present date, free-flight spark ranges have used conventional film technology for recording the position-attitude histories of the projectiles as they traversed the instrumented ranges. The purpose of this paper is to describe the plans for converting the existing film based camera system in the Aeroballistic Research Facility to an electronic imaging system based on modern charge coupled device (CCD) technology. The primary concern associated with this conversion has always been maintaining the facility's accuracy in measuring the projectile's position and attitude at each of the shadowgraph stations. This accuracy is directly related to the resolution of the CCD, i.e., number of pixels. Some other concerns were minimizing the facility down-time while the new imaging system is installed and maintaining a means of analyzing previous film exposures captured during the past 15 years of operation. The solution to these concerns is the development of a film reader system which also uses a CCD type camera to digitize the existing film.

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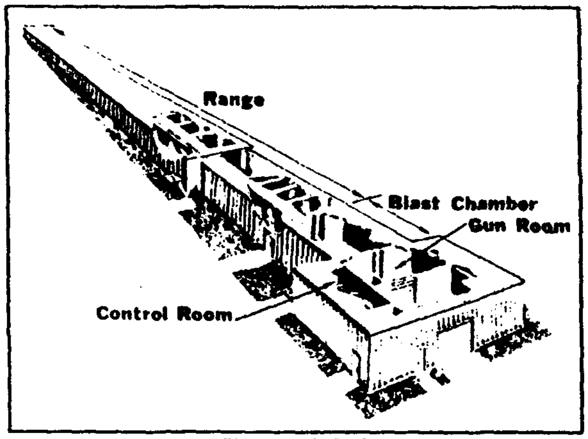
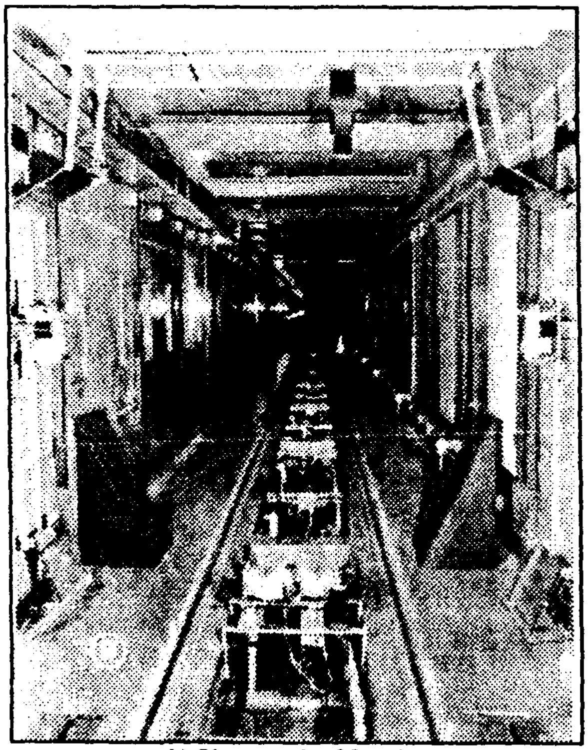
Background

The Aeroballistic Research Facility[1] (ARF) is a classic free-flight spark range containing 50 orthogonal shadowgraph stations over a 200 meter length. Each shadowgraph station consists of 2 cameras, hall and pit, installed in 1 of 130 possible locations. A sketch of the facility and a photograph of the interior are presented as Fig 1a and b. A sketch of a typical shadowgraph station is shown in Fig 2. At present the shadowgraph stations utilize conventional film camera technology to record the images of the projectile in flight. This conventional film technology requires a labor intensive process in film handling, processing and film reading as discussed in more details in the following sections. This process results in significant delays (3 days to 3 weeks) in obtaining the aerodynamic results from a particular flight or set of flights in the facility.



a) Sketch of Facility



b) Photograph of Interior

Figure 1. Aeroballistic Research facility

It has been recognized for many years, that, in order to optimize facility response time and increase productivity a more automatic image recording technique was required. A high resolution television system for the Swedish aeroballistic range was proposed by Mr Sven Nordstrom in 1977.[2] Although that system was never installed it did spark interest in evaluating such systems at Eglin AFB FL. In 1982 an effort was initiated to evaluate the present state-of-the-art of the technology associated with high resolution television systems based on existing vidicon tube technology and the emerging high resolution charge coupled device (CCD) technology. This effort has continued until the present and has resulted in a series of publications[3-10] concerning various aspects of the applications of these technologies to the ballistic range environment.

