TIGHAR TRACKS

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... that they might escape the teeth of time and the hands of mistaken zeal.
— JOHN AUBREY
STONEHENGE MANUSCRIPTS
1660

ON THE COVER

British Colonial Service Cadet Officer Eric R. Bevington. A photo Bevington took during his visit to Gardner Island (now Nikumaroro) in October 1937 may be the best stand-alone piece of evidence of the fate of Amelia Earhart yet discovered. See "The Object Formerly Known As Nessie," page 30.

ON THE WEB

tighar.org

ABOUT TIGHAR

TIGHAR (pronounced "tiger") is the acronym for The International Group for Historic Aircraft Recovery, a non-profit foundation dedicated to promoting responsible aviation archeology and historic preservation. TIGHAR's activities include:

- Compiling and verifying reports of rare and historic aircraft surviving in remote areas.
- Conducting investigations and recovery expeditions in co-operation with museums and collections worldwide.
- Serving as a voice for integrity, responsiblity, and professionalism in the field of aviation historic preservation.

TIGHAR maintains no collection of its own, nor does it engage in the restoration or buying and selling of artifacts. The foundation devotes its resources to the saving of endangered historic aircraft wherever they may be found, and to the education of the international public in the need to preserve the relics of the history of flight.

TIGHAR Tracks is the official publication of The International Group for Historic Aircraft Recovery. A subscription to *TIGHAR Tracks* is included as part of membership in the foundation (minimum donation $55.00 per year). The editors welcome contributions of written material and artwork. Materials should be addressed to: Editors, *TIGHAR Tracks*, 2812 Fawkes Drive, Wilmington, DE 19808 USA; telephone (302) 994-4410, fax (302) 994-7945; email tigharpat@mac.com. Photographs and artwork will be returned on request.

BOARD OF DIRECTORS

July 3 – 29, 2012

Last summer's expedition to Nikumaroro collected new information about the underwater environment in the area we think holds whatever is left of the Earhart Electra but, although analysis continues, the expedition did not return with conclusive imagery of airplane wreckage. We're still working with video of some as yet unidentified objects that appear to be man-made, but definitive investigation will have to wait until the next expedition.

Of the trips TIGHAR has made to Nikumaroro since our first Earhart Project expedition in 1989, Niku VII was unique in several respects. Niku VII was:

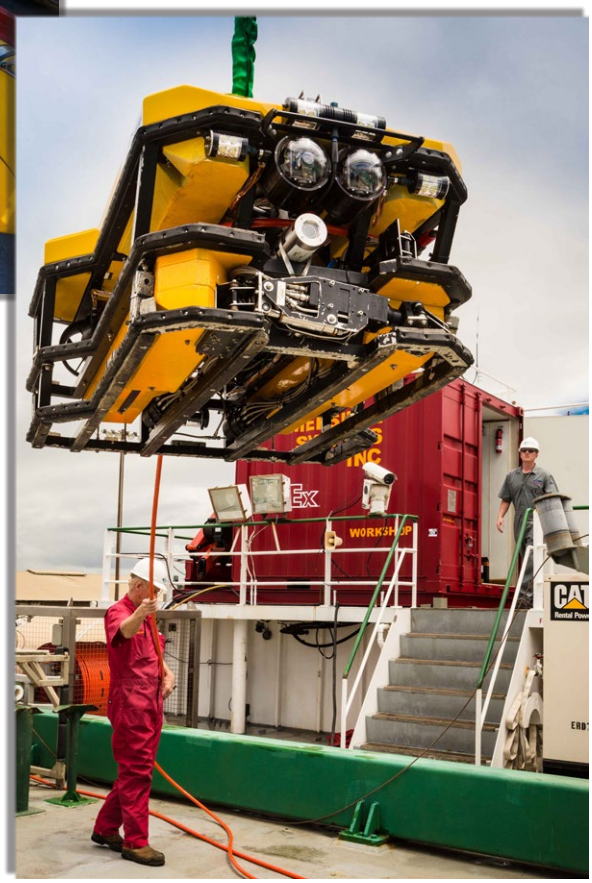
- Organized and launched in the shortest time (four months) of any previous TIGHAR expedition.
- The first TIGHAR expedition for which the timing was dictated by factors other than ship availability and the completion of funding.
- The first TIGHAR expedition devoted solely to underwater search operations.
- The first search conducted entirely by paid contractors rather than TIGHAR volunteers.
- The most technologically complex and expensive ($2,000,000) TIGHAR expedition to date.

Niku VII enjoyed a broad base of support. Corporate sponsors Lockheed Martin, Discovery Communications, and Thursby Software made significant financial contributions but, as with previous TIGHAR expeditions, most of the funding came from individual donations, large and small. Long-time TIGHAR sponsor FedEx provided shipping by air, land and sea for many tons of sophisticated search equipment to and from Honolulu. GeoEye Foundation provided highly-detailed satellite imaging before and during the expedition.

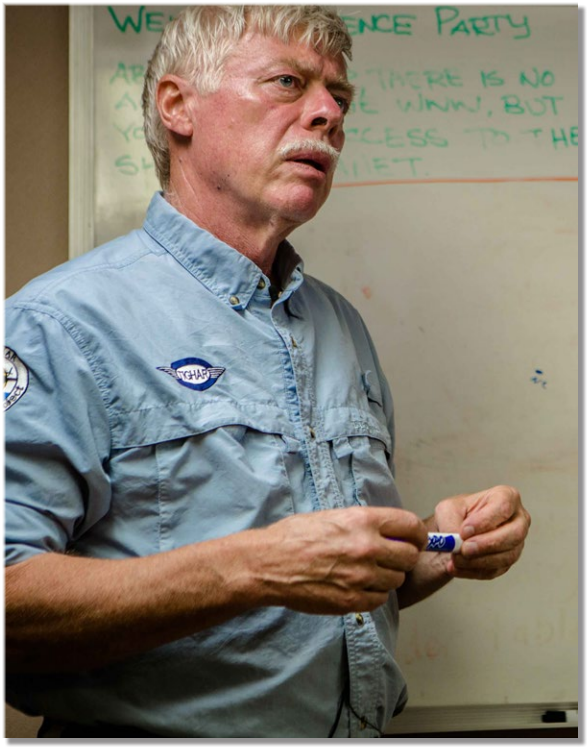
The plan for Niku VII was to use an array of state-of-the-art technologies to conduct a comprehensive search for the wreckage of the Earhart Electra in the deep water off the west end of Nikuamoro. The expedition was to sail from Honolulu on July 2, the 75th anniversary of the Earhart disappearance, for a 26-day expedition – eight days en route to Nikumaroro, 10 days of searching, and eight days back.

The expedition vessel was the University of Hawaii oceanographic research vessel R/V Ka'Imikai-O-Kanaloa *or more commonly "KOK." The ship would map the underwater environment in the search area using its hull-mounted SeaBeam multi-beam sonar. TIGHAR photo by L. Rubin.*

The primary search contractor for Niku VII was Phoenix International of Largo, MD. Five Phoenix technicians, assisted by two technicians from Bluefin Robotics of Quincy, MA would collect side-scan sonar imagery using a Bluefin 21 autonomous underwater vehicle (AUV). TIGHAR photo by L. Rubin.



Targets identified by Phoenix would be investigated by sub-contractor Submersible Systems, Inc. (SSI) using a TRV-M Remote Operated Vehicle (ROV) equipped with a High-Definition video camera provided by Phoenix. TIGHAR photo by L. Rubin.



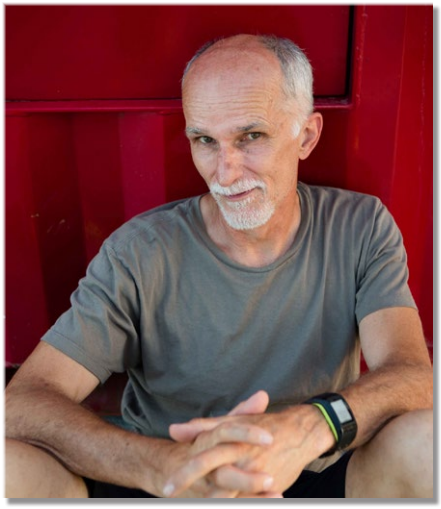
Expedition Leader Ric Gillespie would oversee all search operations. TIGHAR photo by L. Rubin.

TIGHAR Underwater Archaeologist Megan Lickliter Mundon MSc would supervise the archaeological aspects of the search. Megan had been to Nikumaroro before as Artifact Manager on the 2010 Niku VI expedition team. TIGHAR photo by L. Rubin.

