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RESEARCH ARTICLE

# Amelia Earhart and the Nikumaroro Bones
## A 1941 Analysis versus Modern Quantitative Techniques

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**ABSTRACT:** The unknown fate of Amelia Earhart continues to fascinate. One of the most tantalizing clues involves skeletal remains found on Nikumaroro Island in 1940. Some have summarily dismissed these bones as the remains of Amelia Earhart because they were assessed as male by Dr. D. W. Hoodless, principal of the Central Medical School, Fiji, in 1940. The most recent such dismissal is that of Cross and Wright (2015), who argue that Hoodless's methods were sound and therefore his sex estimate was likely correct.

This paper addresses two issues: (1) it evaluates Hoodless's methods and Cross and Wright's support of them, and (2) it compares the Nikumaroro bones with what we can learn about Amelia Earhart's bone lengths.

When Hoodless conducted his analysis, forensic osteology was not yet a well-developed discipline. Evaluating his methods with reference to modern data and methods suggests that they were inadequate to his task; this is particularly the case with his sexing method. Therefore his sex assessment of the Nikumaroro bones cannot be assumed to be correct.

To address the question of whether the Nikumaroro bones match estimates of Amelia Earhart's bone lengths, I compare Earhart's bone lengths with the Nikumaroro bones using Mahalanobis distance. This analysis reveals that Earhart is more similar to the Nikumaroro bones than 99% of individuals in a large reference sample. This strongly supports the conclusion that the Nikumaroro bones belonged to Amelia Earhart.

**KEYWORDS:** forensic anthropology, Amelia Earhart, human identification, multivariate

## Introduction

The fate of Amelia Earhart continues to captivate public and scientific attention. Several hypotheses, some more credible than others, have been advanced about what may have happened to her and her navigator, Fred Noonan, on their ill-fated attempt to fly around the world. One intriguing component of the Earhart mystery involves whether bones found on Nikumaroro Island in 1940 could be her remains, suggesting she died as a castaway on this remote island. This paper will subject this idea to scientific analysis to determine whether the evidence supports the conclusion that the bones belong to Earhart or whether she can be excluded.

The bones in question were found in 1940 when a working party brought to Nikumaroro for the Phoenix Island Settlement Scheme found and buried a human skull. Upon hearing of the discovery, the officer in charge of the settlement scheme, Gerald Gallagher, ordered a more thorough search of the area. The search resulted in additional bones, including a humerus, radius, tibia, fibula, and both femora. The bones were apparently complete, but they had experienced some taphonomic modification. Also found were part of a shoe, judged to have been a woman's; a sextant box, designed to carry a Brandis Navy Surveying Sextant manufactured circa 1918; and a Benedictine bottle. There was suspicion at the time that the bones could be the remains of Amelia Earhart.[1]

Although the bones themselves have been lost (cf. King 1999), Burns et al. (1998) analyzed measurements taken in 1941 by Dr. D. W. Hoodless, principal of the Central Medical School, Fiji. They concluded that the bones were more likely those of a female of European ancestry and between 5'6" and 5'8" tall, a biological profile entirely consistent with Amelia Earhart. These conclusions conflicted with those of Hoodless, who had assessed the remains as belonging to a middle-aged stocky male about 5'5.5" in height.[2] The Burns et al. report prompted a rebuttal by Cross and Wright (2015), who put forth two general arguments: (1) that Hoodless was qualified to conduct a forensic anthropological examination of the remains and therefore was most likely correct in his assessment, particularly the sex assessment, so the bones

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1. For a full account of the discovery, see https://tighar.org/Publications/TTracks/13_1/tarawa.html.
2. For Hoodless's notes on his analysis, see https://tighar.org/Projects/Earhart/Archives/Documents/Bones_Chronology4.html.

were unlikely to have been Earhart's remains; and (2) that Earhart's physique was extremely linear and gracile, and therefore inconsistent with Hoodless's assessment of the remains as those of a stocky male. Both of these arguments turn on the accuracy of Hoodless's assessment.

Cross and Wright (2015:53) acknowledge that Hoodless was "obviously not trained as a modern forensic anthropologist," but they assert that "his background indicates he was perfectly competent to assess sex, age, body type, and ancestry of a human skeleton." Implicit in this argument is that Hoodless's background as a teacher of anatomy and his training in medical practice qualified him to assess biological profile with little probability of error. On the central question of sex, Cross and Wright (2015) do not evaluate the methods Hoodless used but accept them as valid and still in use today. There is also considerable information not considered by Cross and Wright (2015) that bears on the question of Earhart's body size and shape, how these relate to what we know about the bones, and Hoodless's interpretation of them.

This paper consists of two parts. The first part examines the methods Hoodless used and which were so vigorously defended by Cross and Wright (2015). It subjects the application of these methods to quantitative verification, and wherever possible includes new analyses. It examines the state of forensic anthropology in 1941 to provide the context in which Hoodless worked. The second part examines Amelia Earhart's body size and shape to determine whether they fit the meager evidence at hand and whether there may be reasons to believe that Hoodless was deceived by what he saw before him. These analyses result in a refined conclusion as to whether the remains examined by Hoodless were likely those of Amelia Earhart.

## Materials and Methods

Metric data from the Nikumaroro bones are limited to seven measurements, four of the skull (maximum cranial length, maximum cranial breadth, orbital height, and orbital breadth) and three long bone measurements (length of the humerus, radius, and tibia; see Burns et al. 1998 for measurements). I use data from the Forensic Anthropology Data Bank (FDB), Trotter's U.S. military data (see Jantz & Meadows Jantz 2017 for full description of data), and literature sources to evaluate quantitatively both Hoodless's methods and Cross and Wright's (2015) claims about the former's effectiveness. I reassess cranial affinities using Fordisc 3.1 (Jantz & Ousley 2005) with realistic assumptions about who could have been on Nikumaroro Island during the relevant time period. Earhart's bone lengths were estimated using photographic evidence and regression analysis.

Additional information concerning Amelia Earhart's body dimensions came to light in 2017 through study of Earhart's clothing held in the George Palmer Putnam Collection of Amelia Earhart Papers held at Purdue University. These articles of clothing were kindly made available for measurement by Purdue University archivist Sammie Morriss. Historic clothing seamstress Paula Guernsey took the measurements. The measurements used in this report are inseam length and waist circumference taken from a pair of Earhart's trousers.

It has been shown that measurements have considerable potential to individualize. Sassouni (1960) achieved 100 percent matching of premortem cranial radiographs to postmortem candidates using eight cranial measurements. In an analogous situation, pair matching has proved effective in reassociating commingled remains (Lynch et al. 2017). The fit of the Nikumaroro bones to Amelia Earhart was assessed using Mahalanobis distance (D) and considered in relation to all other individuals in the database. Acquisition of Earhart's bone lengths is described further on.

Other statistical methods used are well known and require little description. I introduce them briefly where they are used and describe their applicability to the question at hand.

## Hoodless's Methods and the State of the Art in 1941

There are both general and specific reasons to question Hoodless's analysis. These do not relate to his competence as much as they do to the state of forensic anthropology at the time. Forensic anthropology was not well developed in the early 20th century. There are many examples of erroneous assessments by anthropologists of the period. E. A. Hooton, one of the most prominent and influential biological anthropologists of the early to mid-20th century, had considerable difficulty sexing the skeletons from Pecos Pueblo, ending up with a sex ratio favoring males (Hooton 1930). Weisensee and Jantz (2010) and Tague (2010) have reexamined the Pecos collection and concluded that Hooton sexed too many females as males, likely because he gave the skull more weight than the pelvis in his sex assessments.

G. K. Neumann is known for establishing a typological framework for Native American remains (Neumann 1952). In so doing he examined hundreds of crania from different parts of the United States. Yet when confronted with a cranium from Jamestown, clearly of African ancestry, he misidentified it as Native American (Neumann 1958), presumably because the archaeologist who excavated it thought it to be Native American (see Cotter 1958:24).

