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Tissue Density Determination in Intact Birds

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Summary

Bird "slice" density data of intact birds was acquired using medical diagnostic equipment at the Wright-Patterson Air Force Base, Ohio, hospital. Internal tissue configuration data was collected on twelve species of birds using magnetic resonance imaging (MRI) and two species of birds using computerized tomography (CT). MRI provides detailed information on the location and orientation of internal body tissues and structures without dissection. CT data provides greater detail and the image intensity represents relative density information of the tissue. These techniques, especially CT, could eventually replace the dissection method of determining density and could lead to the development of an improved "virtual bird" for computer modeling of impact forces and an "artificial bird" for use in aircraft component certification testing.

(Keywords: Engineering; Testing; Bird Populations; Body density/weight; Artificial Bird)

1.0 BACKGROUND

U.S. Air Force aircraft average over three thousand birdstrikes each year; about one out of six birdstrikes causes reportable damage. Since January 1989, there have been ten "Class A" aircraft mishaps resulting in loss of life, total loss of aircraft or extensive damage; eight of these birdstrike accidents were a result of engine failure after ingestion of birds, the most recent being the 1995, E-3 "AWACS" crash in Alaska after ingesting Canada Geese (*Branta canadensis*).

Commercial jet airliners also report expensive losses due to birds with as much as one-third of the in-service fleet damage due to engine ingestion (Anonymous 1996). In 1994, U.S. commercial and private aircraft were involved in 2,220 bird strikes, which probably represents less than 20 percent of the actual number (Dolbeer, et al. 1995). The annual cost of bird strikes to civilian aircraft has been estimated at $100 million. Bird strikes to commercial jetliners are most likely to occur when the aircraft are below 500 feet--during takeoff and landing--when strong engine performance is critical. Curtis (1995) showed that engines were involved in over 75 percent of the bird strikes involving damage on Boeing 737-3/4/5, 747, 757, and 767 jets.

2.0 PURPOSE

The purpose of this study is twofold. First, we sought to model the tissue densities of a variety of North American bird species and document variability in the internal tissue densities of birds. Second, we wanted to establish a methodology that could efficiently provide digitized tissue density data for an entire bird. The digitized density data can be rotated to present any aspect to the aircraft component under evaluation. This capability is particularly useful in the development and testing of engine turbine blades which may encounter the birds at any orientation. The density data can be used to model the worst, expected, impact forces presented by birds on aircraft engines, transparencies and airframe components. The study is a collaboration with Wright Laboratories, the U.S. Department of Agriculture, and the Central Science Laboratory of the United Kingdom.

3.0 JET ENGINE DESIGN

The capability of aircraft turbine engines to tolerate bird strikes has improved over the last three decades. Engines are more powerful and can maintain desired safety-of-flight standards. As new standards take effect and new engines are certified, a more cost-effective technique is sought for the design engineering and early certification testing.

The birdstrike problem is directly related to the projected frontal area. As an aircraft component increases in size, the probability increases proportionally that it will be involved in a bird strike. As engine intakes become larger, it becomes more likely that they will ingest a bird. Keeping birds out of the engines altogether while maintaining performance is virtually impossible so considerable efforts have been made to develop engines that can continue to operate after encountering a bird. The development and certification of aircraft engines that can withstand bird strikes is costly and time-consuming, especially if components must undergo full-scale testing.

3.1 Aircraft Certification

The usual design test criteria for simulating an operational bird strike has been a standard, four-pound bird (euthanized domestic chicken). The test bird is physically projected at various speeds to impact aircraft transparencies, engines and other sensitive airframe components. The engines are required to tolerate a single 4-pound bird without creating additional hazard to the aircraft, such as fire. With the tendency to increase engine inlet size, as in turbofan engines, future engines must withstand ingestion of an 8-pound bird (Parker 1994). Parker also reports that future engines must also tolerate ingestion of 1 1/2- and/or 2 1/2-pound birds (depending on engine inlet size) and maintain at least 75 percent operating power for 20 minutes. Revisions in full-scale testing procedures may be required to meet the new engine certification standards. In the past, multiple smaller, birds, such as Starlings (*Sturnus vulgaris*) were used to test engine tolerance to flocking birds. It may be necessary to use larger birds to meet the new standards.

