# THE USE OF PHOTOGRAMMETRY IN THE MANUFACTURE OF HIGH PERFORMANCE AIRCRAFT

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## BIOGRAPHICAL SKETCH

Gary Powell received his B. S. Degree in Physical Science from Southern Illinois University at Edwardsville in 1973. He earned his Master of Science Degree in Civil Engineering from Purdue University in 1982. His experience includes five years as a cartographer with the Defense Mapping Agency Aerospace Center, St. Louis, Missouri. In March 1983, he was employed by the McDonnell Aircraft Company of St. Louis, Missouri, a division of McDonnell Douglas Corporation. He was given the responsibility for the implementation of an Industrial Photogrammetry Laboratory in the Quality Tooling Department.

## ABSTRACT

The use of photogrammetric principles in industrial applications has been written about for years. It seems, however, that the transition to practicality has been limited. McDonnell Aircraft Company has implemented this technology in an industrial setting. This paper will discuss the historical aspects of this decision, the hardware and software involved, the logistical considerations, and in general, how this transition is being made.

## BACKGROUND

In the 1960's overtures were being made to the United States industrial community seeking applications for the use of photogrammetry. At that time photogrammetry was a maturing science looking to broaden its base of applications. Mapmaking had been photogrammetry's main thrust, and it was thought that the principles of this discipline could be directly correlated to needs in industry. The needs that were identified early were in the areas of quality control and numerical data generation.

In early 1972, a group of managers at McDonnell Aircraft Company (MCAIR), a division of McDonnell Douglas Corporation, met to discuss the feasibility of using stereo photogrammetry in the manufacture of aircraft and space vehicles. There was much discussion about the potential applications and benefits of this new area, but it was determined at the time not to pursue the idea of photogrammetry.

Interest was rekindled in photogrammetry when an Air Force sponsored research program was started in May 1978. Air Force contract F33615-78-C-5019 covered a period from May 1978 to August 1981 and was intended to investigate applications of photogrammetry in the aircraft manufacturing industry. MCAIR reviewed the reports submitted under this contract and in early 1980 decided to actively pursue an in-house photogrammetric capability. The first use of this technique would be in the periodic re-inspection of aircraft assembly tools. Quality Tooling, a department within the Quality Assurance Division, had previously managed this function, so the responsibility of investigating a photogrammetric system was assigned to them.

## THE SYSTEM

It quickly became evident that there were many companies who were interested in entering the field of industrial photogrammetry, but few who had any real experience. After two years of investigation, it was decided to purchase an AVIOLYT BC1 analytical stereoplotter complete with CRABS (Close Range Analytical Bundle Solution) software from Wild Heerbrugg Instruments, Inc., of Farmingdale, New York. The CRABS software was developed by JFK, Inc., of Indialantic, Florida. This hardware and software combination has proven to be most effective as both companies have years of experience in close-range work. Also included in the purchase was a Wild P31 camera. Training was provided by both Wild Heerbrugg and JFK so that the system could be efficiently implemented in a production environment. It should be noted that MCAIR is currently working only with convergent photography. The decision to purchase a stereoplotter over a monocomparator was based on two things. First, initial and repeat surveys could be accomplished at a quicker rate with an analytical stereoplotter; and secondly, with state-of-the-art equipment our growth into stereo applications will be unhindered.

## THE APPLICATION

The photogrammetric system was justified on only one application--namely, the periodic recycling (re-inspection) of aircraft assembly tools. MCAIR is currently producing the F-15 Eagle, the F-18 Hornet, and the AV-8B Harrier II aircraft which require large, specially designed assembly tools. To assure accuracy and consistent results in the manufacturing process MCAIR periodically checks the dimensional stability of these tools using master gauges. It is not uncommon for a team of four people to work three days in accomplishing this recycle task. In addition to this expense, the tool being recycled is out of production for that period of time. The expense of these two factors is even more frustrating when you consider that a tool, because of its quality construction, is usually found to be within specifications by the recycle. This situation lends itself perfectly to a photogrammetric system. Tools can be photographed quickly between assemblies and analyzed later while the tool is back in production. When no problems are found, the tool can continue in production until the next recycle is scheduled. If an unacceptable deviation is discovered, the tool will be removed from production only as long as it takes to master reset the defective details and not recycle the whole tool.

## THE METHOD

When the recycle of a tool approaches, a quality engineer assigned to the photogrammetry lab begins to plan the photographing of that tool. This is generally a one-time expense, because once a plan is developed it will be used on subsequent recycles. Many things must be taken into account while the plan is being developed such as:

a. accuracy required
b. size and shape of the tool
c. physical limitations in the surrounding work area
d. depth of field requirements
e. lighting
f. number and type of details to monitor
g. target diameter

Drawing all of this information together, the engineer produces a photographic plan which meets all requirements.