Given the state of the art at the time, why should we suppose that Hoodless, who as far as we know had no formal training in forensic anthropology and had not examined large numbers of skeletons (if any at all), was ahead of his time in the forensic analysis of skeletal remains? It is unreasonable to view Hoodless, or any analyst of that time or this, as capable of making such assessments without error. Modern forensic anthropologists with training and experience still make errors, and the need to have estimates of error rates is receiving increased attention in view of the *Daubert* ruling.[3] Cognitive bias (i.e., bias resulting from prior information) is especially problematic when making visual assessments (Nakhaeizadeh et al. 2014). We do not know whether cognitive bias may have played a role in Hoodless's evaluation, but the possibility cannot be ruled out.

We can agree that Hoodless may have done as well as most analysts of the time could have done, but this does not mean his analysis was correct. All we now have are the few measurements he gave in his report and his brief summary of the methods he used. It is important to extract as much as possible from the information at hand. In doing so, I will show that Cross and Wright (2015) present Hoodless as more unerring in forensic anthropology than most anthropologists of his time, and further that they have misinterpreted some of the other data available about Amelia Earhart.

## Stature Estimation

Hoodless estimated stature using Pearson's (1899) formulae. He cannot be faulted for this, because little else was available at the time. Cross and Wright (2015) argue that Pearson's formulae are still in use today. I am not aware of any contemporary forensic anthropologist that uses Pearson's formulae. Recent forensic anthropology textbooks either mention Pearson as important in developing the regression approach still in use today but omit his formulae, or do not mention him at all. Guharaj (2003) does include Pearson's formulae, but, interestingly, includes the same erroneous constant for the radius that Hoodless used. This suggests that neither Guharaj nor Hoodless consulted Pearson's original paper. Their shared error must go back to a common source.

I have computed estimates from the more recent stature estimation criteria contained in Fordisc 3.1 and compared them to Pearson's (Table 1). Pearson's equations consistently underestimate height compared to modern criteria. Only one of Pearson's estimates exceeds the 20 more-modern estimates in Table 1. Pearson's male tibia estimate exceeds the 20th-century female forensic stature estimate. By any reasonable standard, the height of 65.5 inches (166.4 cm) presented by Hoodless and supported by Cross and Wright (2015) must be considered an underestimate. If the bones actually belong to a male, as Hoodless concluded, then the best estimate of height is about 170 cm, or about 67 inches. If the bones belong to a female, then about 169 cm, or 66.5 inches, is the most reasonable estimate. Using Pearson's equation for females

TABLE 1—*Comparison of Pearson's stature with more recent estimation equations from 19th century, Trotter's WW2 (males only), and modern forensic statures from Fordisc 3.1 (Jantz & Ousley 2005).*

| Equation Source | Humerus (cm) | Radius (cm) | Tibia (cm) | Combined (cm) |
|---|---|---|---|---|
| Pearson males | 164.4 | 166.1 | 167.1 | |
| Pearson females | 160.7 | 163.1 | 162.3 | |
| 19th males | 168.6 | 170.8 | 172.7 | 170.8 |
| 19th females | 168.1 | 171.1 | 168.5 | 170.4 |
| Trotter's WW2 | 170.7 | 172.1 | 170.1 | 170.4 |
| 20th Fstats males | 172.4 | 172.4 | 170.9 | 171.4 |
| 20th Fstats females | 168.2 | 169.0 | 166.3 | 167.9 |

yields a height of circa 161–163 cm (63–64 in.), seemingly a serious underestimate.

An examination of Pearson's sample will clarify why his equations are not appropriate for modern people. Pearson used Manouvrier's French sample, consisting of only 50 individuals of each sex. These were individuals whose birth years would likely have been early 19th century and who were substantially shorter than modern Americans or even Americans of the late 19th century. Pearson used an estimate of 165 cm to calculate the intercept for his male equations. This agrees well with Fogel's (2004) values of 164.3 cm and 165.2 cm for French males reaching maturity in the first and second quarter of the 19th century, respectively. French women were estimated by different methods to arrive at a value of 152.3 cm. By contrast, American males born in the 1890s were 169.1 cm and in the first decade of the 1900s were 170.0 cm (Floud et al. 2011), some 4–5 cm greater than early-19th-century French. Floud et al. (2011) do not present data for females before 1910, but those born in that decade were 160.6, some 8 cm greater than the French value used by Pearson.

Figure 1 shows an example, using the humerus, of the relationship between bone length and stature. It illustrates the nature of the differences between Pearson's sample and Trotter and Gleser's (1952) 19th-century samples. The slopes are approximately equal, but the 19th-century regression lines are elevated, yielding higher estimates for a given bone length.

Parenthetically, it is curious that Hoodless characterized the bones as possibly those of a "short, stocky muscular European," when his own height estimate places the individual only slightly below the average for both American and European males born at the end of the 19th century and early in the 20th century.

## Hoodless's Sex Assessement

Cross and Wright (2015) argue that sex is the Earhart disqualifier, and indeed it could be, if firmly established. They are at some pains to present Hoodless as possessing sufficient expertise to leave little doubt about his sex assessment.

3. On the *Daubert* standard, see http://www.forensicsciencesimplified.org/legal/daubert.html

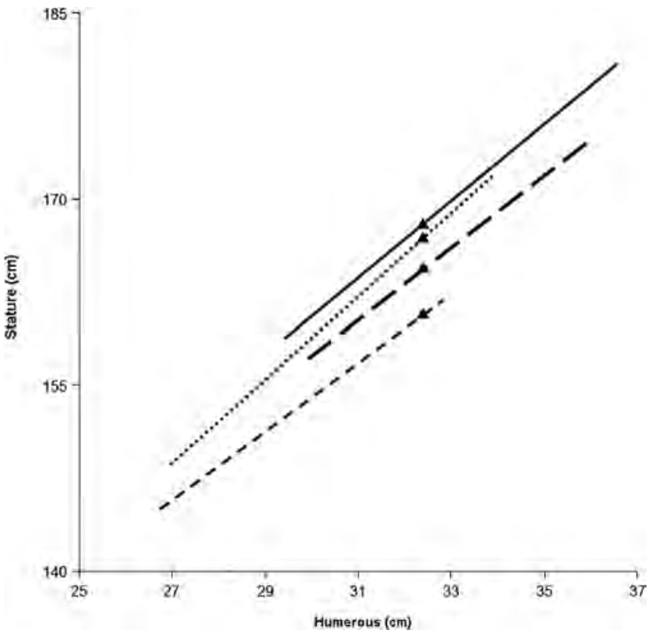



FIG. 1—*Comparison of Pearson's regression lines (short dashes = females, long dashes = males) with Trotter and Gleser's 19th century (dotted = females, solid = males). The lengths of the lines on the x axis are set at ±2 standard deviations from their respective means. The shorter lines associated with Pearson's data show lower variance compared to 19th-century Americans. The triangles are the position of the Nikumaroro humerus. Note that the Nikumaroro point for Pearson females is close to the upper maximum, where estimation is more unreliable, especially with small sample sizes.*

Hoodless's self-reported criteria were (1) half subpubic angle; (2) "set" of the femora; and (3) ratio of the long bone circumferences to their lengths. Cross and Wright (2015) go on to say these features are still used today. I am unaware that "set" of the femora and ratio of circumferences to length are used as a sexing criterion by forensic anthropologists practicing today. Evaluating these variables with data will demonstrate why they are not used. I will also show that estimating sex from the half subpubic angle is by no means foolproof.

***Ratio of femur circumference to length.*** Although Hoodless apparently used the ratio of circumference to length of several long bones, I will use the ratio of femur circumference to its length as an example of this approach. Femur circumference alone is dimorphic enough to qualify as a moderately good sex estimator (DiBennardo & Taylor 1979; Black 1978), but I have been unable to locate published references to use of the ratio of circumference to length as a dimorphic trait to estimate sex. No reference was provided by Cross and Wright (2015).