Several attempts to develop an "artificial bird" have met with varied success. The standard for full-scale aircraft component testing remains intact birds. Recent developments in computational modelling have paved the way for expanded use of a "computer- simulated bird" during the design and manufacturing process. The proposed study will help further development of computerized bird strike design by understanding the microphysical contributions each tissue type makes to the impact forces.

4.0 EXPERIMENTAL APPROACH

The study collected data on the type and distribution of body tissue associated with various cross-sections of twelve species of birds (Table I).

TABLE 1. List of Bird Species Scanned

Common Name	Scientific Name
House Sparrow	(*Passer domesticus*)
Brown-headed Cowbird	(*Molothrus ater*)
Red-winged Blackbird	(*Agelaius phoeniceus*)
European Starling	(*Sturnus vulgaris*)
Common Grackle	(*Quiscalus quiscula*)
Laughing Gull	(*Larus atricilla*)
Rock Dove	(*Columba livia*)
Mallard	(*Anas platyrhynchos*)
Herring Gull	(*Larus argentatus*)
Black Vulture	(*Coragyps atratus*)
Domestic Chicken	(*Gallus gallus*)
Canada Goose	(*Branta canadensis*)

The bird specimens were acquired by U.S. Department of Agriculture, Denver Wildlife Research Center (DWRC) personnel through live-trapping, netting or shooting. Birds were captured, handled and euthanized with gaseous carbon dioxide following standard operating procedures (WRC-139/-214/-256/-383/-404/-245) approved by the DWRC's Animal Care and Use Committee and the American Veterinary Association. All specimens were collected under appropriate State and Federal wildlife collection permits. All specimens were frozen immediately after collection and thawed completely before the scans. The research was conducted under project # R95-030a, which was approved by the Surgeon General of the U.S. Air Force in February, 1995.

Studies were conducted on the twelve species (sex undetermined) to compare the scanned bird densities with the empirical data collected by the water displacement method (Seamans, Hamershock and Bernhardt 1995). The results characterize bird densities for those bird species that have historically caused bird strike problems.

4.1. Medical Diagnostic Systems

The birds were scanned using magnetic resonance imaging (MRI) and computerized tomography (CT) diagnostic equipment at the Wright Patterson Air Force Base, Ohio, hospital. These systems allow the visualization of "slices" through the body at any location and orientation allowing the visual isolation of internal structures so medical professionals can diagnose and treat diseases and other bodily malfunctions. These systems provide a unique technology to compare the position and extent of the interal tissues of birds. The relative positions of the internal structures are the pixel coordinates of the image. Once the specimen is scanned, the pixel data can be depicted at any point or through any plane of the bird. The tissue differences are depicted through varying shades of gray of the pixels and are visually displayed on a "computer" monitor. The data for an entire bird can be combined to show the 3-dimensional relationships of the internal body structures. The data are archived as images since digitized data is seldom required by medical professionals. The data digitizing capabilities of these systems offer many possible ways of applying the data to improve bird strike modeling.

4.1.1. Magnetic Resonance Imaging

MRI scans were performed on twelve species of birds during March, 1995. MRI is a non-ionizing radiography technique to view the internal organs and other structures. MRI uses a strong (1,500 to 20,000 gauss) magnetic field to align certain atoms in the nucleus of body cells. MRI measures the signal, much like a radio signal, that is emitted by atoms as they are excited by these strong magnetic fluxes. This signal is converted into a visual image.

The MRI data can be manipulated through a powerful, mini-computer which can combine separate images and can compute three-dimensional representations of the image data. Tissue density calculations must be incorporated separately at the appropriate image coordinates by substituting the whole organ/structure density values collected during dissection.