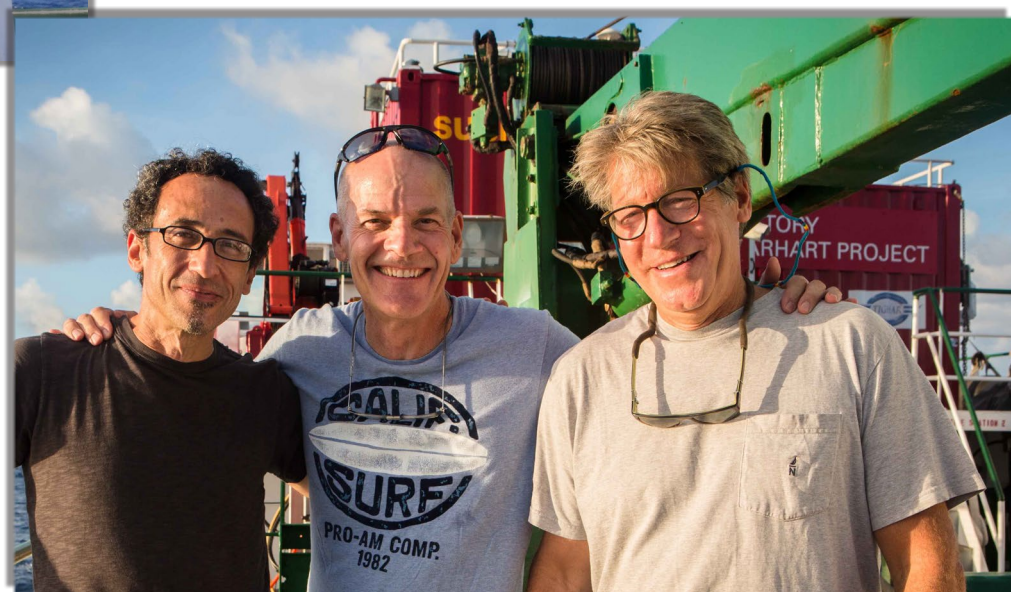
TIGHAR Sponsors Tim Mellon (L) and Andrew Sanger (R) would help monitor search operations. TIGHAR photo by L. Rubin.

Professional photographer Laurie Rubin was a last minute addition to the TIGHAR team. Her photos captured the personalities, the scope and the drama of the expedition. TIGHAR photo by L. Rubin.

Mark Smith of Oh Seven Films was there to provide video documentation for TIGHAR as he had for the past three expeditions to Nikumaroro. He was not there to save the entire underwater video portion of the search – but that's what he ended up doing, TIGHAR photo by L. Rubin.



As with previous trips to Nikumaroro, we were required to have a permit from the Republic of Kiribati to conduct research in the Phoenix Islands Protected Area (PIPA) and bring along a Kiribati Customs agent to stamp our passports and observe our operations. Our Kirabati government representative for Niku VII was Sam Tekiree, Customs Officer for Kiritimati (Christmas Island). TIGHAR photo.



A three-person film crew from the Discovery Channel joined the expedition to shoot and edit video for a documentary that would air soon after our return. L toR: Vin Liota, Don Friedell, and producer Steve Schnee. TIGHAR photo by L. Rubin.

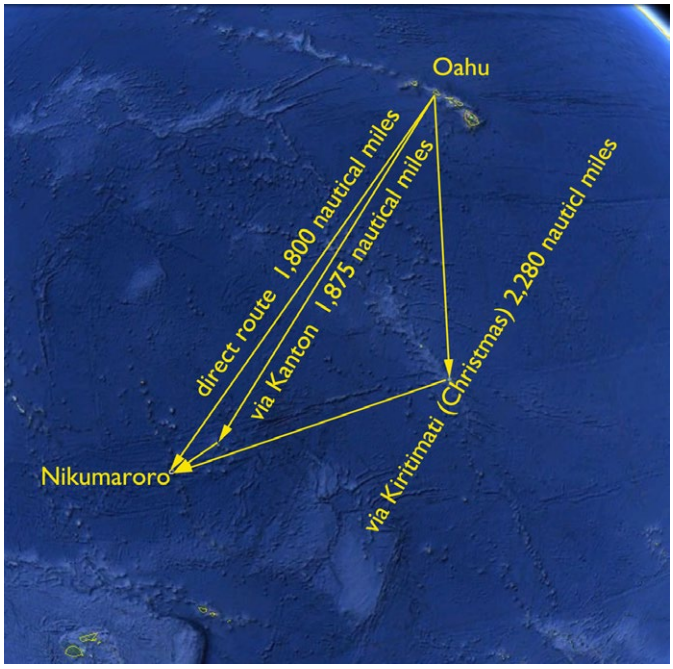
Expedition Leader Ric Gillespie's Personal Journal (excerpts).

Wednesday, June 27

Arrived in Honolulu and came directly to the ship. Tukabu's (Tukabu Teroroko, Director of PIPA) original plan to have a Customs representative from Christmas Island join us in Honolulu has been defeated by the fact that the weekly airline service between Christmas and Honolulu is on Tuesdays and we are scheduled to depart on Monday. The new plan is to have us make a 75 mile diversion to Kanton Island and pick up a Customs representative there. The diversion each way would cost us at least a day of search time.

Thursday, June 28

In Tarawa, Tukabu has learned that his plan to have us pick up a Customs officer at Kanton is not going to work. The Comptroller of Customs informs him that they don't actually have a Customs officer on Kanton. Clearance duties have been outsourced to the policeman on Kanton but he is not authorized to handle Survey & Salvage. Tukabu's new plan is to have us divert to Christmas Island – 480 nautical miles out of our way – to pick up a Customs officer. The diversion would eat up most of our search days but we can't go without a PIPA permit and a Customs officer.



Mark Smith is introduced to Wolfgang Burnside and Malcolm Griffiths of Submersible Systems Inc. (SSI) who are subcontracted to Phoenix for ROV operations. Mark and Wolfgang set up a test to prove the workflow from recording through offloading camera files and soon discover that the HD camera system as delivered does not work.

TIGHAR cameraman Mark Smith and ROV pilot Wolfgang Burnside with the High-Definition video camera. "Somehow we have to get this thing working." TIGHAR photo by L. Rubin.

The HD camera to be used on the expedition has been rented by Phoenix. Wolfgang has seen the manual but he had never seen the camera until he arrived in Hawaii. From reading the manual, Wolfgang knew he was going to have to splice a connector for the camera into the ROV tether. This will create a potential weak spot in the tether at depth but it's the only way to connect the camera. What Wolfgang didn't know was that there is a fundamental mismatch between the camera's capabilities and the ROV system with which it is to be used. The camera will not be controllable from the surface and it might not be possible to trigger HD recording at all. This is a major crisis. There is no point in conducting the expedition without an operational HD camera system. With departure scheduled for the morning of July 2, we have three days to get it working.

Friday, June 29

While Mark is trying to come up with a solution to the HD camera impasse, Wolfgang is having problems getting his ROV equipment up and running. The ship's electrical power is too "dirty" (not steady enough). KOK tries to clean up the output by installing a motorized generator (MG-50) between the ship's generator and the ROV system.

It is apparent to me that the only way to solve the Kiribati Customs problem is to delay the departure of the expedition one day so a representative can make the Tuesday flight from Christmas to Honolulu – if the flight is not sold out. Tukabu embraces that solution. The designated representative is Sam Tekiree. I can't buy him a ticket until I get his passport information but Air Pacific will hold a seat for him for 24 hours.

Saturday, June 30

Sam Tekiree emails me his passport information and I buy him a ticket. If the flight is on time he will land at 10:50 a.m. on Tuesday, July 3. We will depart as soon as he clears U.S. Customs and Immigration and is aboard KOK.

More problems with the HD camera. Even if Mark can get it working, we will not be able to get high resolution still photos as we had expected and the quality of the HD video will be marginal at best. It turns out that the camera is merely a consumer-grade Sony HandiCam in a waterproof housing. Its default resolution is 9 megabits per second – at the bottom end of the HD spectrum and totally inadequate for our purposes. The camera can be manually set to 24 megabits per second – barely broadcast quality – but only after it is running. Maximum recording time at this bit rate is about 6 hours. Since we need to trigger recording before the ROV is launched we'll waste some our sub-surface record time getting the sub launched and down to the depth we want to operate in.

Megan, Mark and Wolfgang ponder the problem of how to get the HD underwater video camera working. The whole point of the expedition is to get high definition imagery – and we're two days from departure.TIGHAR photo by L. Rubin.

The MG-50 hasn't solved the "dirty power" problem. The Phoenix and SSI personnel agreed that the only solution is to rent and install a stand-alone generator that will be completely separate from the ship's power, but is such a generator available for rent in Honolulu?

Sunday, July 1

FedEx holds a press event beginning at 9:00 a.m. dockside. Nice tent, good food, podium, lights – well attended by film crews from CNN and local media.

Afterward, news crews are given tours of the ship and do interviews with me and other team members.

A brave face for the media. Lots to worry about – and we haven't even left port. TIGHAR photos by L. Rubin.

A dedicated generator for the ROV is located, arrives, and is lifted aboard. If it doesn't solve the "dirty power" problem it will mean that there is a flaw within the ROV system, but tests indicate that it does solve the problem and it gets welded to the deck.

The addition of a dedicated generator (white unit at right) to the ROV system solved the "dirty power" problem. TIGHAR photo.

