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May 21, 2016

Mr. Ric Gillespie
TIGHAR
2366 Hickory Hill Road
Oxford, PA, 19363

RE: FORENSIC DETERMINATION OF AMELIA EARHART'S HEIGHT

Dear Mr. Gillespie,

I understand that there is no reliable and traceable information regarding Amelia Earhart's ("Earhart") height, and that there is an independent research track that requires this information. This report describes the process used to forensically establish Earhart's height from historical imagery.

Approach. Apply the science of Photogrammetry to the objective examination of photographs. Locate a photograph of Earhart containing a measurable referent. Obtain measurements of the referent. Use the referent to establish the height of Earhart. Correct any distortions in the photographs. Correct any measurement confounders.

Methodology. A photograph was located showing the full vertical extent of Earhart while standing co-planar with the propeller of her Vega 5B NR7952 (Figure 1). The Vega 5B is in the Smithsonian Institution's Air and Space Museum aviation collection and can be measured and used as the referent.

Figure 1. Earhart standing co-planar with Vega 5B propeller.
(Photograph amelia-earhart-435.jpg)

A reference photograph of Earhart's Vega 5B using a surveyor's rod as a scale was taken on Monday, January 11th, 2016 with the same perspective as figure 1 (Figure 2).

In Figure 2 the surveyor's rod has been placed co-planar with the Vega 5B's ("Vega") propeller. There are potential confounders related to the reference image:

1) The Vega is on a jack stand, increasing its height and preventing compression of the tires;
2) The Vega has been tipped forward to aid in its display to museum visitors;
3) The Vega's propeller is in two different angular rotations in figures 1 and 2 limiting the propeller's utility;
4) Obstructions within the exhibit limited the useful photographs which could be taken;
5) The placement of the camera was limited due to conflicts with museum displays and museum operations;

6) The length of the surveyor's rod had to be limited to avoid damage to the Vega and the museum display;
7) Placement of the surveyor's rod had to be limited to avoid damage to the Vega and the museum display;
8) A time restriction limited the work time available.

Figure 2. Reference photograph of Earhart's Vega 5B (Photograph 6I3A0016.JPG).
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Nonetheless, photograph 6I3A0016.JPG shown in figure 2 is sufficient to establish the height of Earhart. The overall approach is to scale figure 1 to match figure 2. This will be done by using the horizontal mirror of figure 2; correcting figures 1 and 2 for barrel distortion and rotational error; scaling figure 1 to match figure 2; overlaying figure 1 on figure 2; reading the surveyors scale in figure 2 to measure elements co-planar with the propeller in figure 1; correcting for measurement confounders if and as needed including: the Vega's display angle; the Vega's vertical lift by the jack stand; the Vega's tire compression; Earhart's shoe heel height and top crown hair height.

Equipment. Primary image acquisition was performed with a Canon 5DSR DSLR S/N 062021002343 using a full-frame 51 megapixel sensor in raw mode, and a Canon EF 28-300mm 1:3.5-5.6 L IS lens S/N 112458. Natural lighting was used. The surveyor's rod was a Bosch GR16 Aluminum 16-Foot Telescoping Rod S/N 40723 marked in feet, inches and quarters.

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[1] This photograph is © Copyright 2016, Jeff Glickman. This photograph may be reproduced without permission provided that the copyright attribution accompanies the photograph.

Distortion Correction. The photograph in figure 1, amelia-earhart-435.jpg, was reviewed for barrel distortion by drawing straight lines through where paver elements should be straight. The measurements of straight lines in the image are materially straight establishing that no barrel distortion is present in the photograph, therefore no barrel distortion correction was performed. The photograph in figure 2, 6I3A0016.JPG, was reviewed for barrel distortion by drawing straight lines along museum display cabinets which should be straight. Barrel distortion was detected, corrected, and reviewed again. The photograph in figure 2, 6I3A0016.JPG, was tested for rotational error and corrected by -0.1° since this photograph is the referent for measuring the contents of figure 1.

Scale Establishment. The photograph in figure 2 was taken at the same horizontal angle so as to mimic the content of figure 1. Multiple components of the airplane, including the landing gear and struts, were used to replicate the alignment. Due to an obstruction in the museum exhibit the referent image had to be taken in reverse, therefore the horizontal mirror of figure 2 must be taken. The vertical angle could not be replicated because of the forward tilt of the aircraft that is incorporated into the museum display.