As mentioned earlier we use convergent photography. This is done to increase the accuracy of our computed values over what could be achieved using stereo. The only disadvantage of this is that we must pre-target all locations of interest. We use permanent targets, fabricated from aluminum and then anodized. A white center of plastic is then placed flush with the surface and concentric with the shaft of the target. We normally use dot diameters of .060" and .090" centers, but have some with .040" and .120" centers. A particular detail that is going to be monitored will receive at least three targets. This is done to give us a solid basis for deciding if the detail has shifted or rotated in any way.

When the time for recycle arrives, the tool is checked first with the master gauges (some tools have up to four master gauges). This is done to insure that our data base of target X, Y, and Z's will be derived from a "perfect" tool. It will not be necessary to reinstall the master gauges on any subsequent recycle of that tool. After the master recycle is completed, we install our targets and photograph the tool as per our plan. The tool is then released back to production. For the twenty tools we have planned to date, we have averaged eight photographs per tool.

At our convenience we measure the glass plates for a tool using the BC1 as a monocomparator. Files are built that contain individual target locations for each glass plate with respect to the center of that plate. This along with other miscellaneous information forms the basis to start the photogrammetric bundle solution. Once the bundle solution is completed, we have a relative set of X, Y, and Z coordinates for each target on the tool. At this point we can leave the data arbitrary or transform it to some specific system of our choosing. For all practical considerations we could leave the data in an arbitrary form for its intended use. In this case when the tool is recycled again (using only photogrammetry), another set of photographs will be taken and another independent solution will be determined. This solution will be arbitrary in nature but would be transformed into the system arrived at the previous year. After this transformation, relative motion of the targets can be detected by simply comparing last year's target coordinates (historical data base) to this year's target coordinates. Relative motion detection is all with which we are really concerned; that is, has a target and its detail moved and to what extent. It was decided for our purpose, however, that we would transform all coordinates into the tool's coordinate system which can then be related to the aircraft coordinate system. If a detail has moved, we can relate this directly to the effect it would have on the aircraft.

Each tool has its own floppy disk on which historical and other information is stored. While we are actively working on a tool, its floppy is downloaded to a hard disk on our system's computer. This provides for more efficient operation. When a tool is completed, the pertinent information is placed on its floppy disk for future access. It was mentioned earlier about the advantage of having a computer-driven stereoplotter. In subsequent surveys of a tool, after a quick resection, the computer will drive the BC1 automatically to each target location.

## THE RESULTS

The photogrammetry lab at MCAIR has been in full operation as of this writing for only seven months. With this in mind, it is a little premature to discuss in great depth the results we have achieved. During this time we have photogrammetrically reduced fourteen sets of photographs (another six sets are at various stages of processing). One sigma standard deviations are produced from error propagation during the least squares adjustment of the bundle solution. These are converted to tolerances by a multiplier. The average tolerances achieved have been X = ± .004", Y = ± .007" and Z = ± .003". (Note that at MCAIR the Y-axis is in the depth of the tool.) These tolerances fall well within the expected limits and also will satisfy tool recycle inspection requirements.

We have also completed one mock photogrammetric recycle. Using a newly constructed tool, we took two complete sets of photographs. The first set was reduced as if it was the historical data base. The solution tolerances were X = ± .004", Y = ± .006", and Z = ± .004". The second set of photographs were reduced independently (as they will be during subsequent recycles) with solution tolerances of X = ± .005", Y = ± .007", and Z = ± .004". The two surveys were then compared to each other. The RMS difference in repeatability was X = .002", Y = .003" and Z = .003", and 98.6% of points were within .007" of their expected (historical) position.

The photogrammetry lab has also completed one special project involving a time-motion study of an F-18 wing frame. As a result of our survey the tool design department was made aware of a difference between two pre-supposed identical tools.

## CONCLUSION

The photogrammetry lab has been viewed with much curiosity since its doors were opened. A new office area was constructed complete with darkroom facilities. Two large picture windows allow passersby the ability to see our seemingly strange and exotic equipment. Many tours have been conducted through our office ranging from production personnel to a company vice president. Each participant has been excited about the potential uses for our facilities. Obviously in such short time we have only scratched the surface of applications. Though we have not yet ventured into the field of stereo photogrammetry, we plan to do so.

We have received good support from Wild Heerbrugg and JFK, Inc., and we have been equally impressed with the quality of their hardware and software. The system is meeting the expectations of management in its operation, accuracies, and manpower savings. The photogrammetry lab was authorized based on a projected two-year payback on the investment. This projection is still valid.

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