By the end of the day, Mark has the HD camera situation to the point where we have a reasonable expectation of it being usable.

Mark Smith with the connector that proved to be the key to making the HD underwater video camera at least marginally operational. TIGHAR photo by L. Rubin.

Monday, July 2

An oddly quiet day while we wait for our Kiribati representative to get here tomorrow. We're glad for the extra time to sort out technical problems, but all of the media events were built around us leaving today so I'm not doing back-to-back interviews like I have been all week.

At noon, the captain moves the ship about a half mile down the channel to the fueling dock to "bunker" for the trip. Local TIGHAR member Lisa Hill comes along for the ride and brings me a bon voyage gift from the TIGHAR forum – a bottle of Benedictine. KOK is a dry boat so it will have to remain unopened until we return.

We take on 46,000 gallons of diesel and are back at the University of Hawaii dock by 17:00.

Tuesday, July 3

At 10:30 I head for the airport to meet Sam's flight. The airport monitors tell me that his plane has landed but after more than an hour of waiting for him to emerge from U.S Customs and Immigration there is still no Sam. Did he miss the flight? Is there some problem with his passport? Is he in there or not? There's no way to tell. Finally, a stout young I-Kiribati man comes out, spots the white hard-hat I told him to look for, and breaks into a big grin. "Mauri Ric!" "Mauri Sam!"

By 14:00 KOK's gangplank is pulled, the lines are let go, and we're on our way.

TIGHAR photo by L. Rubin.

TIGHAR photo by L. Rubin.

For the next week KOK plodded southward at more or less 9 knots. It soon became apparent that the voyage to Nikumaroro was going to take nine days each way instead of eight. Our time on-site would therefore be eight days instead of ten – a 20% loss in anticipated search time. Once we reached our destination we would need to make every minute count. KOK crossed the Equator early on the afternoon of July 10. Arrival at Nikumaroro would be in the wee hours of July 12.

The Kiribati national flag features a frigate bird over the sun rising on the blue Pacific. The TIGHAR burgee has flown on every expedition to Nikumaroro. TIGHAR photo by L. Rubin.

Wednesday, July 11

At sunset I hoist the TIGHAR banner on KOK's starboard halyard. On the port halyard I raise the national flag of Kiribati.

The swallow-tailed TIGHAR flag – technically a "burgee" – bears the old TIGHAR logo in orange on a blue background. It has flown on every TIGHAR expedition to Nikumaroro since our first trip in 1989 and is now a bit tattered. Out of respect, we only fly it now upon departures and arrivals.

1st Day On Site

Thursday, July 12:

- 01:30

  KOK arrived off NW tip of Nikumaroro. Sea calm, scattered clouds, light easterly winds.

- 02:00 to 07:30

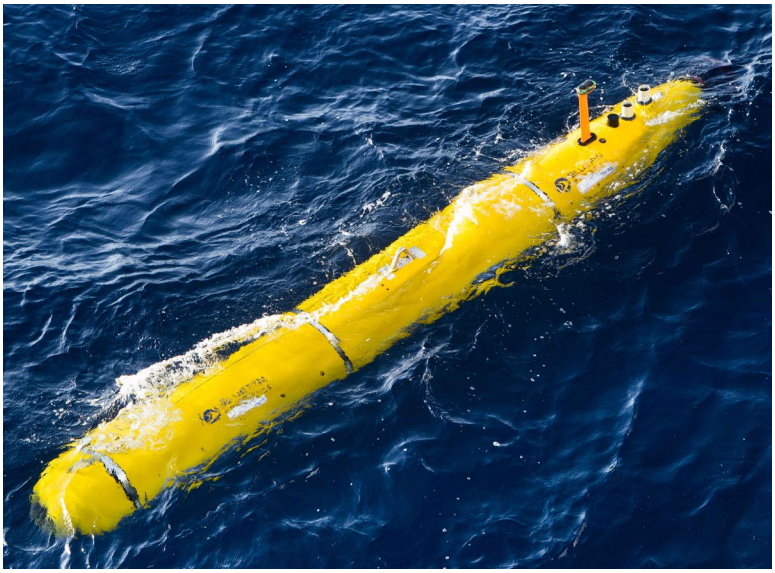
  SeaBeam system collected mapping data in search box and along southern coast of atoll. Mapped all of search box except last line close to reef – to be done in daylight.

- 08:40 to 09:40

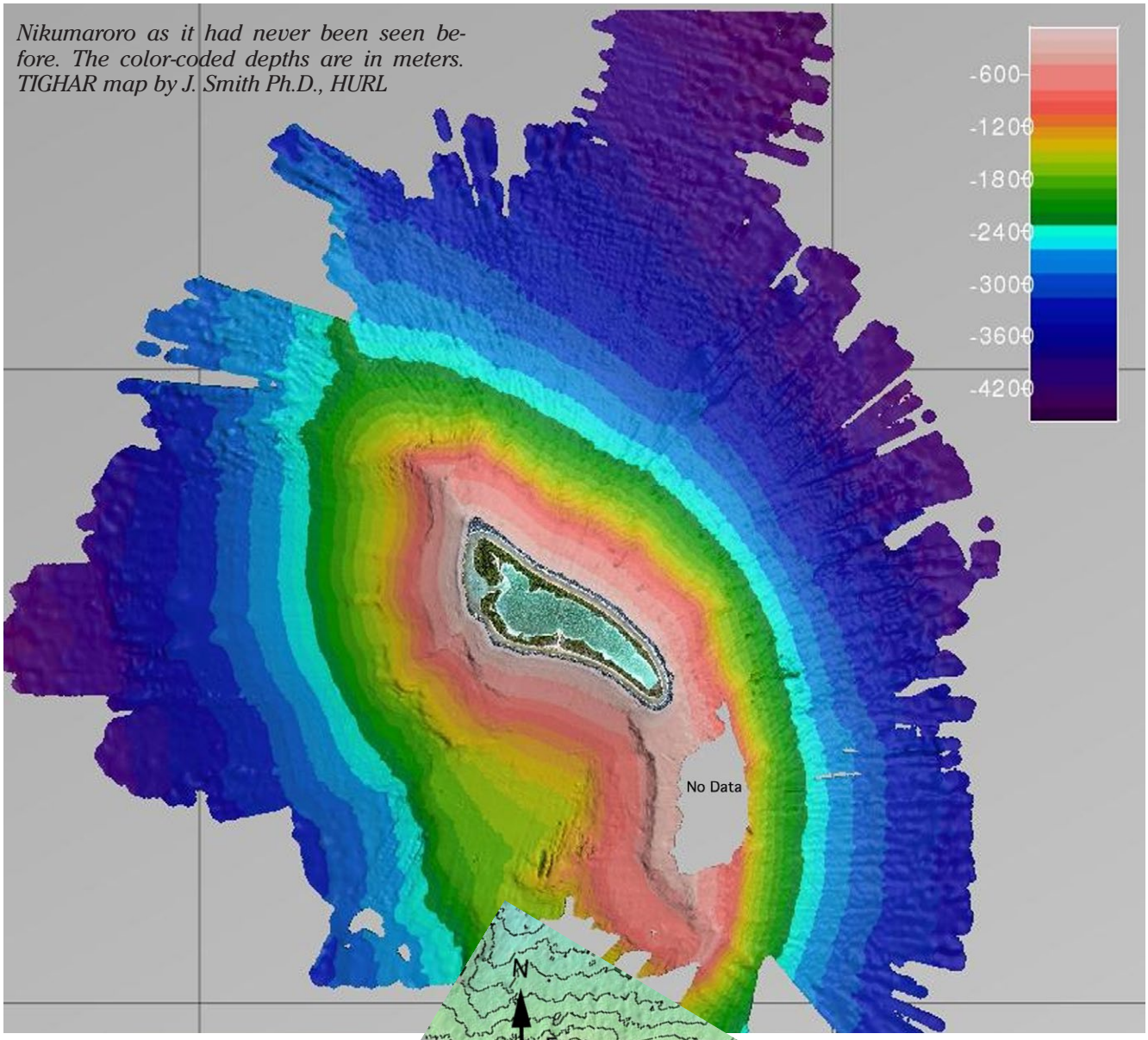
  Launched and ballasted AUV.