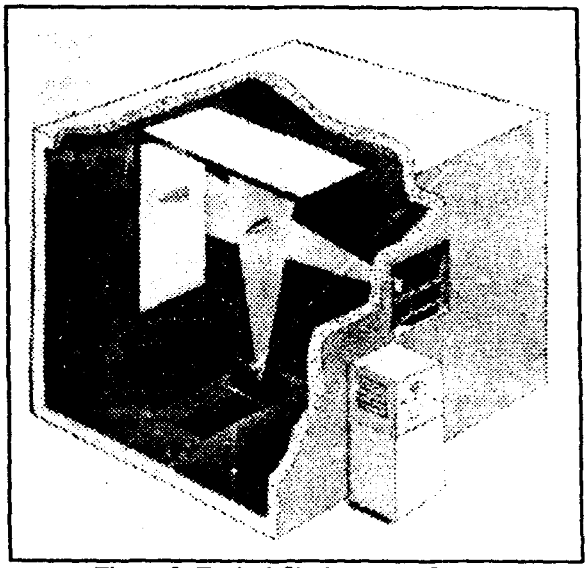


Figure 2. Typical Shadowgraph Station

These initial studies resulted in the following conclusions:

1. Vidicon technology possessed the resolution required in the ballistic range but not the light sensitivity. Cost, size, and uniformity were also major issues.

2. CCD technology had superior uniformity and sufficient light sensitivity to produce high contrast images of the projectile, but initial devices tested had insufficient resolution to image the desired field of view.

3. The pixel density, sensitivity and uniformity of the CCD cameras were increasing yearly at an astounding rate and non-television aspect ratio chips were becoming available as integrated machine vision systems.

4. The CCD camera technology would be a viable option to film camera systems in the near future.

Since the early studies were completed in 1988, this conversion has been waiting for the resolution of the CCD cameras to improve and quality of the supporting electronics to both improve and reduce in cost per unit. The initial cameras evaluated during the initial experiments had an array resolution of 512 by 512 pixels. Subsequent sensor resolutions have increased dramatically over the past three years, culminating in the latest evaluation of 4 million pixel based sensors. As discussed in the later sections, these chips demonstrate the resolution requirements for free-flight spark range applications.

Facility Imaging System

Present Film System

As mentioned in the previous section the present imaging system in the ARF uses conventional film/camera technology. A photograph of a camera/spark unit is shown in Fig 3. The camera body consists of an aluminum casting with mating surface for lens, film cassette holder, spark gap holder, spark gap housing and flanges for mounting in the walls of the range. The camera utilizes a 17.8 centimeter focal length, f/2.5 Aero Ektar lens with a 10.2 by 12.7 centimeter Graphlok film back. The solenoid operated shutter is a two leaf capping type. Internally there are 12 numeric light emitting diodes (LEDS) for recording spark function time and other fixed data onto the edge of the film. Spark function is initiated by pulse output from an infrared light sheet reflected from the Scotchlite reflective screens which are mounted approximately 3660 cm from the camera system. Originally designed to use thick-base Kodak Royal X-Pan film, the range has used Kodak TMAX 400 since the discontinuance of the Royal X-Pan film by Kodak in 1987. A typical shadowgraph is presented in Fig 4. The spark unit used in conjunction with the camera is a modular spark system built by High Voltage Components, Inc.[11].

The film handling associated with the present conventional camera system is a labor intensive process, as outlined below:

a. Loading film into cassettes
b. Loading cassettes into cameras (100)
c. Pulling cassette slides such that the film will be exposed as the projectile passes the successive shadowgraph stations.