Whether the ratios Hoodless employed are dimorphic enough to provide an indication of sex is subject to empirical verification. Table 2 shows discrimination statistics, using Euro-American femur data from the FDB for the circumference ratio, circumference alone, and femur length alone. Classification efficiency was assessed using an index of discrimination defined by Maynard-Smith et al. (1961) as $(x_m - x_f)/(sd_m + sd_f)$, the difference between sex means divided by the sum of the standard deviations. The percentage of correct classifications can be estimated by relating the index to a cumulative normal distribution. This provides a close approximation to empirical classification rates.

The best single variable is circumference, sexing around about 80% correctly. Femur length yields almost 78%. The sex difference in the ratio of circumference to length is highly significant, showing that males have a more robust midshaft than females. But the accuracy of assessing sex this way is 60%, only about 10% better than guessing. The ratio dilutes dimorphism, so it is almost 20% worse than circumference alone.

***"Set" of the femora.*** Using the femur for sex estimation is now common (Spradley & Jantz 2011), but I have been unable to find any reference to "set" of the femora, clarified by Cross and Wright (2015) as the angulation to the pelvis. Presumably it has something to do with angle of the femur neck and the distal condyles to the diaphysis. The angle of the distal condyles to the diaphysis was included in Dibenarrdo and Taylor's (1983) analysis of sex and ancestry variation of the femur. For Euro-Americans of the Terry collection these values were 79.8 and 78.1 for males and females, respectively. The standard deviations were 2.1 for both sexes. The sex difference is small and significant ($t = 4.5$, $df = 128$, $p < 0.001$), but the overlap of the two distributions is too large to allow reliable sexing. Estimating accuracy from the index of discrimination yields an expectation of about 65% correct. It is

TABLE 2—*Sexing accuracy of circumference of the femur (C), length of the femur (L), and ratio of circumference to length.*

| | Females | | Males | | Discrimination Statistics | | |
|---|---|---|---|---|---|---|---|
| Femur Variable | Mean | SD | Mean | SD | F ratio | Index of Discrimination | Percent Correct |
| (C/L)*100 | 18.869 | 1.306 | 19.595 | 1.161 | 58.19 | 0.294 | 61.6 |
| C | 82.483 | 5.895 | 92.328 | 5.722 | 469.01 | 0.848 | 80.2 |
| L | 437.605 | 21.381 | 471.674 | 23.060 | 369.25 | 0.767 | 77.8 |

slightly better than the ratio of circumference to length, but still only 15% better than guessing, not something that could be used to reliably assess sex. The sex difference of 1.7° would presumably be very difficult to appreciate via visual assessment.

The angle of the femur neck to the diaphysis is no better. Anderson and Trinkaus (1998) could not identify consistent sex differences among world populations. In a sample of modern Euro-Americans the sex difference was 1.9°, which was not significant and would be difficult to appreciate by visual inspection.

***Half subpubic angle.*** The subpubic angle is defined as the angle formed by the two ischio-pubic ramii with an apex at the inferior junction of the pubic bones. This feature is undeniably a dimorphic feature, and in the hands of an experienced forensic anthropologist it can yield high accuracy rates, although not 100%. While it can be measured, in my experience that is rarely done by forensic anthropologists. The half subpubic angle requires assessing the angle from a single innominate, presumably more difficult than assessing it when both are present. There are some issues that reduce the certainty of Hoodless's estimate. Especially important is Hoodless's description of the condition of the bones: "All these bones are very weather-beaten and have been exposed to the open air for a considerable time. Except in one or two small areas all traces of muscular attachments and the various ridges and prominences have been obliterated." (W.P.H.C.:15) Damage to the bones was most likely due to scavenging by crabs, as originally observed by Gerald Gallagher, administrator of the Phoenix Island settlement scheme, who also opined that the bones were from a female based on association with a women's shoe sole.[4] The fragile pubic bones would have been especially susceptible to damage. It is not beyond imagination that bone morphology was sufficiently modified to reduce ability to accurately assess the half subpubic angle.

Even without taphonomic change, sex estimates can vary widely. A method put forth by Phenice (1969) is commonly accepted as reliable. The Phenice method uses three features of the pubic bone, including the subpubic contour. It should be noted that the subpubic contour does not entirely define the subpubic angle, but as Klales et al. (2012) note, the female concavity results in a greater subpubic angle, which would likely play a large role in visual assessment of the subpubic angle. Klales et al. (2012) present the results of eight tests of the Phenice method. They range from 59% to 99% in sexing accuracy. Of the eight tests presented, four sexed correctly at less than 90%. These tests used all three of Phenice's traits; presumably the subpubic contour alone would perform worse than all three combined.

4. See https://tighar.org/wiki/Bones_found_on_Nikumaroro.

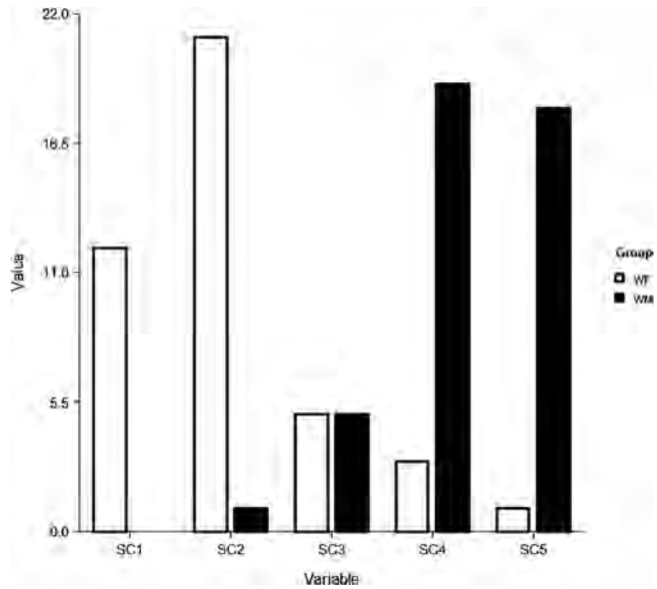



FIG. 2—*Barchart of ordinal scores for the subpubic contour, which forms one half of the subpubic angle. A substantial minority (20%) of females (white bars) have scores that are either ambiguous (SC = 3) or male (SC = 4 or 5). Data from Klales et al. (2012).*

Klales et al. (2012) have devised a systematic, five-stage ordinal scoring system for the Phenice traits, including the subpubic contour. Part of their sample was drawn from the Hamann-Todd anatomical collection, which is a reasonable reference sample for the Nikumaroro bones. Figure 2 shows the distribution of the Hamann-Todd sample on the five-stage scores of Klales et al. (2012). The scores range from strongly female (stage 1) to strongly male (stage 5). The graph shows that most females are stage 1 or 2, and most males are stage 4 or 5. But there is a sizable minority of females (21% of the female sample) in stage 3 or higher. Stage 3 is the antimode between the two distributions and describes an ambiguous subpubic contour that could easily be called either male or female. Klales (2016) has documented that the subpubic contour has experienced secular change, the number of ambiguous females declining since 1940. These data suggest that Hoodless could easily have been presented with morphology that he considered male, even though it may have been female.

**Overall Assessment of Hoodless's Sex Estimate**

Hoodless based his conclusion on three features, one of which—the ratio of circumference to length, as exemplified by the femur—is not sufficiently dimorphic to provide useful information. The second feature, "set" of the femora, is also minimally informative. The subpubic angle, the most reliable of Hoodless's criteria, is also subject to considerable variation, much of which was little understood in 1941. We do not know what weight Hoodless attached to each feature.

He must have considered the two doubtful features to some degree, and perhaps given them weights equal to the subpubic angle. Otherwise he would not have mentioned them.