- 10:30

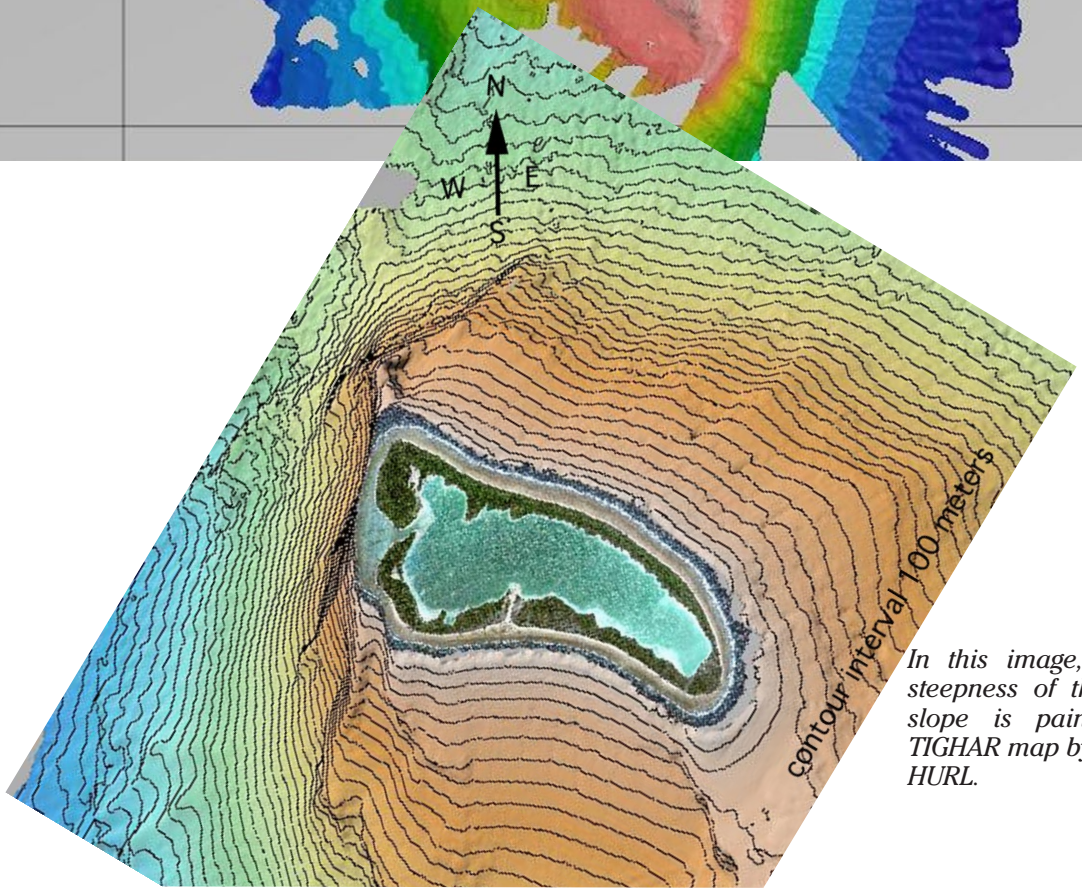
  SeaBeam data processed. Impressive three-dimensional maps of steep reef slope. AUV began its 4-hour initial test run.



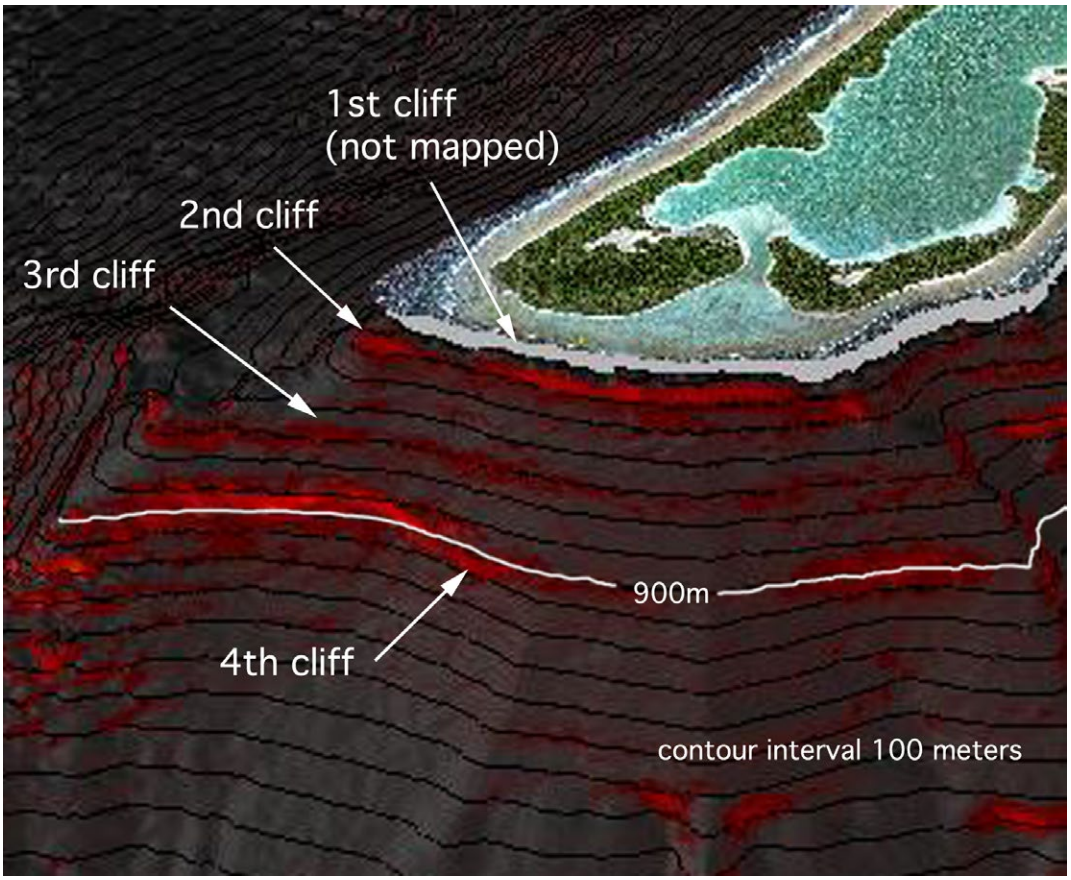
The AUV must be properly balanced and ballasted. TIGHAR photo by L. Rubin.



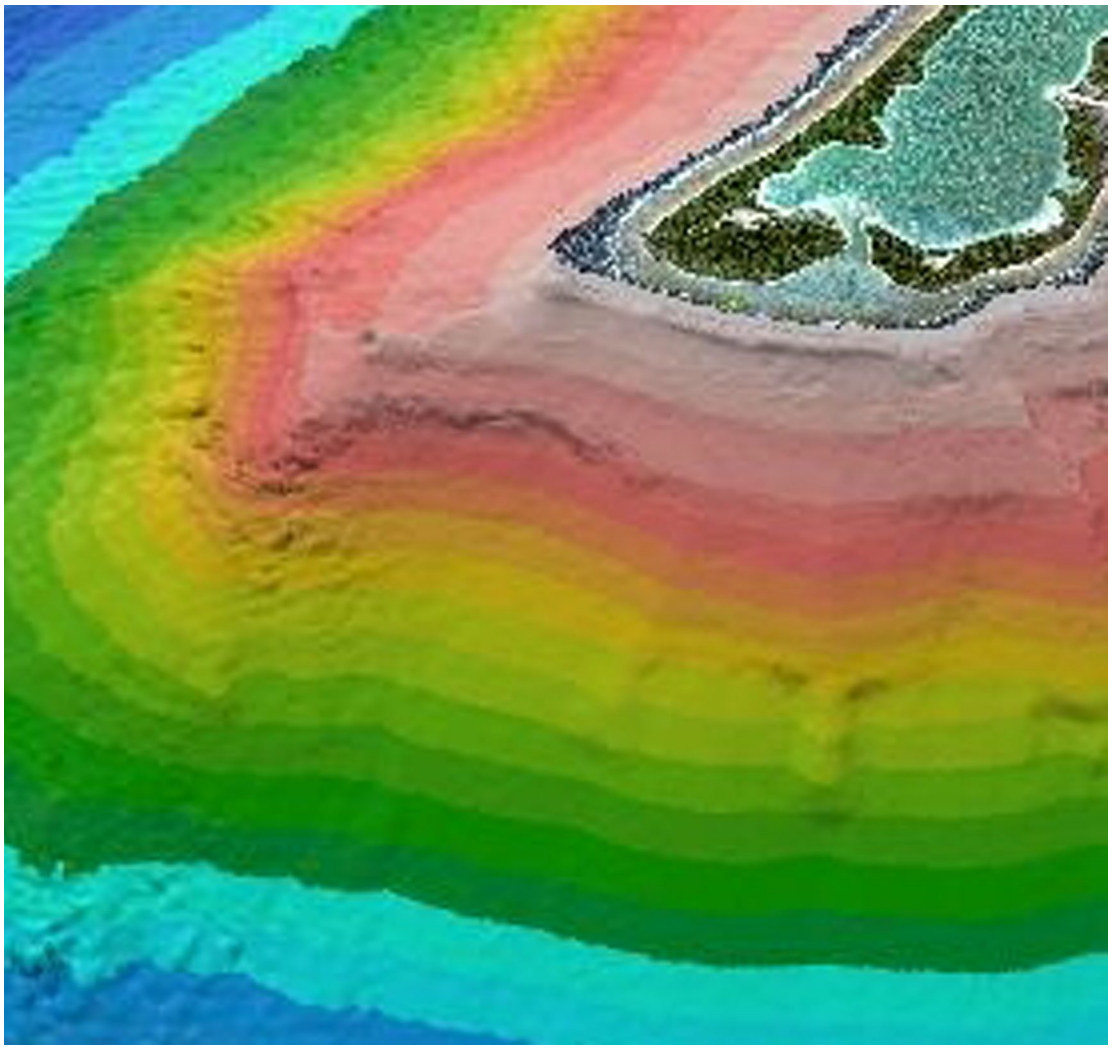
Nikumaroro as it had never been seen before. The color-coded depths are in meters. TIGHAR map by J. Smith Ph.D., HURL



In this image, the staggering steepness of the western reef slope is painfully apparent. TIGHAR map by J. Smith, Ph.D., HURL.