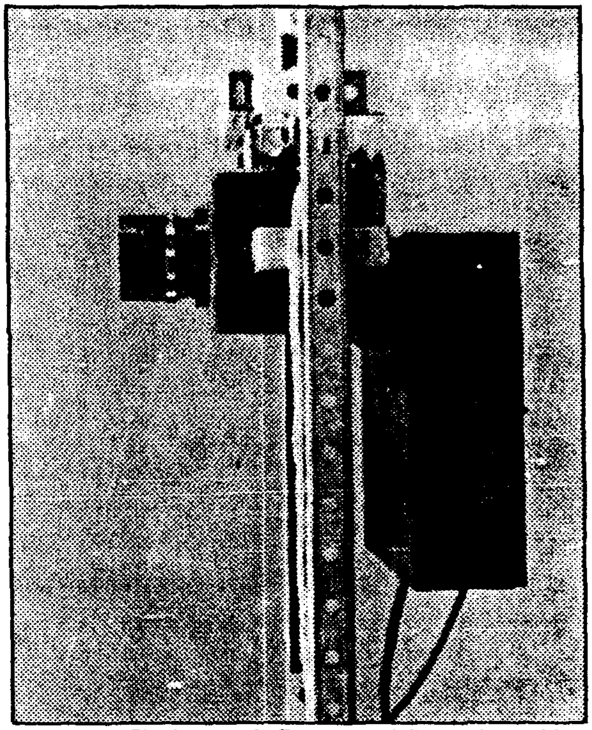


Figure 3. Shadowgraph Camera and Spark Assembly

d. Reinserting the cassette slides after the shot is completed
e. Remove the cassette from the cameras
f. Transportation of the cassettes to the film processing site
g. Removal of the film from the cassettes
h. Process the film
i. Transportation of the film to the film reader for analysis
j. Manually positioning each sheet of film into the reader[12]
k. Manual reading of each catenary wire reference bead and of the individual model coordinates
l. Transportation of the film to a storage location

The film handling process frequently dictates the rate at which tests can be performed in the ARF. In fact, it is often necessary to evaluate the film from one flight prior to the next planned test flight, requiring a one day delay for the film to be returned from processing.

The advantages of the existing film system is its high sensitivity to low light levels, the good resolution inherent in the film negative, and the automatic resulting archival hardcopy from each flight. Obviously the resolution of any imaging system is of