Cross and Wright (2015) argue that Hoodless undoubtedly made an overall assessment of the remains, including the skull, but only reported the less detailed information appropriate to his audience. How this overall assessment might have informed his decision is pure speculation. No one knows what the skull or postcranial skeleton looked like, nor what Hoodless used to arrive at his assessment of robusticity. It is also worth noting that while demonstrating awareness of Pearson's (1899) stature estimation paper, Hoodless was either unaware of or chose not to mention Pearson and Bell's (1919) paper—which provided valid sexing criteria for the femur, such as the femur head diameter. The state of the art at the time, and the fact that Hoodless was not an experienced forensic anthropologist, reduce the reliability of Hoodless's sex estimate considerably below that accorded it by Cross and Wright (2015). The most prudent position concerning sex of the Nikumaroro bones is to consider them unknown.

**Hoodless's Ancestry Estimate**

It is the case, as Cross and Wright (2015) have stated, that little convincing evidence concerning the ancestry of the Nikumaroro bones can be gained from the four cranial measurements Hoodless provided. However, this is not to say we cannot get more evidence than offered by Hoodless, or by Cross and Wright (2015). Hoodless's assessment that the skeleton is not full Pacific Islander but could be a "short stocky, muscular European or even a half-caste or a person of mixed European descent" (W.P.H.C.:15) may reflect assumptions that conflict with his own assessment of the two indices he computed—orbital and cranial—both of which indicated European. Cross and Wright's (2015) CRANID analysis is flawed because they included samples from all over the world, most of them including individuals from populations that had zero or near zero probability of having been on Nikumaroro. Konigsberg et al. (2009) have shown the importance of an informative prior probability in ancestry estimation. If the prior probability is zero, then the posterior probability must also be zero.

If the problem is approached using only samples of populations that might reasonably have been on the island, somewhat more definitive results are obtained. Ancestries other than European would include Micronesians and Polynesians. I use a Euro-American sample of the early 20th century, a Micronesian sample (Guam), and a Polynesian sample (Moriori), the last two from Howells's data. Ideally the Micronesian sample should come from the Eastern Micronesians, but data are limited. Pietrusewsky's (1990) samples are small and limited to males, but they argue for a basic continuity among Micronesians. The same is true for Polynesians, so Guam and Moriori can be accepted as reasonable representations of these two areas.

Table 3 shows Fordisc results for Euro-Americans and Pacific Islanders, each with both sexes. The lowest Mahalanobis distance and the highest posterior probability belong to early-20th-century Euro-American females. Because the discriminating ability of four measurements is low, the skull cannot be excluded from any of the populations used, as shown by the typicality probabilities. The Typ R, the ranked typicality probability column, provides some additional useful information. Typ R is the ranking of each skull's distance from the sample mean. A typicality probability of 1.0 would indicate that all the values are identical to the mean. Euro-American females have the highest typicality probability. Only 6 crania of 90 are more typical than the Nikumaroro skull. Typicalities for all other groups are 0.65 or less.

Another avenue toward ancestry assessment could lie in the long bone lengths, since different populations have different long bone proportions. This can be approached quantitatively using distance statistics parallel to those used for the cranial analysis. We do not have a database containing bone lengths from different populations, but it is possible to use published means as long as one has a covariance matrix. It has been shown that the long bone length covariance matrices from widely different populations are homogeneous (Holliday & Ruff 2001). Therefore I use mean long bone lengths from Hawaiian and Chomorro people as representative of Pacific Islanders (Polynesia and Micronesia) (Ishida 1993), and 19th-century (Terry collection) and 20th-century Whites (FDB) from which the covariance matrix was obtained.

Figure 3 shows the distances plotted on the first two canonical axes obtained from humerus, tibia, and radius

TABLE 3—*Fordisc 3.1 output for Nikumaroro skull, compared to Euro-Americans and Pacific Islanders.*

| Group | Classified into | Distance from | Probabilities | | | | |
|---|---|---|---|---|---|---|---|
| | | | Posterior | Typ F | Typ Chi | Typ R | |
| E20F | **E20F** | 0.8 | 0.318 | 0.941 | 0.940 | 0.933 | (7/90) |
| GUAMF | | 1.7 | 0.200 | 0.802 | 0.788 | 0.500 | (15/28) |
| MORIF | | 1.7 | 0.199 | 0.795 | 0.786 | 0.654 | (19/52) |
| GUAMM | | 2.3 | 0.146 | 0.691 | 0.673 | 0.581 | (14/31) |
| E20M | | 3.3 | 0.092 | 0.523 | 0.514 | 0.624 | (48/125) |
| MORIM | | 4.7 | 0.045 | 0.333 | 0.317 | 0.276 | (43/58) |

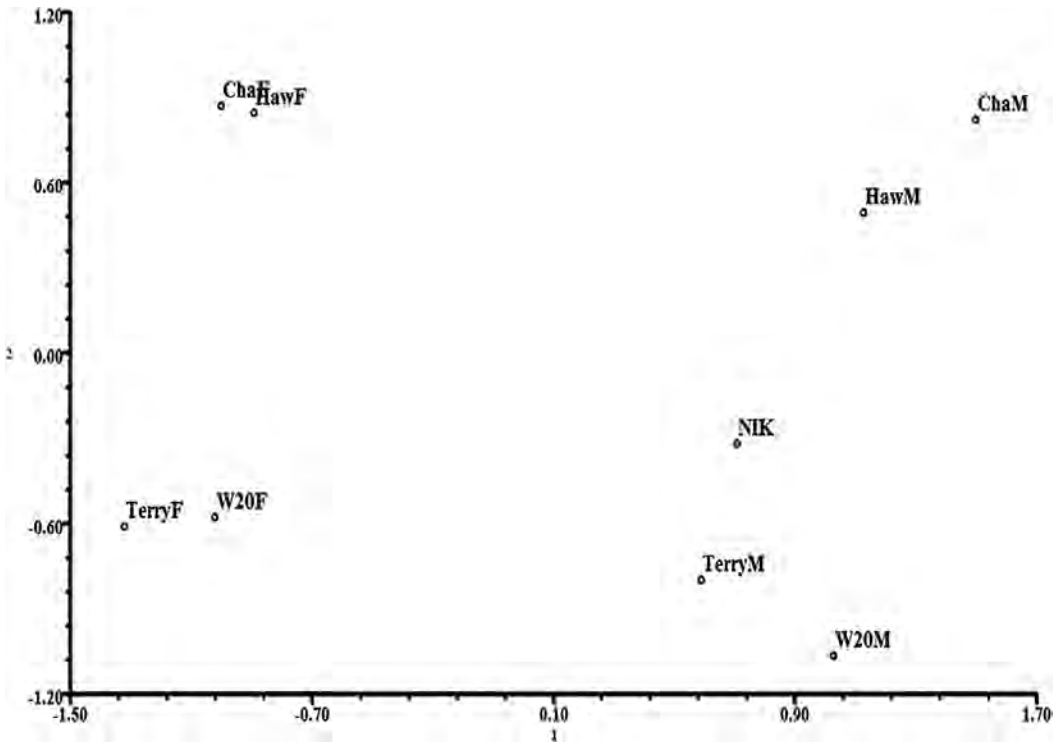



FIG. 3—*Canonical plot of Euro-Americans, Hawaiians, and Chomorro from bone lengths. The Nikumaroro bones were interpolated into the plot using distances from other groups. The first axis mainly reflects size and hence sex differences. The second axis mainly reflects humerus and tibia lengths, low scores reflecting longer humeri and tibiae. The Nikumaroro bones fall on the male side on CV1 and on the Euro-American side on CV2.*

length. The first axis is mainly size and therefore reflects sex differences. The second axis reflects mainly humerus and tibia lengths, low scores reflecting longer humeri and tibiae. The Nikumaroro bones were interpolated into the plot using the distances from each group as described by Gower (1972). The Nikumaroro bones are most similar to White males. They are most distant from Pacific Islanders, particularly Chomorro Micronesians.

## Amelia Earhart's Height, Weight, Body Build, and Limb Lengths and Proportions

I will now try to reconstruct what I can about Amelia Earhart's, height, weight, body build, and limb lengths and proportions. This will serve two purposes: (1) allow testing of Cross and Wright's (2015) assumption that she was extremely linear and gracile, and (2) allow explicit evaluation of the Nikumaroro bones against Amelia Earhart to determine whether she can be excluded or included.