In this image, the red areas indicate extreme "rugosity." Nikumaroro's western reef slope is a series of four virtually vertical cliffs. The first cliff is close to the reef edge in water too shallow to map. The ROV could investigate down to a maximum depth of roughly 900 meters (2,952 feet). TIGHAR map by J. Smith Ph.D., HURL.



Although extremely useful for mapping the daunting underwater landscape, the SeaBeam sonar lacks the resolution necessary to see wreckage. TIGHAR map by J. Smith, Ph.D., HURL.

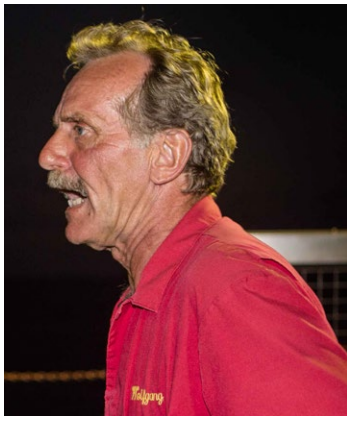
- 11:15
  AUV test run aborted. AUV not behaving as programmed.
- 12:30
  AUV re-programmed for another test run.
- 13:00
  AUV still not working right. Keeps returning to the surface.
- 14:00
  Decision to recover AUV. Suspect problem with propulsion vectoring system. While AUV is back aboard we'll run tests on the ROV.
- 15:00
  AUV is back aboard. Launching ROV for test.
- 16:00
  ROV test to 800 feet. Spotted a target with the ROV's sector-scan sonar, maneuvered to it and identified it with video – piece of *Norwich City* debris roughly two feet long. Excellent proof-of-concept.

The AUV's articulated propulsion system. TIGHAR photo by L. Rubin.

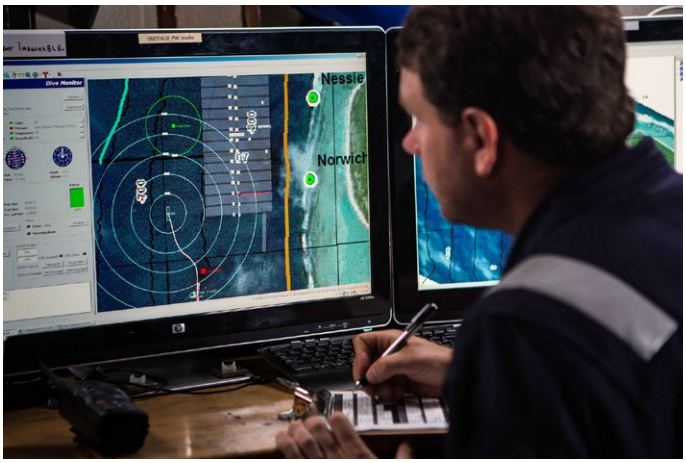
AUV is repaired. Prop was not turning on prop shaft. Ready to deploy on another test as soon as ROV is recovered.

- 16:30
  AUV launched on 4-hour test mission along reef slope. If this mission is successful they'll re-program for a 12-hour all night mission.
- 17:15
  AUV is stuck or hung-up on the reef slope off the mouth of Tatiman Passage at a depth of 1,604 feet. Mobilizing for rescue attempt with the ROV. ROV must be configured for deep mission.
- 20:00
  ROV launched for rescue attempt and begins descent.

Launching the ROV. TIGHAR photo by L. Rubin.



The need to make a deep dive so soon worried Wolfgang Burnside, the ROV pilot. The tether for the ROV had been modified to accommodate the feed for the high-definition video camera and the seal had not had time to properly cure. If the seal failed at depth it would flood and ruin the tether. No tether, no ROV – but with a $2 million dollar AUV needing immediate rescue there was no choice but to deploy the ROV as quickly as possible. (TIGHAR photos by L. Rubin.)



Bluefin Robotics technician Will O'Halloran watches the navigation screen as the ROV tries to rescue the hung-up AUV. TIGHAR photo by L. Rubin.

- 20:30 to 21:30
  ROV unable to locate stuck AUV but, in the process of searching, the ROV's tether apparently knocked the AUV loose and it appeared on the surface.
- 23:00
  AUV and ROV recovered aboard.

End of Day Assessment

- SeaBeam system provides good general picture of reef morphology. No surprises so far. The sonar map confirms what we already knew. The reef slope is extremely steep. The 3-D graphics are spectacular but, as expected, not detailed enough to guide actual search operations.
- ROV appears to be an effective tool for searching a closely defined area.
- AUV, based on today's operations, is not an appropriate search tool for this environment. Final decision tomorrow.

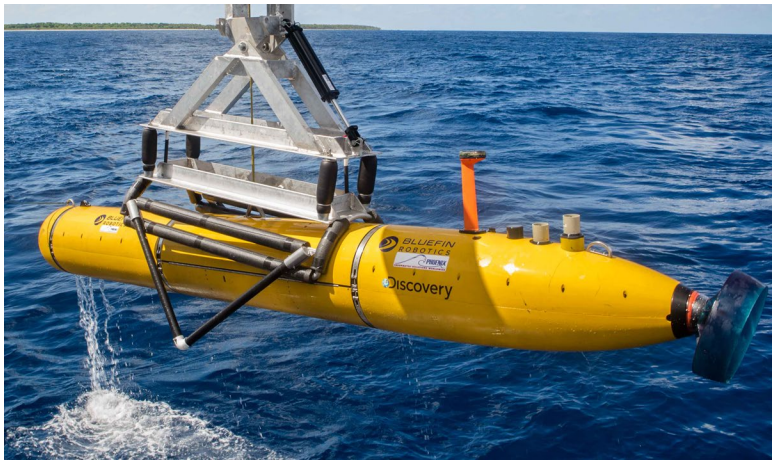
2nd Day On Site

Friday, July 13

Objective:

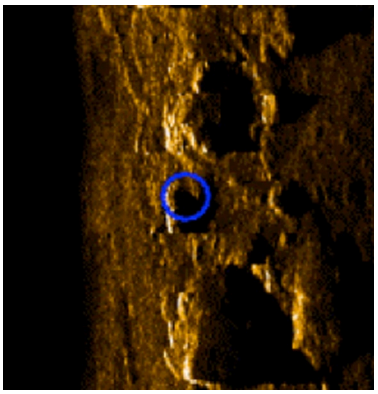
If AUV not operational by end of day, switch to ROV as primary search tool.

- 08:00
  AUV launched for 1-hour test run.
- 09:00
  Test run successful. AUV re-programmed for 4-hour data collection run up and down reef slope.
- 10:30
  After successful downhill run, AUV turned around to begin uphill run and collided with an underwater obstacle (probably the cliff face). Loss of communication for 15 minutes triggered automatic emergency ascent by jettisoning a 20 lb. weight.
- 12:00
  AUV reached the surface and was recovered.



As the wayward AUV is recovered, water drains from where the emergency ascent weight was jettisoned. TIGHAR photo by L. Rubin.

- 12:30
  Discovered that collision impact had cracked one of the lithium battery housings allowing water to enter the battery. Damaged battery smoking heavily and shorting out the rest of the system. Damaged battery removed. Ship's fire-fighting crew alerted in case of lithium spill and fire. No spill. No fire. No serious damage to the AUV.
- 14:15
  Sonar data collected during aborted mission analyzed. Good imagery. "Targets" are put in one of three categories:
  Category 1 targets are really good.
  Category 2 targets could be man-made objects and are worth checking out.
  Category 3 targets are probably natural objects but might be worth checking out.
  The aborted run produced one "strong 2" target. Anomalous object roughly 2 x 6 m with one sharp right angle corner.



The blue circle designates side-scan sonar target 14_0048. Categorized by Phoenix as a "strong 2" – anomalous object, possibly man-made, roughly 2 x 6 meters with one sharp right-angle corner, this target was at a depth of 520 meters (1,705 feet) and directly offshore the Bevington Object location.

Expect to launch in one hour for all night mission. AUV will collect data only on downhill run, then will ascend vertically to 150 m depth and run downhill again. Assuming that this "Ski Resort" tactic works, we agreed on a plan for the AUV to run at night and the ROV to run during the day. Phoenix will concentrate on AUV ops. I will supervise ROV ops.

- 16:00

  Still working on AUV. Now estimate launch in two hours.

  The last line of SeaBeam mapping – the line closest to the reef edge – has now been run.