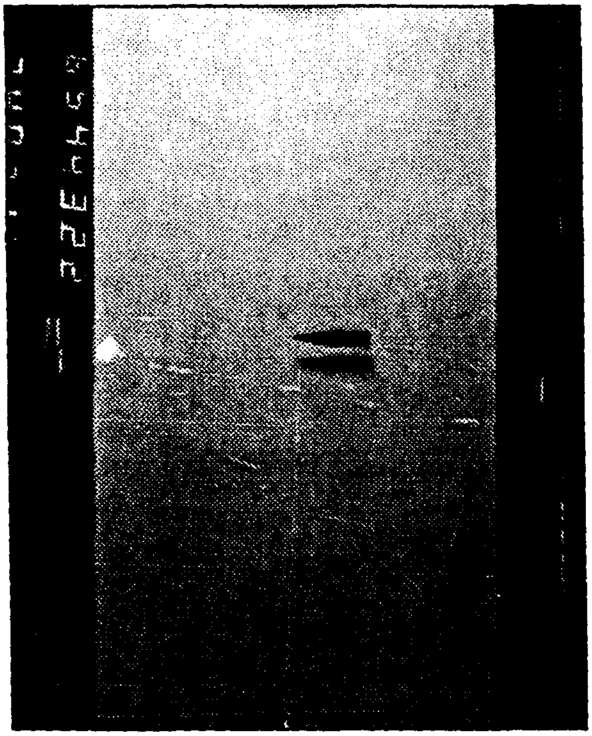


Figure 4. Typical Shadowgram

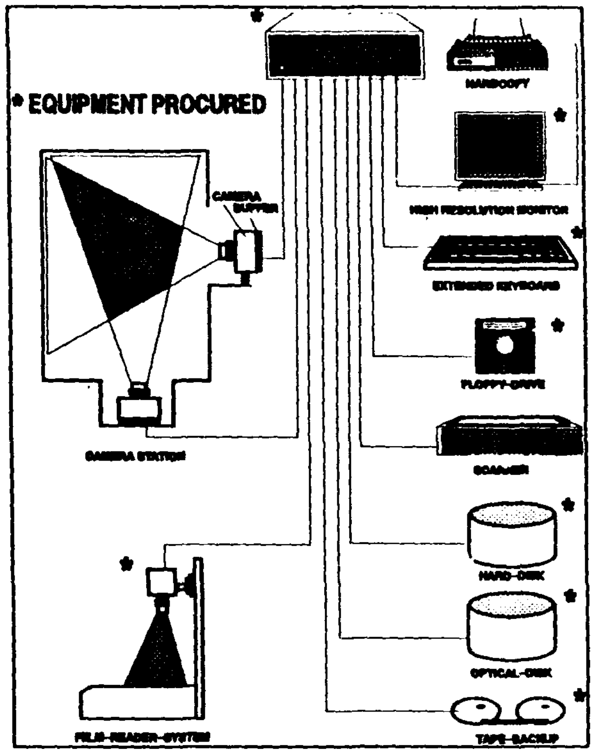


Figure 5. Schematic of Electronic Shadowgraph System

utmost importance since this determines the accuracy of the position-attitude measurements obtained from the images. The present film camera system provides a measuring capability of approximately 0.08 degrees and 0.08 cm respectively for the orientation and position of well defined points in space.[13]

Planned Electronic Imaging System

Obviously, the ideal system to replace the existing film camera system would be one that would eliminate the film handling steps mentioned above (a through l) and simultaneously maintain the advantages associated with film. In this regard, CCD technology has been proposed to replace the existing film camera system in the ARF during fiscal years 1993 through 1995. A schematic of the proposed electronic shadowgraph system is shown in Fig 5. This system would use the existing spark units and consist of the CCD cameras, buffers, data image processor, monitor, disk units, hardcopy unit and film reader. The importance and application of the film reader will be discussed in a later section of this paper.

This proposed system certainly eliminates the film handling and provides other advantages including direct digital data transfer from each station and continuous status monitoring. Another major advantage is that since the data is in an electronic form, it can be immediately displayed and processed on-site to extract near real time feedback for the test analyst. While these are significant advantages the two major concerns were resolution and hardcopy. The latter issue has disappeared with the recent market availability of high resolution continuous tone hardcopy devices. Therefore, the primary issue has been to define the resolution performance of the image sensor and the electronic camera system.

Since film is a continuous media the sampled image from a electronic image sensor array cannot fully reproduce the information density achievable in the film negative. A major part of the technology evaluation has been associated with the concern of losing the existing accuracy in the determination of projectile position and attitude. It was demonstrated[5] that an electronic camera/CCD chip would require about a 3500 by 1600 pixel array density to preserve