### Height

The source routinely employed for Amelia Earhart's height has been her pilot's license, where 5'8" is recorded. This is called a forensic stature, meaning that it comes from a document rather than being explicitly measured. The air commerce regulations for 1928 state the following:

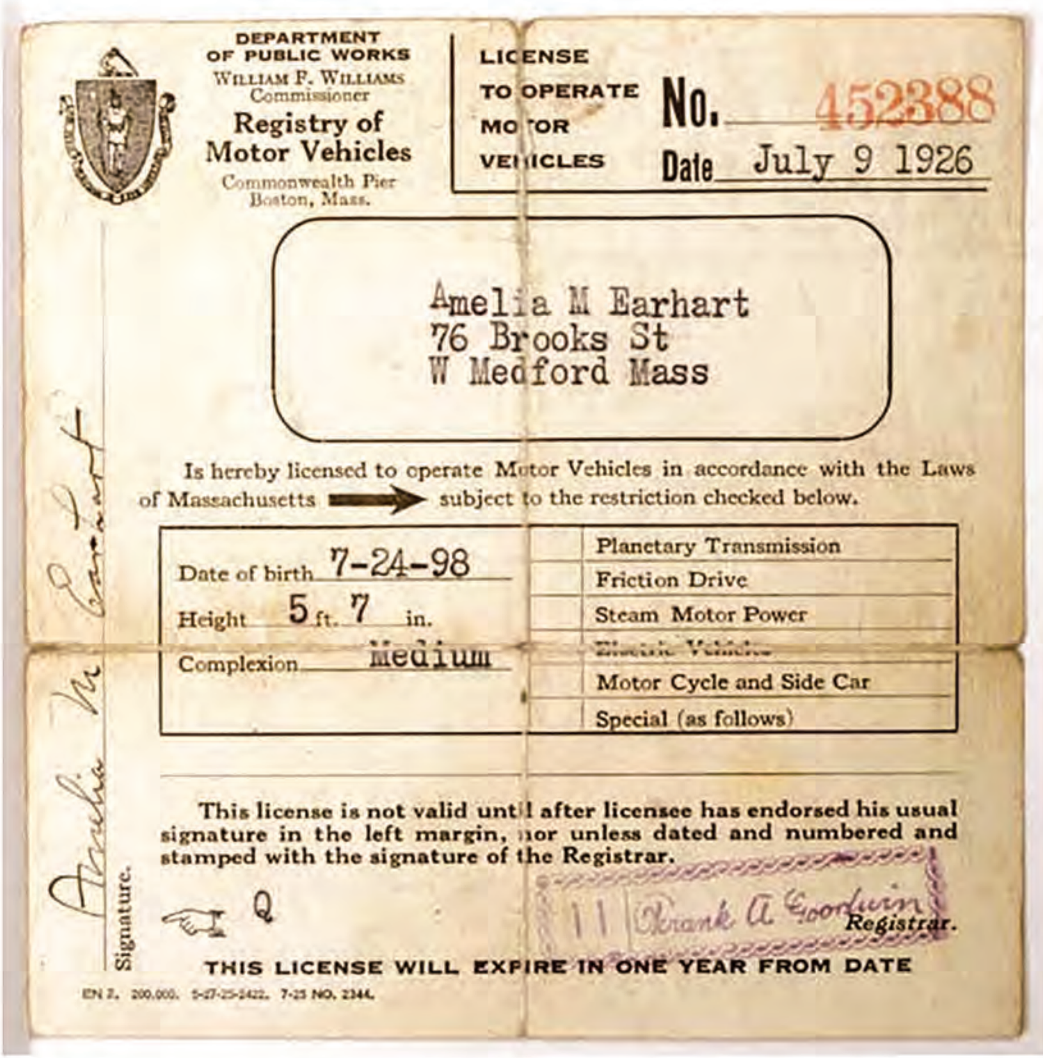
> An application for a pilot's license must be filed, under oath, with the Secretary of Commerce upon blanks furnished for that purpose. An applicant for a pilot's license, including a student's pilot license, must appear for a physical examination before a physician designated by the Secretary of Commerce and pass such examination, unless he is exempt under these regulations.

There appears to be no explicit requirement that height must be measured. If it was measured, it could have been done either freestanding or standing against a wall. We have no idea of the skill or attention to detail the examiner might have brought to the task. Was Earhart properly positioned with shoes off? Was the instrument properly calibrated? Did the examiner round; for example, did 67.5 inches become 68 inches? All of these can introduce variation into the measurement. Or the examiner may merely have asked Earhart how tall she was.

Driver's licenses are commonly used as sources of forensic statures. Figure 4 shows Earhart's Massachusetts driver's license for 1927, where 5'7" is recorded. It is unlikely that the height on her driver's license was measured. It is a forensic stature that is as valid as the one on her pilot's license. This makes the point that height is not a fixed attribute that is measured or reported consistently. It was therefore necessary to seek a measured height which can be obtained photographically by scaling her to known dimensions of an aircraft. Glickman (2016a) estimates her height at 67.125 inches, almost an inch less than the height reported on her pilot's license but in agreement with her driver's license. Glickman's height has the advantage that it was measured, the methods described, and it is subject to verification. While the difference between the forensic heights and measured height is relatively inconsequential, I will use the measured height of 67 inches for the remainder of the paper.

Whether she was 5'8" or 5'7", Earhart was a tall woman for the time in which she lived. This can be illustrated by comparing her height to anthropometric data collected on Pembroke College Women in 1927 by A. M. Tousley and on University of Tennessee women measured in 1930 by I. G. Carter, both series reported by Carter (1932). If Amelia Earhart was 67 inches (170 cm) tall, she was taller than 85% of Pembroke College women and 92% of University of Tennessee women. If she was 68 inches (172.7 cm) tall, she was taller than 88% of Pembroke College women and 97% of University of Tennessee women. Males of her birth cohort were 169.1 cm (Floud et al. 2011), so Earhart was slightly taller than the average male of her time.

It turns out, too, that American "high society" women of the 19th century were substantially taller than average and seemed to be immune to the stature decline affecting the general population (Sunder 2011). Sunder estimates the average height of high society women, which probably includes



DEPARTMENT OF PUBLIC WORKS
WILLIAM F. WILLIAMS
Commissioner
Registry of Motor Vehicles
Commonwealth Pier
Boston, Mass.

LICENSE TO OPERATE MOTOR VEHICLES No. 452388
Date July 9 1926

Amelia M Earhart
76 Brooks St
W Medford Mass

Is hereby licensed to operate Motor Vehicles in accordance with the Laws of Massachusetts subject to the restriction checked below.

| | |
|---|---|
| Date of birth 7-24-98 | Planetary Transmission |
| Height 5 ft. 7 in. | Friction Drive |
| Complexion Medium | Steam Motor Power |
| | Electric Vehicles |
| | Motor Cycle and Side Car |
| | Special (as follows) |

This license is not valid until after licensee has endorsed his usual signature in the left margin, nor unless dated and numbered and stamped with the signature of the Registrar.

Q

Frank A. Goodwin Registrar.

THIS LICENSE WILL EXPIRE IN ONE YEAR FROM DATE

Signature. Amelia M Earhart

EN 3. 200,000. 5-27-25-2422. 7-25 NO. 2344.

FIG. 4—*Amelia Earhart's 1927 Massachusetts driver's license showing her height as 5'7", one inch shorter than that given on her pilot's license.*

Earhart, at the end of the 19th century at 64.9 inches (164.8 cm), more or less equal to what it is today.

## Relationship between BMI and Skeletal Robusticity

Cross and Wright (2015) argue that Amelia Earhart is excluded because her physique was extremely linear and gracile, and therefore inconsistent with the skeletal remains which Hoodless assessed as belonging to a stocky individual. They argue, using height and weight (68 in. and 118 lb.) from her pilot's license, that Earhart's body mass index (BMI) is 17.9, placing her in the extreme lean range. From this they leap to infer a gracile skeleton that Hoodless would not have mistaken for that of a stocky male.