- 18:30

  AUV launched and seems to be functioning normally.

- 21:00

  AUV is running its programmed mission and collecting side-scan sonar data. Plan is to collect data throughout the night. In the morning we'll recover the AUV, download the data for processing, and launch the ROV to begin the visual survey of the reef slope.

End of Day Assessment

Initial indications are that the Ski Resort tactic for deploying the AUV is working.

3rd Day On Site

Saturday, July 14

Objectives:

- Process collected side-scan data to identify and categorize potential targets.
- Begin visual reef slope search with ROV.

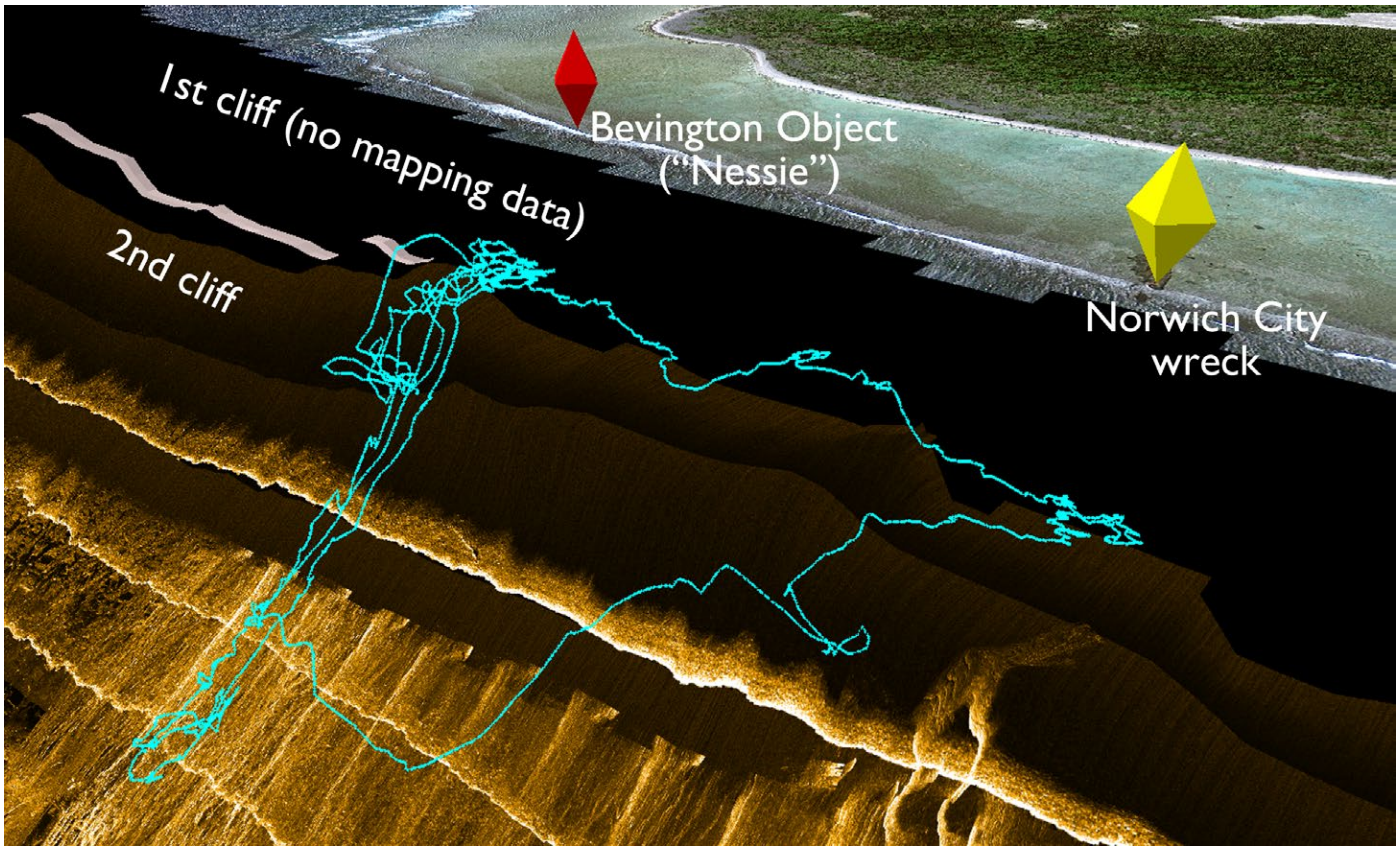
- 08:00

  Recovered AUV after successful all-night mission. Covered northern half of primary search area at depths of 400 meters (1,312 feet) down to 1,000 meters (3,280 feet). Data downloaded for processing.

- 09:45

  Launched ROV for six-hour search mission. Pilot Wolfgang Burnside. Observer Ric Gillespie. Immediately offshore the reef edge in the primary search area the reef slope drops away in an essentially vertical cliff hundreds of feet tall. Coral outcroppings on the steep slope tend to snare the ROV tether, forcing the pilot to back-track to free the snare. Further out and deeper, the slope moderates somewhat. Except for some *Norwich City* debris, no man-made objects were seen today in two 60-foot search swaths from 21 meters (70 feet) down to 365 meters (1,200 feet). There are, however, many flat coral surfaces with right angle corners resulting in numerous false alarms.

In this schematic of ROV Dive 3 on July 14, 2012 the yellow pyramid marks the shipwreck on the reef and the red pyramid marks where the Bevington Object appears in the 1937 photo. The blue line is the track ("snail trail") of the ROV against the brown side-scan sonar map of the reef slope. HURL Graphic by J. Smith, Ph.D.



- 15:45

  Recovered ROV.

  The AUV side-scan data have been processed and evaluated. No Category 1 targets were detected in last night's data but we have 14 Category 2s and a similar number of 3s.

- 17:45

  Launched ROV for second mission but immediately after deployment and while the ROV was still close to the ship, the generator powering the entire ROV system failed causing a blackout of all propulsion, video and positioning telemetry. There was great concern that the ROV tether might run afoul of the ship's propellers before power could be restored, but the ship maneuvered clear of the tether and the ROV was soon recovered safely aboard. Today's second mission was cancelled and the generator problem is currently being addressed.

- 19:30

  The AUV was launched for an all-night side-scan mission to cover the southern half of the primary search area at depths similar to last night and will then try to cover some of the shallower, more hazardous, portions of the northern half.

- 21:30

  At last report the AUV was running well.

End of Day Assessment

Objectives accomplished. A good first day of search operations.

Biggest concern is to get the generator problem correctly diagnosed and fixed.

4th Day On Site

Sunday, July 15

Objective:

Continue search operations

- 08:00

  The problem with the generator appears to have been a dirty fuel filter. The filter has been cleaned and the generator is working fine.

- 09:00

  AUV has completed its all-night mission and been recovered. Now downloading data and recharging the navigation beacon before installing it on the ROV. We only have one beacon operational and it must do double duty on both the AUV and ROV.

Phoenix technician Jesse Doren with the SonarDyne acoustic positioning beacon that had to be transferred back and forth between the AUV and the ROV. TIGHAR photo by L. Rubin.

- 10:30

  ROV launched for "ground-truthing" mission. "Esmerelda," as Wolfgang calls her, will examine several targets identified in the side-scan imagery collected by the AUV. The first target is at 520 meters (1,705 feet). At that depth the reef slope is an undulating, barren mountainside with a light dusting of snow (coral "talus" drifting down from above). The target turned out to be car-sized hunk of coral with one flat side that produced a strong sonar return.

Searching the reef slope at depths below about 300 meters (984 feet) is like exploring a rugged mountain side with a flashlight on a dark night in a snow storm. TIGHAR screen capture from HD video.

- 13:00

  Two more targets have been found and inspected. Both were coral boulders. New mission: Start due west of the *Norwich City* wreck at a depth of 400 meters and track eastward up the slope looking for the main body of wreckage from the aft half of the ship. The freighter struck the reef on the night of November 29, 1929. The front half of the ship went firmly aground. The rear half stuck out over the reef edge until the first week of January, 1939 when the ship broke in two in a storm

and the stern tumbled down the reef slope. We had always wondered how deep the main body of ship wreckage had gone because airplane wreckage seems unlikely to have gone deeper. A search to 150 meters (492 feet) in 2010 using a small ROV revealed only some scattered ship debris on the steep slope. Today we discovered the aft half of the ship – an enormous pile of twisted wreckage – at a depth of 330 meters (1,082 feet), over 600 meters (nearly 2,000 feet) seaward from the reef edge where it started.

- 15:15

Another AUV-acquired target just north of the wreckage proved to be a heavy metal hatch, almost certainly *Norwich City* debris but reassuring in that at least it wasn't a rock. Less encouraging was the realization that the AUV had not seen the far larger main body of wreckage.

- 17:00

ROV recovered and navigation beacon removed for recharging and installation on AUV.

- 19:00

AUV launched for another all-night mission, part of which is to re-fly the near-shore areas to get better data.

The plan for tomorrow is to resume running search lines with the ROV up and down the reef slope in the primary search area, examining AUV-acquired targets along the way.