All birds were positioned in the MRI device with wings slightly spread and head and tail situated as in flight. The birds were scanned axially at 2 mm intervals. Since the hospital MRI was originally for the imaging of people, the bore of the machine was too narrow to accommodate large birds with their wings spread. Birds larger than a Rock Dove required two or three separate scans to obtain data on their full length. The data from the separate scans were combined afterwards to form one image. Birds collected by shooting were not imaged because of the possibility that the remaining shot would constitute a hazard in the high magnetic field.

4.1.2. Computerized Tomography

CT-scanning uses ionizing (X-ray) radiography techniques to view internal body structures. The X-rays are focused on a specific plane of the body and the beam is picked up by an instrument called a scintillator which feeds the exact density of the tissue the x-rays passed through to a computer. The image depicts the relative density of the tissue.

In May, 1995 the CT system software was modified to allow collection of continuous image data (versus individual, "slice" data which must be recombined later to form a whole body representation). In June, 1995, specimens of a domestic chicken and a mallard duck were imaged to compare the results obtained with the MRI images. This data was downloaded to floppy disks in UNIX format.

The CT sagittal image of the female (note egg in abdomen) mallard duck (Figure 1) shows clearer definition of the organ tissue than does the MRI images. As a legend to this and subsequent figures, the rectangular box in the lower left shows the positioning (pixel coordinates) of the CT "slice" (R=right; L=left; A=anterior; P=posterior; I=inferior; and, S=superior) as viewed on the monitor. Additionally, the bird specimen was laid over a "phantom", a collection of blocks of known density, which visually showed relative tissue density. Density increases in blocks from left to right. The far right density block approximates that of bone.

The CT system operator can define up to three, random points of interest for close examination. Figure 2 shows a sagittal view of a domestic chicken and three points corresponding to (1) bone, (2) muscle, and (3) an empty space. The corresponding numerical values are shown at the lower right of the image.

CT values relate directly to the density of the structures, which makes this technique preferable over MRI in the study of bird tissue density. Figure 3 shows two "slices" across the duck at different points: through the upper part of the thorax and across the lower part of the abdomen. The small square, or "region of interest", can be scaled and moved to any location on the image by the system operator. In Figure 3a, the "region of interest" is centered on the point where the ribs meet the sternum, which bisects the attached breast muscle and overlies the thoracic cavity. The associated values within this "region" can be displayed numerically as an 11 x 11 matrix at the right of the image. Again, a high negative number denotes fluid-filled or empty space (the thoracic cavity). High positive numbers denote increasingly dense tissue (bone). Note the small variations within the same tissue type, especially the breast muscle (on either side of the sternum) which is fairly homogeneous.

5.0 DISCUSSION

Perhaps the strongest aspect of using either MRI or CT is the systems' ability to show detailed relationships of internal structures. The MRI and CT data collected for this study has been available only as images; the software used to convert to numerical arrays is proprietary and expensive. While it is useful to view the relationship of the internal organs of the birds, the digitized data is needed for application of advanced computer-aided design of jet engine components. The alternative requires physically removing various body parts from each bird, measuring the density and reconstructing each slice into a three dimensional representation of the bird. Collecting bird density data in this way is tedious, time-consuming, and birds must be sacrificed to obtain the information. CT-scanning could be used on living specimens and the data could be available almost immediately.

We are continuing our search for software that can reduce the images to a readable data field. In the near future, we hope to access specialized computer software (e.g., ANALYZE), which can be used to convert the tomographic images into manipulable data arrays. This numerical data will be useful in refining finite element models used to design engine components. A possible spin-off of this research may the development of a standardized bird density model--either real or virtual--for use in aircraft component certification or airworthiness testing. This could help "level the playing field" for the industry and could reduce, if not completely remove, the need for actual bird specimens for impact testing.

For possible future studies, it may be useful to determine if CT values collected here are representative of the tissue density values for "live" birds. This information could be important in the development of an "artificial bird" for impact testing.