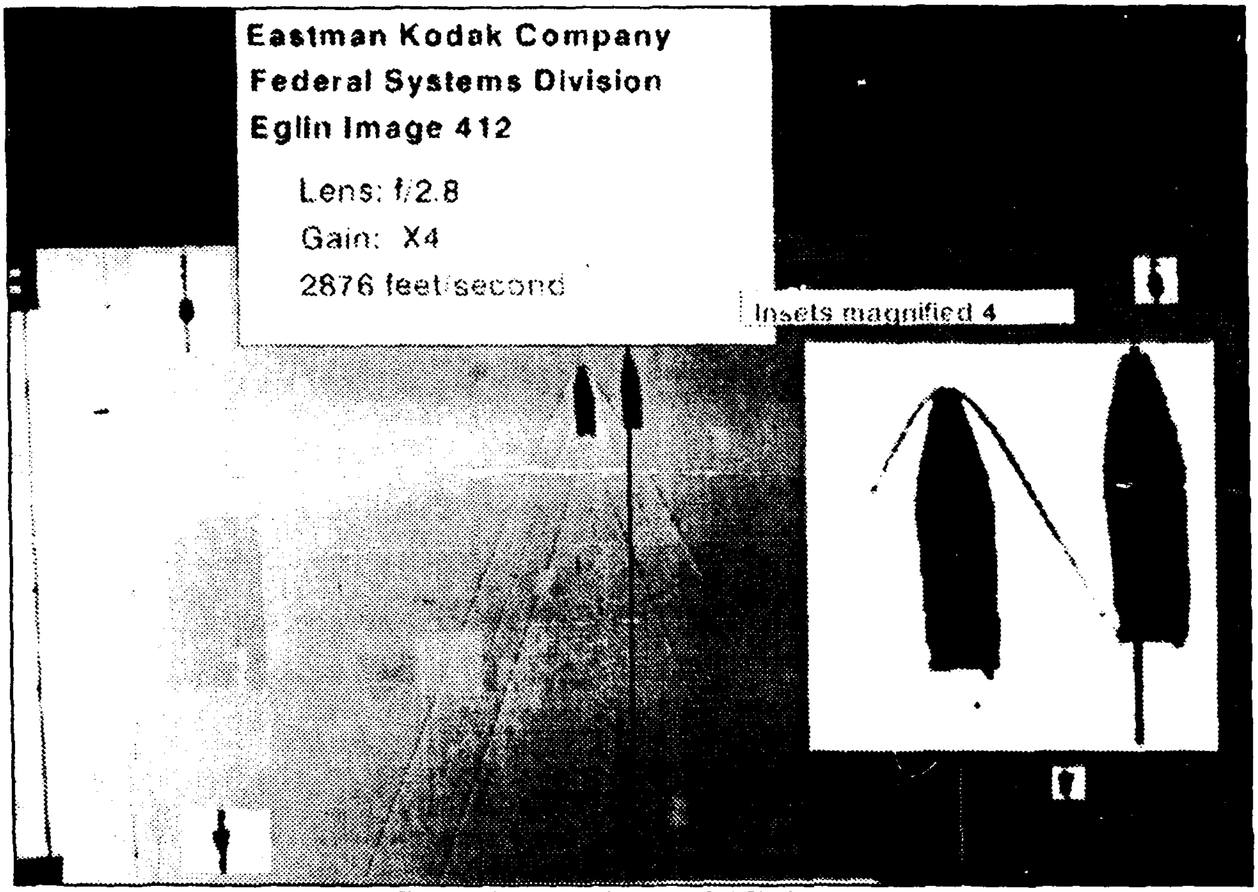


Figure 6. Electronically Recorded Shadowgram

the information transfer achieved in the current manual film data reduction process which requires the digitizing of discrete points on the image of the model and reference points. With an electronically recorded image the process of determining the position and attitude of the projectile can be performed with commensurate accuracy as detailed in Reference 6. Unlike manual data reduction, where an operator has to visually define and by cursor or light pen precisely designate the key coordinates of the projectile, the newly developed technique utilizes all of the resolved pixels of the projectile and reference beads to define centroid derived moments which in turn provide a highly accurate representation of the test objects orientation. Since this process can be automated, reduction of operator subjective bias over a large number of images provides for both increased speed and accuracy. Using this technique, significantly less than the estimated 3500 by 1600 equivalent pixel resolution represented by the manually evaluated film negative is required.

In late 1989 and early 1990 an evaluation was performed of a Texas Instruments CCD based camera system manufactured by EG&G and Hadland Photonics (1134 by 486 pixels). A wire grid target was manufactured with wire sizes approximating various size fiducials (catenary wires and spin pins). From these experiments it was subjectively estimated that a CCD chip with approximately 2000 by 1000 pixel density would be required.