- 20:30

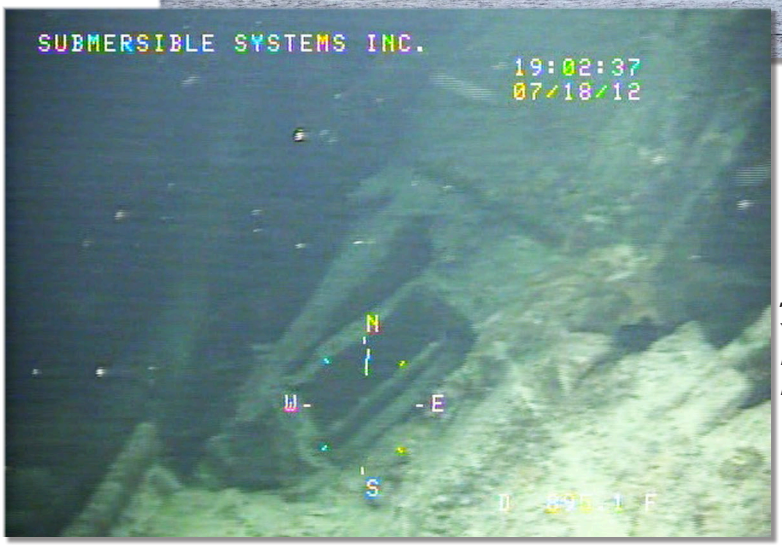
At last report AUV running well.

End of Day Assessment

All the equipment is working and the weather is holding good. A productive day but too much time spent chasing scattered targets. Incorporating ROV target-checking with mow-the-lawn coverage of the primary search area will be more efficient.

This 1935 photo is the earliest known picture of SS Norwich City *aground on the reef. The stern half of the ship, aft of the funnel, broke off and tumbled down the reef slope in 1939. TIGHAR collection.*

SS Norwich City *in 2012. The triple-expansion steam engine with protruding shaft was below the funnel in the 1935 photo.*



Some of the wreckage of the stern half of SS Norwich City. *Category 2 targets were turning out to be mostly coral boulders, and the problem-plagued AUV had failed to see a towering mass of ship wreckage. TIGHAR screen capture from ROV video.*

5th Day On Site

Monday, July 16

- 08:30

  AUV back aboard. During the night it flew into the bottom on a down-slope run and shattered the nose cone but kept going and collected good data. Will replace with spare. Beacon removed and being recharged for installation on ROV.

- 10:30

  Launched ROV after several technical delays.

- 10:45

  Aborted ROV mission. Intermittent outage on HD camera. Will recover and change to spare camera.

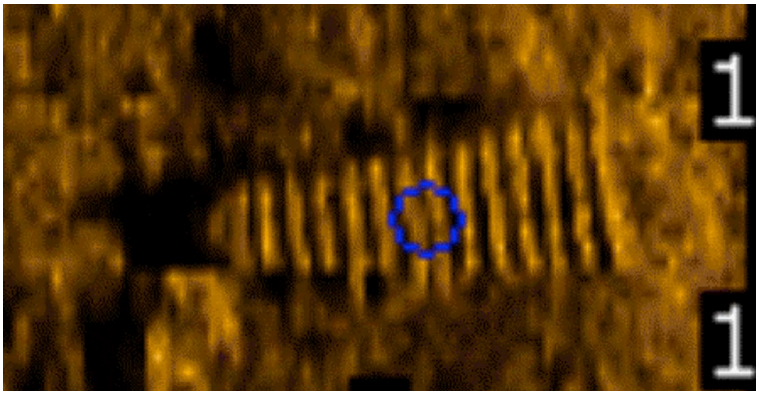
- 11:30

  Ready to re-deploy ROV but ship's throttles on the "doghouse" (aft control station used to maneuver ship during ROV operations) are not working correctly. Delay while that problem is addressed.

Last night's AUV sonar data has been partially processed. Main body of *Norwich City* wreckage shows up clearly. The problem the night before was the angle at which the sonar was looking at the wreckage. Sonar is like that. It reads the reflections of sound off objects. An irregularly shaped object will reflect sound differently from different angles.

Sonar data from last night revealed a target of special interest (strong Category 2 or maybe even 1.5). We're eager to check it out as soon as the ROV can go back in the water.

The target is a series of 12 parallel lines similar in shape and dimensions to an Electra outer wing panel. The AUV passed over it from several angles and the returns are consistent. Sonar often cannot see aluminum skin but picks up internal structure. There are twelve ribs in an Electra outer wing panel.



The target of special interest soon became known as the "wing target." TIGHAR sonar image by Phoenix International.

Initial plot of the target's position put it in 400 feet of water slightly north of *Norwich City*. We couldn't find it there. Refined plot put it at 1,000 foot depth roughly 10 meters southwest of the main body of NC wreckage. This is an extremely hazardous environment for the ROV with great danger of tether entanglement in the heap of ship wreckage. Also, increasing wind and sea conditions made *KOK* less stable. After struggling for two hours we ultimately called it off and returned to running search lines. We'll try again tomorrow.

- 13:25

  Ship throttle problem fixed. ROV launched. New mission is to check out the interesting new target.

- 14:15

  Lots of fishing line and tangled nets hung up on coral outcroppings on near-vertical sections of the reef slope.

- 16:30

  After repeated attempts in a hazardous environment for the ROV (danger of tether entanglement on underwater obstructions) we were not able to locate the target. We'll try again tomorrow.

- 16:40

  Examined and photographed tangled strip of black material at 1,100 feet. Appears to be man-made, possibly a gasket from around a hatch or door. Did not recover but feel we can find it again if necessary.

Found at a depth of 319 meters (1,046 feet), this object was later matched to sealing material of a type in use aboard KOK. TIGHAR screen capture from HD video.

- 17:30

  Recovered ROV.

- 21:00

  AUV launched. Tonight's mission is to collect more data on the interesting target and fill in gaps in previous data runs.

End of Day Assessment

Frustrating day. Lost the entire morning to mechanical issues. It's good to have an interesting target to examine but we still don't know what it is. There are three days of searching left.

6th Day On Site

Tuesday, July 17

Objectives:

Find and examine the "1.5" target with ROV; continue search lines

- 07:00

AUV was hung-up underwater for four hours last night. Freed itself and continued mission but got stuck again as it was ascending for recovery. Depth 722 meters (2,368 feet) west of the island's NW tip.

Option 1:

Leave the AUV where it is for now, go search for target with ROV and come back this evening to recover AUV with ROV if it hasn't freed itself by then.

Risks to Option 1:

- The good navigation beacon is on the AUV so we would have to do the target search using the marginal navigation beacon.
- If the AUV frees itself during the day and comes to the surface and they lose radio contact with it, we could end up searching for it visually. Not good.

Option 2:

Immediately go after the AUV with the ROV.

Risks to Option 2:

- ROV will have to use the marginal navigation beacon – but that is also true of Option 1.
- 722 meter (2,368 feet) depth is near maximum for ROV.

- 8:30

Decision to go for Option 2. Preparing ROV for rescue mission. We'll lose the morning for search operations but we'll run the ROV into the night if need be.

- 11:30

Rescue mission successful – but it was a real cliff-hanger. Operating literally at the end of our tether, we searched for over an hour in nightmare terrain. Vertical cliff face pockmarked with caves and covered with fern-like marine growth. Finally came across the AUV wedged cross-wise (parallel parked) in a narrow cave. Wolfgang flew in and used the claw to gently grab a handle near the stern of the fish. He then pulled the AUV out of the cave and well clear of the cliff face before releasing it to float to the surface. Once the ROV and AUV are recovered aboard, we'll reposition and try again to find yesterday's promising sonar target.

- 12:30

Hard throttle usage keeping the ship in position during the AUV rescue caused a propulsion system control failure that will take 6 to 7 hours to repair. We just lost the afternoon. Considering

The AUV was found stuck in a cave on the face of the 3rd cliff. Actual depth was 716 meters (2,349 feet). TIGHAR screen capture from ROV video.

the possibility of using this hiatus to go ashore for a few hours. Tide is currently low but rising. Now moving the ship south to check out the landing channel.

- 14:00

TIGHAR cameraman Mark Smith and I go with ship's bosun in skiff to check landing channel conditions. Mid-tide on a rising tide with a moderate swell. Landing conditions not great but acceptable. We'll ferry ashore anyone who wants to spend a few hours on the island. Roughly 25 people availed themselves of the opportunity.

Tourists. TIGHAR photo by L. Rubin.

- 18:30

All tourists back aboard safely. Everyone was impressed with the island's beauty.

This was a good break from the tension of underwater operations

- 19:00

Ship's propulsion system problems have been repaired and are being tested tonight. We'll resume ROV search operations at 08:00 tomorrow with a dive to locate and examine the promising target we couldn't find yesterday. Analysis of last night's AUV side-scan data shows yet another "strong Category 2" target in a different location. With luck, we'll find and identify them both tomorrow. If neither turns out to be aircraft debris we'll resume "mowing the lawn" in the primary target area.