There are two problems with this inference: (1) there is no necessary relationship between BMI and skeletal robusticity, and (2) available evidence does not support the inference that Earhart's skeletal structure was gracile. I shall examine both of these in turn.

The purpose of computing a BMI is to assess body fat, albeit an imperfect indicator. Since it is a ratio (weight/height$^2$), all components of weight, including muscle and bone, in addition to fat, contribute to the value. Body proportions also play a role (Norgan 1994). On average, however, higher BMIs correspond to more body fat. But what does that say about skeletal robusticity? There are several lines of evidence suggesting that the relationship is not close.

The size of articular surfaces is one measure of bone robusticity. In the FDB data, using forensic height and weight to calculate BMI, the humerus and femur head diameters, femur epicondylar and tibia proximal breadths do not have significant correlations with BMI. Normalizing them by bone lengths increases the correlations slightly but they still do not reach statistical significance. Ding et al. (2005) measured proximal tibia articular surface area from MRI scans and compared it to BMI. The correlations were 0.25 and 0.16 for medial and lateral tibia articular surface areas, respectively. These correlations are statistically significant but so weak they lack predictive power. Joint surface size is likely a good indicator of lean body mass but has little to do with BMI. Femur head size has a moderately high correlation with weight and has been used to estimate weight in archeological samples (Auerbach & Ruff 2004), which would not normally have excessive fat. However, height is weakly correlated with weight, so the ratio of weight to height$^2$ diminishes the relationship with skeletal robusticity.

Another measure of robusticity is the size of the midshaft in relation to length, already discussed above concerning Hoodless's sexing method. Femur midshaft robusticity has a moderate correlation with BMI in our forensic database, 0.46 for females and 0.44 for males, which is statistically significant but also too weak to discriminate robust from gracile skeletons using BMI.

The problem of course is that neither Cross and Wright (2015) nor anyone else has any idea how Hoodless made the judgment that the skeleton was that of a stocky person. But what is clear is that the inference from BMI provides no basis to exclude the bones as belonging to Amelia Earhart, Hoodless's assessment notwithstanding.

## Amelia Earhart's Body Build

It is now possible to address the question of what Earhart's body build actually was, since it bears on what Hoodless may have seen before him. Cross and Wright (2015) characterize Earhart as tall, slender, and gracile, citing numerous photos of her to support this assessment. However, the few photos showing Earhart's bare arms or legs (Figure 5) show a woman with a healthy amount of body fat. The photos in Figure 5 are inconsistent with a weight of 118 pounds and a BMI of 17.9, which according to contemporary standards is in the underweight or undernourished category. If her height is actually 5'7", that brings her BMI to 18.5, just to the lower border of healthy weight. But even that is inconsistent with the photos in Figure 5.

It is evident from Figure 5 that Earhart's calves and ankles cannot be described as slender. In the 1933 photo she is standing next to a woman somewhat taller, but with rather more slender ankles. One of Earhart's biographers, Susan Butler (1997), recounts that because of her thick ankles, her legs could be described as "piano legs." Thick ankles are not normally due to an undesirable distribution of fat; the subcutaneous fat layer is normally thin, the ankle configuration owing to underlying bone and muscle (Weniger et al. 2004). Ankle circumference is often used as a measure of frame size (Callaway et al. 1991). Calf and ankle circumference are strongly correlated with weight (Cheverud et al. 1990a), the former reflecting mainly muscle and fat, the latter mainly bone.

## Empirical Estimation of Weight

Weight can be estimated within reasonably tight limits if appropriate information is available. Circumferences typically have the highest correlation with weight. The extensive U.S. military anthropometric surveys provide the simple bivariate correlations of 259 variables (Cheverud et al. 1990a). These correlations and the means and standard deviations (Gordon et al. 1989) allow construction of a covariance matrix from which regression equations can be calculated.

Waist circumference at the level of the umbilicus was used to estimate weight. It is above the rim of the pelvis and corresponds to the level at which the trousers were worn.


FIG. 5—*Photos of Amelia Earhart showing body fat/body mass of arms and legs inconsistent with a weight of 118 pounds. Photos courtesy of Remember Amelia, the Larry C. Inman Historical Collection on Amelia Earhart.*

Waist circumference obtained from Earhart's trousers is 27.375 inches (69.53 cm). The average for U.S. military women is 79.2 cm, about 10 cm larger than Amelia Earhart's measurement. This supports what is evident from the photographic record, that she had a narrow body. Table 4 shows estimates of Earhart's weight using waist circumference and a height of 67 inches.

Waist circumference alone estimates Earhart's weight at slightly more than the weight given on her pilot's license, but with a large error. Including height raises the estimate 10 pounds, to 129.7, and reduces the error more than a kilogram. The 90% confidence interval (114.8–144.3) includes the weight on her pilot's license, but it is equally likely that she weighed somewhat more than 130 pounds.

TABLE 4—*Regression estimates of Amelia Earhart's weight using waist circumference alone and waist circumference combined with height.*

| X Variables | Estimated Weight | RMS Error (kg) | $R^2$ |
|---|---|---|---|
| Waist C.* | 54.6 kg (119.9 lb.) | 5.38 | 0.585 |
| Ht, WC** | 58.9 kg (129.7 lb.) | 4.18 | 0.750 |

* Weight = 0.7724*wc + 0.8436.
** Weight = 0.5402*ht + 0.7022*wc − 81.8166.

Using a height of 67 inches and a weight of 130 pounds yields a BMI of 20.4, a normal value very much in keeping with the photographic evidence in Figure 5. The calf and ankle morphology may also suggest that her limb bones were not as gracile as supposed by Cross and Wright (2015) based on their assessment of her BMI. Unfortunately, we have only photographic and anecdotal evidence of Earhart's ankle and calf size, but Butler's (1997) characterization suggests that they exceeded those of most women of her height and weight.

**Estimation of Humerus and Radius Length**

Among the many photos of Amelia Earhart is one showing her standing with right arm fully extended holding a can of Mobile Lubricant (Figure 6). An exemplar of the can was obtained by Jeff Glickman of Photek. A known dimension of the oil can provides a scale allowing the pixel coordinates of points on Earhart's arm to be converted to linear distances (Glickman 2017). The major difficulty is identifying osteological points underlying the soft tissue. Figure 6 shows the locations for proximal and distal humerus and radius estimated to correspond to measuring points on dry bones. It is not possible to locate these points exactly, but they should provide reasonable approximations. The points shown in Figure 6 yield a humerus length of 321.1 mm and a radius length of 243.7 mm, compared to 325 and 245 for the corresponding Nikumaroro bones. The brachial index obtained from these estimate is 75.9, which compares favorably to the 76 obtained by Glickman on a different photograph (Glickman 2016b)

**Estimation of Tibia Length**

Estimating Amelia Earhart's tibia length is more problematic than the radius and humerus because we have not identified a photo showing her lower leg allowing identification of osteological points and a scalable object. Therefore, two regression methods have been used: (1) estimating from stature and (2) estimating from inseam length of Earhart's trousers. Estimating from stature is straightforward and was accomplished by regressing tibia length on stature using females from our database. The equation is:

$$\text{Tibia length} = 2.1601\ (\text{height}) + 4.8335 \pm 12.50$$

FIG. 6—*Amelia Earhart with right arm extended and points marked where humerus head, distal humerus, proximal radius and distal radius were located. Photo courtesy of Purdue Special Collections, Amelia Earhart Papers, George Putnam Collection.*

Substituting Glickman's measured height of 67 inches (170.18 cm) into the equation yields a point estimate of 372.4 mm.