Subsequently, in July 1990, Eastman Kodak's Government Systems Division demonstrated a CCD based electronic camera system in a NIKON 35MM form factor with the 1.3 million pixel CCD array inserted in an electronic film back (1280 by 1024 pixel). A shadowgram of one of the exposures is shown here as Fig 6. One particular aspect noted was the major increase in sensitivity, allowing an additional 2 f/stop margins in exposure using the existing spark sources. This resulted in an equivalent ASA of over 1800 for this CCD. More recently, March - April 1992, both Kodak and EG&G have demonstrated in the facility sensors having approximately 4 million pixels arranged in a square format (nominally 2000 x 2000).

With the determination that CCD technology could in fact provide the contrast and sensitivity required to successfully image the test projectiles, and reference points in the range, the next step was to quantitatively evaluate the current film "system" and determine what an actual CCD Fig of merit was for the proposed solid state cameras. This was accomplished and reported on in Reference 14. Again, the result of that study indicates that to fully reproduce the film system capability requires an electronic image sensor beyond the current production state-the-art. However, when addressing the system functional requirement, the required performance was determined by the ability of the electronic system to faithfully reproduce the smallest feature of the projectile being imaged. The smallest object to be resolved is the shadow cast by the 0.5 mm diameter spin pin located in the base of the projectile. When traveling down the tunnel centerline, this object casts a 1.0 mm shadow on the reflecting screen. In terms of spatial frequency, the electronic system was found to be 2 to 3 times better than the minimum requirement.

In determining the required size of image sensor, the specified 0.5 cycles/mm resolution was compared with the object size. The required area of the reflective screen to be imaged is 19.4 times the usable film area of 90 by 60 mm or 1750 mm by 1160 mm. To achieve 0.5 cycles/mm resolution a minimum of two pixels per cycle, or one pixel per millimeter of screen is required. This implies a 1750 by 1160 pixel array which is within the 2000 x 2000 arrays demonstrated by both Kodak and EG&G. This indicates that the existing technology can adequately reproduce the information as measured from the film system.

There are several other design considerations of the proposed system which should be mentioned. It is important that the horizontal and vertical pixel dimensions and spacing be equal to preserve symmetrical frequency response. The imager size to be developed must be compatible with production high quality optics to minimize unique formats. To prevent noise corruption of the image in the ballistic range environment the cameras and the storage system will be coupled with a fiber optic data, trigger and timing bus. On-line image analysis will provide quick look results and a successive frame display would permit a "movie" mode to animate the flight of the test object.

It is believed that this proposed imaging system will increase the output of the facility by a factor of 2 to 3. Very rapid turn around of the data will reduce program time from weeks to days resulting in a major productivity increase and better final products from the ability to do more testing at a much lower cost. The human inconsistency in data reduction will be eliminated with the automated process providing consistency from measurement to measurement. Since the film processing, film transportation and handling will be eliminated the system will have a maximum direct payback period of approximately 10 years. Factoring in productivity and program cost savings, this payback could be realized in less than 5 years. The value, however, associated with shortened program test and evaluation times for future weapon systems in a decreasing budget environment is inestimable but of primary significance.

Film Reader

Requirements

Assuming that an affordable electronic imaging system with the required resolution and all the other desired features is obtainable, there are two other major considerations which much be addressed prior to the installation of the electronic imaging system. The first of these considerations is the facility downtime during the change over period. Since it is planned that the development and installation will span an 18-month period from fiscal year (FY) 93 through 95, the facility cannot be inoperable during that period. In fact, it would be preferable not have any downtime at all. Secondly, it is recognized that once the new electronic cameras are installed, the present film reading capability would quickly deteriorate due to lack of use. That means that the previous 15 years of critical film archival data (3000 flights) presently in storage would become useless and without means of further analysis. Re-analysis of past flights is not an uncommon occurrence, hence this capability must be maintained.

The solution to both of these concerns lies in the concurrent development of an electronic film reader which is compatible with the electronic camera's data system. Once installed the data from both film and the on-line electronic cameras can be merged in a common format. With the ability to do both film and electronic images, the electronic cameras can be installed a few at the time without major disruption of day to day operations. This film reader also permits development of the operational image processing and data reduction software prior to the installation of the CCD cameras.