The propeller cannot be used to directly establish scale between figure 1 and figure 2, because its angular rotation is different in the two photographs. Instead, the inside engine cowling width located approximately where the left-hand tangent is 90° was used to establish scale between the two photographs. While the engine cowling is not co-planar with the propeller, its minor oblique recession from the propeller's geometric plane is equivalent in both photographs, enabling the correct scaling in the geometric plane of the propeller.

A repeatable location in both photographs must be selected. For this analysis, the location where the top left of the black rod-like structure oriented at 270° within the engine is obscured by the cowling, was chosen. Horizontal alignment at the location selected is essential. Vertical alignment is unimportant, because the forward tilt of the airplane creates an anamorphic compression in the vertical axis with the horizontal scaling unaffected.

Measuring from the chosen location directly across to the right-hand inside edge of the engine cowling, figure 1 measures 2308 pixels, and figure 2 measures 217 pixels, for an image scale of 2308 pixels / 217 pixels = 10.64. Figure 1 was therefore scaled by 10.64x.

To aid in the visual alignment, figure 1 was equalized, and a contrasting blue gradient applied to create a false color image. To increase the visibility of the overlay, a second unprocessed copy of figure 1 was overlaid and aligned at the chosen location to increase the contrast. The resulting composite image is shown in figure 3.

Measurement Method. The surveyor's rod enables both absolute and relative measurements. If absolute measurements from the ground are used, we must correct for the lift of the Vega on the jack stand, the forward tip of the displayed Vega, the compression of the tires in figure 1, Earhart's top crown hair height and shoe heel height. On the other hand, if relative measurements along the surveyor's rod are used, Earhart's height including her top crown hair height and shoe heel height can be read directly from the surveyor's rod as a difference measurement, and correction for the lift of the Vega on the jack stand, the forward tip of the Vega, and the

compression of the tires in figure 1 are not necessary. If the relative measurement is used, correction for Earhart's top crown hair height and shoe heel height must still be made.
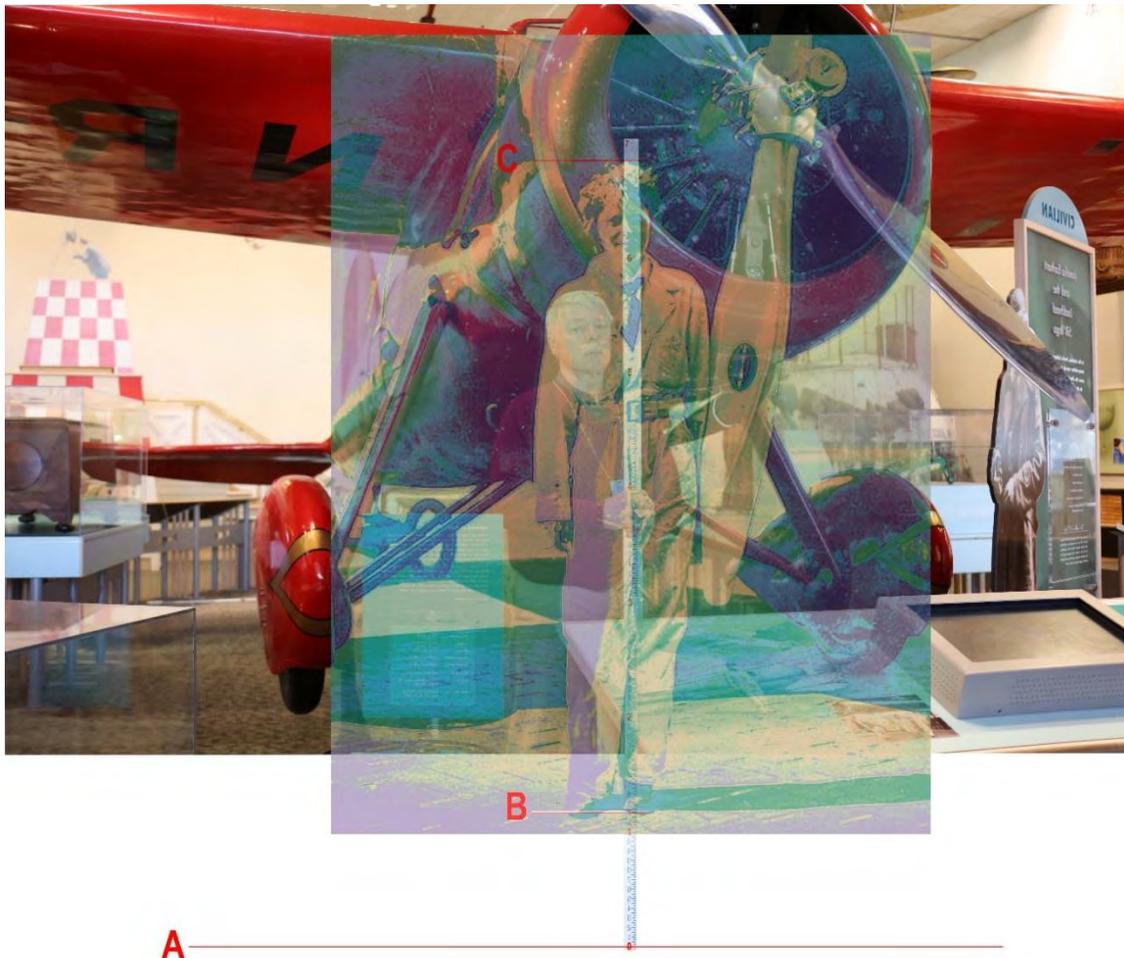