Estimating from inseam length is less straightforward and involves using regression equations from U.S. military anthropometric data. Unfortunately, a direct measurement of tibia length is not included in the military data. The two dimensions most closely approximating my needs are crotch height and lateral femur epicondyle height. The procedure is as follows:

1. Adjust inseam length to crotch height by adding ankle height. This assumes that Earhart's trouser legs were level with the sphyrion landmark, the tip of the fibula. Earhart's inseam measurement is 28.625 inches, or 727 mm. The ankle height adjustment, obtained from Cheverud et al. (1990b), is 63 mm, making Earhart's crotch height = 727 + 63 = 790 mm.
2. Estimate Earhart's lateral femur condyle height using regression equation in Cheverud et al. (1990b:780). The equation is:
Lateral femur epicondyle height = 0.526 (crotch height) + 55.195 ± 8.53
Substituting 790 mm yields a point estimate of 470.7 mm.
3. Adjust lateral femur condyle height to tibia length by subtracting ankle height (63 mm, as above) and femur distal condyle height, 36 mm (Simmons et al. 1990). The point estimate is 470.7 − 63 − 36 = 371.7.

There are admittedly several adjustments involved in this process, but they are all reasonable. Most of the variation in lateral condyle height involves tibia length, so minor variation in adjustments will not have major influence on the estimate. Crotch height has a much higher correlation with femur lateral condyle height, and hence with tibia length, than height. However, the estimates from height and lateral femur condyle height are very similar, 372.4 versus 371.7, so I will take 372 mm as the estimate of Earhart's tibia length.

**Do the Nikumaroro Bones Fit Amelia Earhart?**

When confronted with human remains of unknown origin, the procedure followed in ordinary forensic practice is to develop a biological profile, and from among missing persons, select those that fit the profile. At that point one attempts to make a positive identification by using features seen on the bones that can also be seen in premortem records of the possible victims. The premortem records may consist of dental or frontal sinus images, or increasingly, DNA taken from remains and comparing to the victim or relatives of the victim. A positive identification is made when premortem features match the victim and have a low probability of matching anyone else.

In the case of the Nikumaroro bones, the only documented person to whom they may belong is Amelia Earhart. Her navigator, Fred Noonan, can be reliably excluded on the basis of height. His height was 6'1/4", documented from his 1918 Seaman's Certificate of American Citizenship. I made nine stature estimates of the Nikumaroro bones, three each for the humerus, radius, and tibia, using male equations in Fordisc for 19th-century males, WW2 males, and 20th-century males. Noonan's height falls outside the 90% confidence intervals for all nine estimates, and outside the 95% for five of the nine estimates. It is clear that the Nikumaroro bones are unlikely to have belonged to Noonan.

Eleven men were killed at Nikumaroro in the 1929 wreck of the *Norwich City* on the island's western reef, something over four miles from where the bones were found in 1940.[5] This number included two British and five Yemeni that were unaccounted for, but we have no documentation on them and there is no evidence that any survived to die as a castaway. The woman's shoe and the American sextant box are not artifacts likely to have been associated with a survivor of the *Norwich City* wreck. If an Islander somehow ended up as a castaway, there is likewise no evidence of this.

If the skeleton were available, it would presumably be a relatively straightforward task to make a positive identification, or a definitive exclusion. Unfortunately, all we have are the meager data in Hoodless's report and a premortem record gleaned from photographs and clothing. From the information available, we can at least provide an assessment of how well the bones fit what we can reconstruct of Amelia Earhart. Because the reconstructions are now quantitative, probabilities can also be estimated.

Estimates of humerus, radius, and tibia lengths obtained from Amelia Earhart allow one to proceed as one normally would in a forensic situation. The Nikumaroro remains can now be compared to Amelia Earhart to address the question of whether she can be excluded or included. It is already apparent that Earhart's vector of measurements, [321.1,243.7,372] is similar to that of the Nikumaroro bones [325,245,372]. These vectors contain both size and shape information, so a comparison should capture both of those elements. This was accomplished by computing Mahalanobis distance (D) of 2,776 individuals in our postcranial database from the Nikumaroro bones. Amelia Earhart's data were included to yield $N = 2{,}777$.

Figure 7 displays a histogram of the distances, by sex, of 2,777 individuals from the Nikumaroro bones. The vertical line shows Earhart's position in the two distributions. She is clearly in the left tail of both distributions, but more so for females. Her z-score in the female distribution is −2.38 ($p = 0.017$) and in the male distribution −1.87 ($p = 0.061$). She has a low probability of coming from the male distribution and a much lower one for the female distribution. Earhart is in the first bin of the histogram for females, along with only two other females (0.526%). There are 16 males in the first bin (0.725%)

One might argue that if the Nikumaroro bones are actually those of Amelia Earhart, the distance should be zero, but that expectation is unrealistic for at least two reasons:

5. See https://tighar.org/Projects/Earhart/Archives/Research/ResearchPapers/WreckNorwichCity.html.

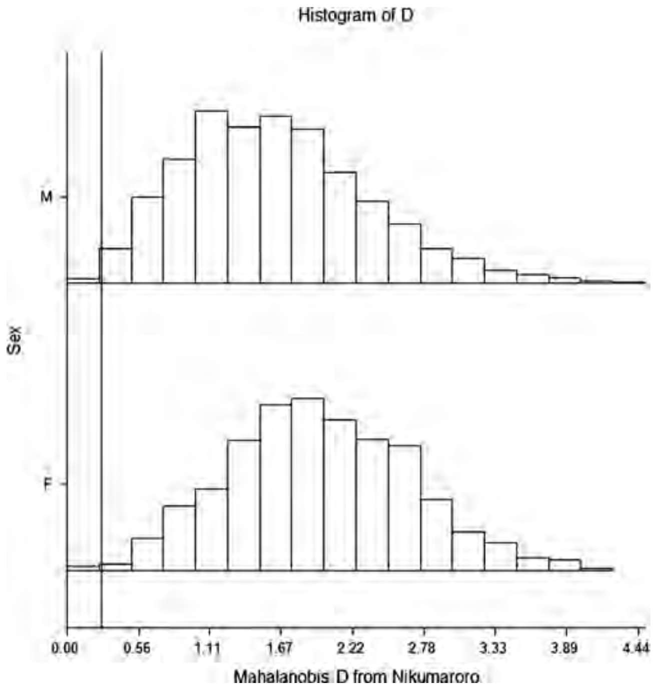



FIG. 7—*Histograms of 2,777 Mahalanobis distances (D) from the Nikumaroro bones, by sex. The line shows Earhart's position in the distribution.*

(1) it would require that my estimates of bone lengths were made without error, which is highly unlikely, and (2) it would require that Hoodless measured the Nikumaroro bones without error, which is also unlikely.

It should be mentioned that a sample of Micronesian or Polynesian bone measurements was unavailable to test against the Nikumaroro bones. I consider it highly unlikely that inclusion of such a sample would have changed anything. As Figure 3 shows, the Nikumaroro bones are more similar to Euro-Americans than they are Micronesians or Polynesians, which suggests they would produce even fewer nearest neighbors.

Another approach to the question is to examine Earhart's rank in the distributions. For clarity, I should point out that if any individual in our sample had a vector of measurements identical to the Nikumaroro bones, the distance would be zero and have a rank of one, that is, most similar to the Nikumaroro bones. But not one from our 2,776 individuals had a vector identical to Nikumaroro's. The lowest Mahalanobis distance is 0.12599, resulting from a vector of [322,243,369]. That vector is noteworthy because its elements are uniformly shorter than Nikumaroro, 3 mm for humerus and tibia and 2 mm for radius. Hence the most similar individual is almost identical in shape but differs slightly in size. The largest distance is 4.57, from a vector of [361,252,430]. It is larger than Nikumaroro in all dimensions, but shape still dominates because the differences range from only 9 mm (radius) to 58 mm (tibia). These examples suggest that the particular combination of bone lengths has considerable power to individualize.