During this transition period film processing and handling will be required (by the same process as previously outlined) but, the amount of film will decrease as the electronic cameras are installed. Certainly, the film reader solves the problem of maintaining the existing capability for re-analysis of film data and provides the ability to support both film and electronic data analysis software development. The film reader also permits a direct comparison of results obtained from both sources (film and electronically recorded images). This comparison will be invaluable when evaluating and checking out the final results obtained from the CCD cameras.

Since the film reader is a single unit as compared to the 100 plus cameras required in the shadowgraph system, a very high resolution line scanner type solid state camera can be used in the reader (static images). These chips typically provide significantly higher pixel counts (for example 1 by 4096 in one axis) than two dimensional arrays. The higher resolution is also balanced by slower image capture rates, mechanical complexity of the scanning mechanism, and lower light sensitivities. With the predominate use of negative type exposures from the spark range, a uniformly back-lighted scanning linear array with an exposure defined scanning rate is ideally suited to this application.

Hardware

The film reader and most of the peripheral hardware have already been procured as illustrated by the asterisks show in Fig 5. A picture of the film reader itself is also shown in Fig 7 and uses an Eikonix

Figure 7. Photograph of Film Reader System

1412 - A high resolutions digital camera. This camera can achieve a maximum pixel array of 4096 x 4096 for a total of 16.8 million pixels, scanned one line at a time. Located on the stage inside the camera, the array is moved by an electric motor to scan in the pictures. The aluminum camera housing contains the electronic logic, the solid state single array CCD and is equipped with a 60 mm Nikon lens. The analog-to-digital conversion is done with 8 or 12 bits and has a data transfer rate of 440 KB/sec. The computer requires an IEEE-448 interface board, which allows the communication between computer and camera. The camera has a built-in optical viewer lens, that makes image setup and focusing easier; but it's more precise to focus the camera with the aid of the software. The field size can be set to one of eight standard values or to any nonstandard field size. The camera is mounted on a Gordon desktop stanchion. The transparent shadowgrams are back illuminated by the light sources.

The associated control system and peripherals include a Macintosh IIfx with a 4 MB memory. The extensive software runs on a 160 MB hard disk. The digitized images can be stored on erasable and removable 880 MB optical disks. The computer system has a color monitor, with a resolution of 1,280 x 1,024 pixels, a mouse and an extended keyboard. The software can be exchanged with a built-in 1.4 MB floppy drive. The Max-Stream 150 MB external tape backup allows unattended, automatic backup of the drives. The software contains a PASCAL compiler for adding and changing of programs and tasks.

The hardware and software associated with the film reader system will also be utilized to handle the data from the electronic shadowgraph system. Since the film reader is already in place, much of the image analysis and trajectory software will be completed prior to the installation of the electronic cameras in the range. This significantly reduces the risks associated with the facility change over.

Concluding Remarks

A decade long study of the state-of-the-art associated with electronic imaging devices (CCDs) and their feasibility of replacing the existing film cameras in the ARF has been completed. The results of that study indicate that the nominal 2000 x 2000 pixel CCDs presently in production are adequate for use in the ARF. These CCDs will provide at least the same measurement resolution as the existing film cameras and will eliminate film handling, processing, and storage associated with 100 sheets of film per shot. The CCD technology also provides a basis for automatic image analysis and thereby eliminates the human factor associated with film reading. This makes possible a real time trajectory analysis process which will significantly decrease test times and simultaneously increase the facility output. It is expected that the system will pay for itself in 5 to 10 years.

Even though this new CCD camera system will eliminate the use of film in the facilities shadowgraph cameras, a new film reader is the key to the successful installation of the electronic shadowgraph system. This new film reader utilizes a line scanner solid state camera which digitizes the individual sheets of film and permits handling the digitized images in the same manner as an image obtained from a CCD camera. This capability permits a phased installation of CCD cameras without any significant facility downtime. This is accomplished by merging the film data, via the electronic film reader, with the data coming from the newly installed CCD cameras. The reader also allows re-analyzing the film stored from the previous 15 years of facility operations. Lastly, the reader permits the image processing algorithms to be written and checked out prior to installing the first CCD camera in the range. This film reader system has been procured and is presently on site.