Figure 3. Scaled overlay of Earhart photo of figure 1 on reference image of the Vega 5B.
© Copyright 2016, Jeff Glickman[2]

Gross Height Measurement. In figure 1, Earhart's weight is on her left foot and her right foot is forward, therefore the left foot will be used for the height measurement. In figure 3 line A shows the location of the National Air and Space Museum floor, line B the bottom of Earhart's left shoe, and line C the top of Earhart's hair. Line C is located at 6' 10 1/8" on the surveyor's rod, and line B is located at 1' 2" on the surveyor's rod for a difference of 5' 8 1/8", which is Earhart's gross height including her top crown hair height and shoe heel height.

Heel Height Correction. There is no direct evidence in figure 1 as to the height of Earhart's shoe heel. Typically, Earhart wore oxford shoes which have a heel height of approximately 1". It is the opinion of the author that the footwear seen in figure 1 is more likely a boot than a shoe due to the absence of lace details on the front of the left shoe and the raised toe. Accordingly, the

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author has chosen a lower ½" height correction for the shoe heel, however this may be adjusted by the reader as they deem fit.

Top Crown Hair Height Correction. There is little in the scientific literature regarding the vertical extent of hair above the top of the crown. Casual observation by the author suggests that this is typically ½", however this may be adjusted by the reader as they deem fit.

Corrected Net Height. Earhart's net height, corrected for top crown hair height and shoe heel height is 5' 8 1/8" – ½" – ½" = 5' 7 1/8".

Error Analysis. The error in measuring the cowling diameters at the chosen location is 2308±1 pixels / 217±1 pixels = [10.58x, 10.68x]. Propagating this range into Earhart's gross height we arrive at the gross height range of [5' 7 3/4", 5' 8 3/8"].

Conclusion. Given the evidence, my experience and the application of the science of Photogrammetry, I conclude that to reasonable levels of scientific accuracy that Earhart's gross height, including top crown hair and shoe heel height is 5' 8 1/8". In the opinion of the author, a reasonable estimate of top crown hair height is ½", and an estimate of shoe heel height based upon the image content of figure 1 is ½", yielding a net height for Earhart of 5' 7 1/8". My conclusions are based upon the facts that I have received and I reserve the right to revise my report should new information become available.[3]

Sincerely,

Jeff B. Glickman, BSCS, BCFE, FACFE, DABFE
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Chair Emeritus, Institute of Electrical and Electronics Engineers, Seattle Section
Member Emeritus, State of Washington Forensic Investigations Council
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[3] Jeff Glickman and The International Group for Historic Aircraft Recovery (TIGHAR) wish to thank the Smithsonian Institution for granting access to Amelia Earhart's Vega 5B located at the National Air and Space Museum. The Smithsonian Institution and the National Air and Space Museum granted this access for research and informational purposes only, and does not indicate the Smithsonian's endorsement, sponsorship of, or affiliation with Jeff Glickman or TIGHAR, or support of their positions or opinions, or support of this report and its conclusions. The Smithsonian has no control over, makes no representation or warranty, and bears no responsibility for the accuracy, legality or content of this report or the photographs appearing in it.