Earhart's rank is 19, meaning that 2,758 (99.28%) individuals have a greater distance from the Nikumaroro bones than Earhart, but only 18 (0.65%) have a smaller distance. The rank is subject to sampling variation, so I conducted 1,000 bootstraps of the 2,776 distances, omitting Earhart, then replacing her to determine her rank. Her rank ranged from 9 to 34, the 95% confidence intervals ranging from 12 to 29. If we take the maximum rank resulting from 1,000 bootstraps, 98.77% of the distances are greater and only 1.19% are smaller. If these numbers are converted to likelihood ratios as described by Gardner and Greiner (2006), one obtains 154 using her rank as 19, or 84 using the maximum bootstrap rank of 34. The likelihood ratios mean that the Nikumaroro bones are at least 84 times more likely to belong to Amelia Earhart than to a random individual who ended up on the island.

The Gardener and Greiner method requires intervalizing a continuous distribution. The above procedure dichotomized the distribution, breaking it at Earhart's rank, and at the maximum bootstrap rank. It might be argued that this weights the result in favor of similarity of Earhart to the Nikumaroro bones. Even if one breaks the distribution into deciles, the likelihood ratio is still 10. Regardless of how one chooses to break the distribution, the fact remains that Earhart is more similar to the Nikumaroro bones than all but a small fraction of random individuals.

The above analysis considers only the comparison of Earhart to the Nikumaroro bones in relation to every other distance from Nikumaroro in our database. A more robust distribution of distances can be obtained by randomly sampling individuals from the database and comparing them to the sample as described above. Each randomly sampled individual serves as an unknown in the same manner as the Nikumaroro bones in the previous analysis. I randomly sampled 500 individuals from the database, omitting each randomly sampled individual in turn from the comparison because it would obviously have zero distance from itself. Sex was ignored for this exercise. From the 500 randomly sampled individuals, 17 had zero distance from another individual, that is, had an identical vector of measurements. One had an identical vector with two individuals, giving a total of 19 identical vectors from the 500 random samples, or 3.8%. This illustrates that identical vectors are a comparatively rare event. Summary statistics of the means, standard deviations, minima and maxima obtained from the 500 random samples are shown in Table 5. The summary statistics of the Nikumaroro bones are included for comparison.

The data in Table 5 reveal that the entire 500 randomly sampled individuals have limited similarity to any other bones in the sample. The mean of the 500 means (2.2268) is somewhat higher than that for the Nikumaroro comparison,

TABLE 5—*Descriptive statistics of Mahalanobis distances (D) for 500 randomly sampled individuals from 2,775 individuals in the database.*

| | Descriptive Statistics of 500 Random Samples for | | | |
|---|---|---|---|---|
| | Means | SDs | Minima | Maxima |
| Mean | 2.2268 | 0.82167 | 0.1681 | 5.4836 |
| SD | 0.4545 | 0.0727 | 0.1046 | 0.6665 |
| Min | 1.5777 | 0.6590 | 0 | 4.2496 |
| Max | 4.4622 | 0.9684 | 0.8277 | 8.2367 |
| Nikumaroro | 1.6969 | 0.7338 | 0.1260 | 4.5700 |

and the average minimum (0.1681) is also higher than the Nikumaroro comparison. But the Nikumaroro statistics are within the range of the 500 randomly sampled individuals. That the Nikumaroro comparison has somewhat lower distances only means that the Nikumaroro bones are closer to the average than many of the randomly sampled individuals.

## Discussion

Let us suppose, for the sake of argument, that the Nikumaroro bones are the remains of Amelia Earhart. In light of the above, we can now reconsider what Hoodless might have seen before him and how he might have assessed what he saw. The skeleton before him would have had bone lengths clearly in the male range. From what we see of Earhart's lower leg morphology, it is quite possible, even likely, that the tibia was relatively robust. As a tall and narrow-bodied female, the "set" of the femora could well have appeared male to Hoodless. It is apparent from the many photos of Earhart, and from her waist circumference, that her hips were narrow for a female. This, in combination with her height, does not require a femur angle one might expect of a female. It may also suggest an ambiguous half subpubic angle that could easily have been called male by an inexperienced eye, or even an experienced one, particularly if taphonomic processes had modified the morphology.

If Hoodless's analysis, particularly his sex estimate, can be set aside, it becomes possible to focus attention on the central question of whether the Nikumaroro bones may have been the remains of Amelia Earhart. There is no credible evidence that would support excluding them. On the contrary, there are good reasons for including them. The bones are consistent with Earhart in all respects we know or can reasonably infer. Her height is entirely consistent with the bones. The skull measurements are at least suggestive of female. But most convincing is the similarity of the bone lengths to the reconstructed lengths of Earhart's bones. Likelihood ratios of 84–154 would not qualify as a positive identification by the criteria of modern forensic practice, where likelihood ratios are often millions or more. They do qualify as what is often called the preponderance of the evidence, that is, it is more likely than not the Nikumaroro bones were (or are, if they still exist) those of Amelia Earhart. If the bones do not belong to Amelia Earhart, then they are from someone very similar to her. And, as we have seen, a random individual has a very low probability of possessing that degree of similarity.

Ideally in forensic practice a posterior probability that remains belong to a victim can be obtained. Likelihood ratios can be converted to posterior odds by multiplying by the prior odds. For example, if we think the prior odds of Amelia Earhart having been on Nikumaroro Island are 10:1, then the likelihood ratios given above become 840–1,540, and the posterior probability is 0.999 in both cases. The prior odds or prior probability pertain to information available before skeletal evidence is considered. It is often impossible to assign specific numbers to the prior probability, because it depends on how the non-osteological evidence is evaluated, and different people will usually evaluate it differently. In jury trials, experts are often advised to testify only to the likelihood ratio developed from the biological evidence. The jury then supplies its own prior odds based on the entire context (e.g., Steadman et al. 2006).

In the present instance, readers can supply their own interpretation of the prior evidence, summarized by King (2012). Given the multiple lines of non-osteological evidence, it seems difficult to conclude that Earhart had zero probability of being on Nikumaroro Island. From a forensic perspective the most parsimonious scenario is that the bones are those of Amelia Earhart. She was known to have been in the area of Nikumaroro Island, she went missing, and human remains were discovered which are entirely consistent with her and inconsistent with most other people. Furthermore, it is impossible to test any other hypothesis, because except for the victims of the *Norwich City* wreck, about whom we have no data, no other specific missing persons have been reported. It is not enough merely to say that the remains are most likely those of a stocky male without specifying who this stocky male might have been. This presents us with an untestable hypothesis, not to mention uncritically setting aside the prior information of Earhart's presence. The fact remains that if the bones are those of a stocky male, he would have had bone lengths very similar to Amelia Earhart's, which is a low-probability event. Until definitive evidence is presented that the remains are not those of Amelia Earhart, the most convincing argument is that they are hers.

## Acknowledgments

Many colleagues, friends, and family members have contributed to this paper in various ways. Ric Gillespie and TIGHAR's resources enabled me to get information from Amelia Earhart's clothing and from photographs allowing quantification of several aspects of her body size and limb lengths and proportions. Ric also answered many questions that sometimes puzzled an Earhart neophyte. Jeff Glickman of Photek estimated her height, brachial index, and, most importantly, the scale to estimate her arm length segments. Joe Cerniglia conducted analyses of Hoodless's stature calculations and called my attention to the Guharaj *Forensic Medicine* text, which led to the discovery of the intercept error shared with Hoodless. He also discovered Earhart's Massachusetts driver's license, adding to the record of her forensic stature. Paula Guernsey took detailed measurements of Earhart's trousers and jacket. Richard Wright called my attention to the 1928 Air Commerce Regulations describing the medical examination required for a pilot's license. Tom King and Ric Gillespie read at least two drafts and offered many helpful comments. Tom also provided helpful editorial assistance. An anonymous reviewer offered several useful comments which also improved the paper. My wife, Lee Meadows Jantz, and daughter Mariana Jantz also read the manuscript and offered useful comments. My entire nuclear family provided enthusiastic support and reveled in the possibility that something new and interesting may still be learned about the Earhart mystery. To all those named above, and any I may have inadvertently omitted, I am deeply grateful for your help. I, of course, bear ultimate responsibility for the content of the paper.

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