The successful installation of the complete system, as described in the paper, represents a major step in achieving the long sought after goal of real time-on site trajectory analysis. The goal of launching the test item, determining the experimentally measured trajectory, and extracting the aerodynamic coefficients and derivatives prior to launching the next test item has always been the vision and now appears of becoming possible in the foreseeable future.

References

1. Kittyle, Robert L., Packard, James D., and Winchenbach, G.L., "Description and Capabilities of the Aeroballistic Research Facility", AFATL-TR-87-08, May 1987.

2. Nordstrom, Sven, "A High Resolution Television System with Immediate Evaluation of the Position and Yaw Data for a Projectile in an Aeroballistic Range", 28th Meeting of the Aeroballistic Range Association, Eglin AFB, FL, September 1977.

3. Brown, R.R. and Parker, J.R., "A High Speed Electronic Imaging Application in Aeroballistic Research", SPIE Vol 497, High Speed Photography, Videography and Photonics II, San Diego, CA, August 21-22, 1984.

4. Brown, R.R., Parker, J.R., and Kelley, R.J., "System Design Aspects of Using High-Speed Electronics Imaging Techniques in Aeroballistic Research", Proceedings of the International Conference on Instrumentation in Aerospace Simulation Facilities (ICIASF), 1985 Record, Stanford University, August 1985.

5. Brown, R.R., and Parker, J.R., "Conceptual Design and Analysis of High Speed Electronic Imaging-Phase I", AFATL-TR-85-65, October 1985.

6. Holt, D.M., "Centroid/Second Moment of Inertia Method of Locating a Model in 3-Space from Two Orthogonal Projections", 38th meeting of the Aeroballistic Range Association, Tokyo, Japan, October 1987.

7. Holt, D.M., and Winchenbach, G.L., "An Electronic Shadowgraph Station and Control System", AIAA paper no. 88-2061, 15th Aerodynamic Testing Conference, San Diego, CA, May 18-20, 1988.

8. Snyder, D.R. and Powell, R.M., "High Speed Photography, Videography, and Photonic Instrumentation Development at the Air Force Armament Laboratory", SPIE Vol 981, High Speed Photography, Videography and Photonics VI, pgs 255-256, San Diego, CA, August 1988.

9. Snyder, D.R. and Kosel, F.M., "Application of High Resolution Still Video Cameras to Ballistic Imaging", SPIE Vol 1346, Ultrahigh- and High-Speed Photography, Videography, Photonics, and Velocimetry '90, pgs 216-219, San Diego, CA, 10-13 July 1990.

10. Eastman Kodak Company, "The Aeroballistic Research Facility Electronic Shadowgraph, White Paper", Federal Systems Division, 1447 St Paul Street, Rochester, NY, 31 August 1990.

11. Shower, R. and Winchenbach, G.L., "A Modular Short Duration High Intensity Light Source for Free Flight Spark Ranges", 34th Meeting of the

Aeroballistic Range Association, Williamsburg, VA, October 1983.

12. Lucas, B.F., "An Advanced Reader for Free Flight Spark Range Shadowgraph Film", 31st Meeting of the Aeroballistic Range Association, California Institute of Technology, Pasadena, CA, October 7-8, 1980.

13. Winchenbach, G.L., and Davis, T.D., "A Mathematical Technique of Free Flight Spark Range Calibration", 30th Meeting of the Aeroballistic Range Association, Burlington, VT, September 1979.

14. Becker, B., Winchenbach, G.L., Snyder, D.R., Macke, H., and Rowe, W.J., "Upgrade to the Aeroballistic Research Facility Image Analysis System and Film Reader", 42nd Meeting of the Aeroballistic Range Association, Adelaide, Australia, October 1991.