6.0 Conclusions

The use of CT is preferred over MRI in the study of body density. The density of birds can be determined through any plane without complicated and time-consuming dissection. Since CT relates directly to tissue density, little manipulation of the data is necessary to support numerical modeling needs of aircraft designers.

7.0 LITERATURE CITED

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FIGURE 1. Computed X-ray tomography (sagittal view) image of Mallard hen.

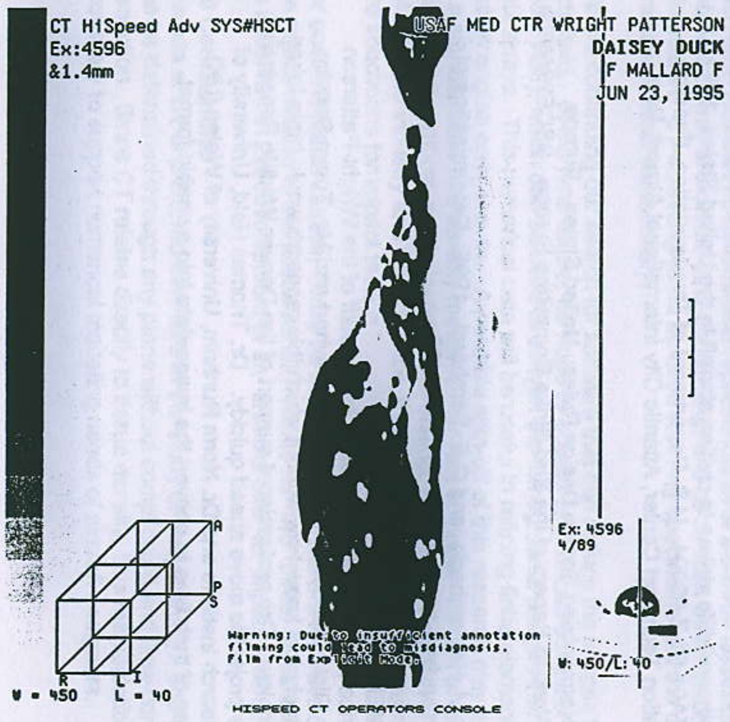


FIGURE 2. Computed X-ray tomography (sagittal view) image of a domestic chicken showing points of interest and corresponding values

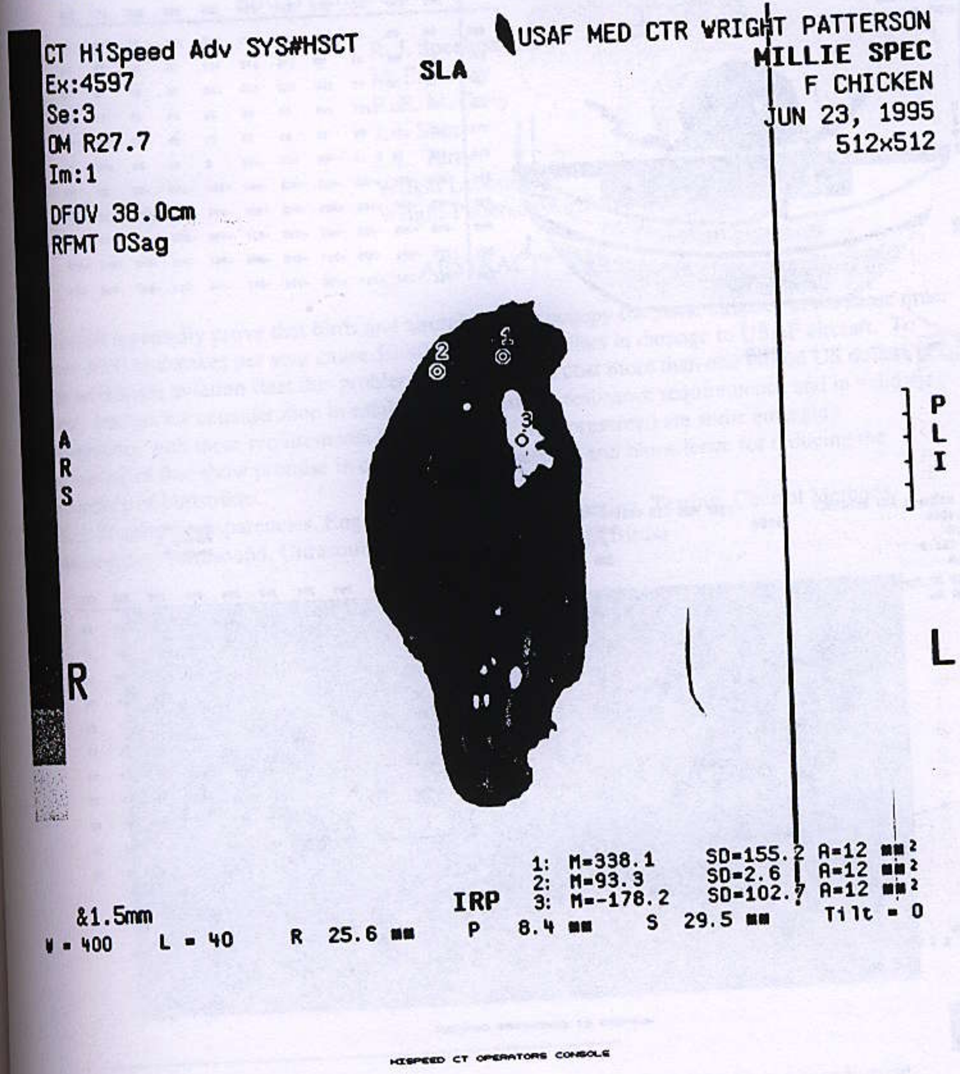
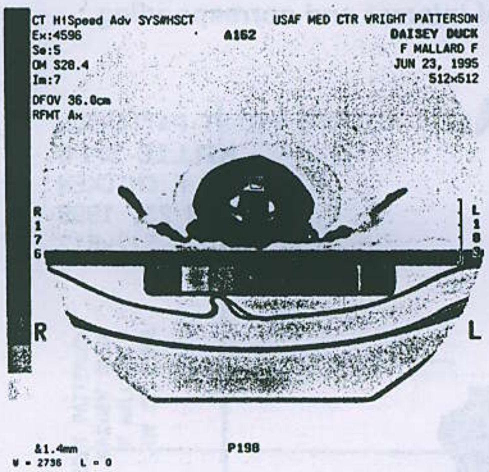


FIGURE 3. Computed X-ray tomography (cross-sectional view) images of Mallard hen (a) thorax and (b) posterior abdomen, showing region of interest and associated numerical data.



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Pat. ID: MALLARD F
Report #1

Exam: 4598
Series: 5
Image: 7

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203	-845	-705	-758	-802	-830	-827	-705	-575	-417	-273	-173
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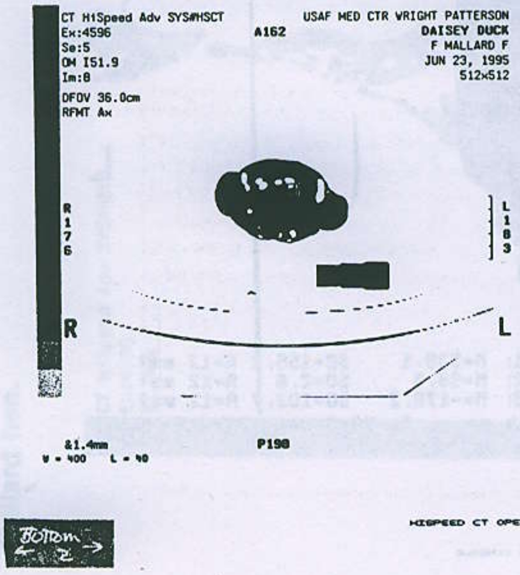

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