Tour Guide. TIGHAR photo by L. Rubin.

End of Day Assessment

Lost day due to need to rescue the AUV and then repair the ship's propulsion control system but it was good to get people ashore for a few hours.

7th Day On Site

Wednesday, July 18

Objectives:

Find and investigate two "strong Category 2" targets.

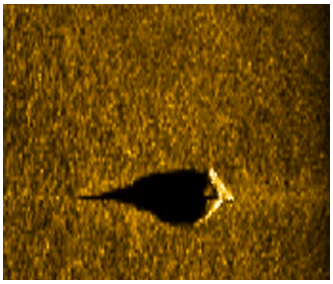
Continue mowing the lawn.

- 08:30

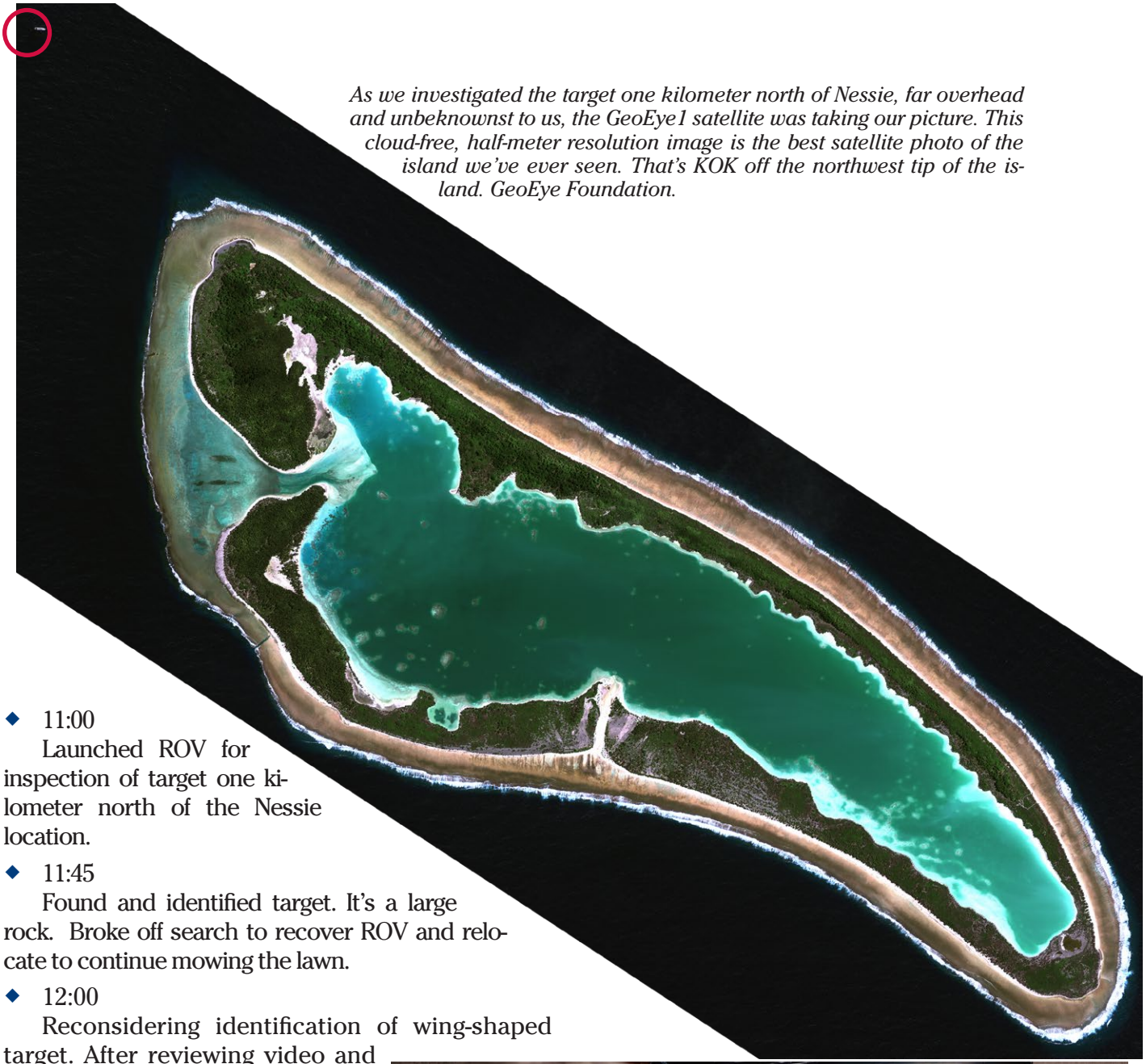
Launched ROV for inspection of wing-shaped target in among known *Norwich City* wreckage.

- 10:00

Found section of *Norwich City* wreckage that Phoenix decided was the wing-shaped target. Broke off search to recover ROV and move to second target.



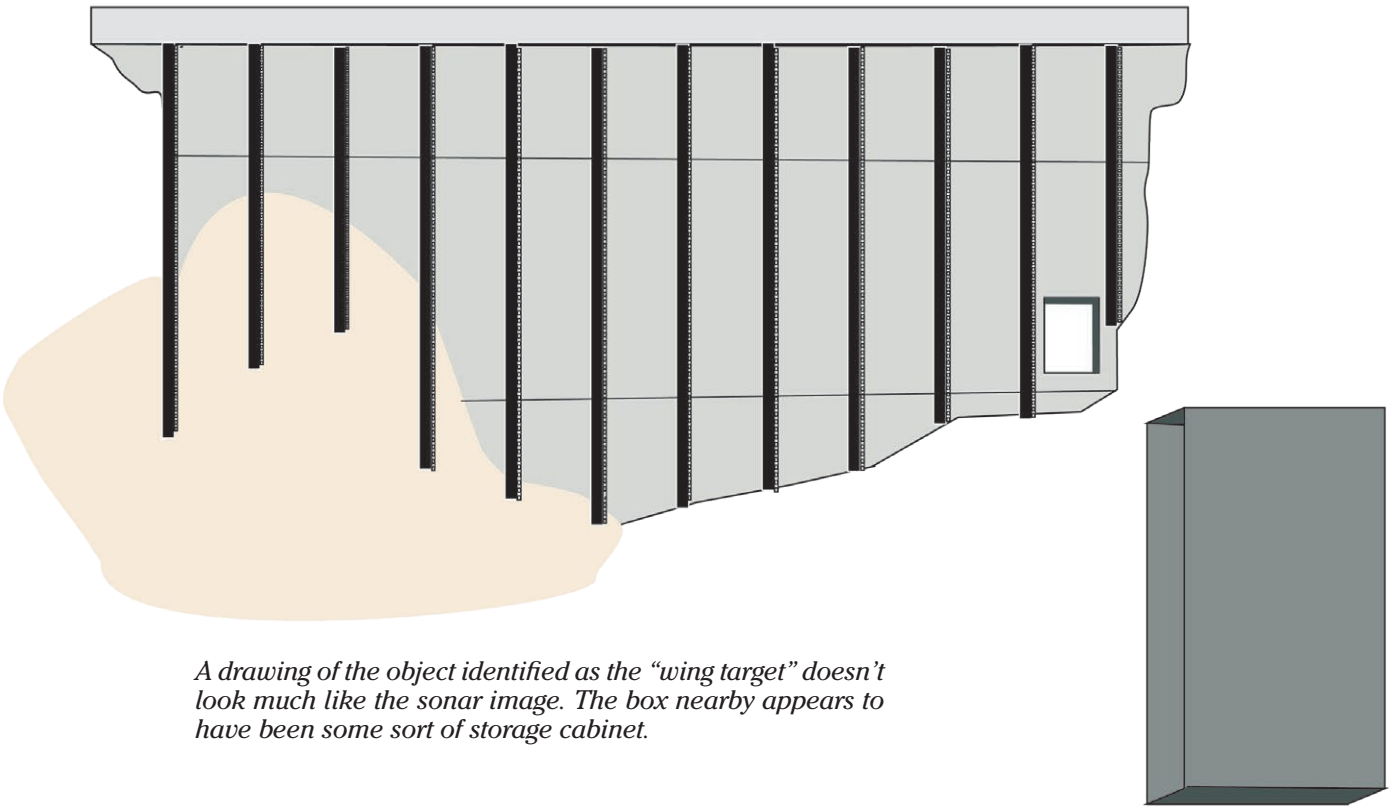
We called this sonar target "the TeePee." It was all by itself on a fairly level plain far to north of our primary search area. Phoenix felt there was a high probability that it was a man-made object. It's a rock. TIGHAR sonar image by Phoenix International.



As we investigated the target one kilometer north of Nessie, far overhead and unbeknownst to us, the GeoEye1 satellite was taking our picture. This cloud-free, half-meter resolution image is the best satellite photo of the island we've ever seen. That's KOK off the northwest tip of the island. GeoEye Foundation.

- 11:00
  Launched ROV for inspection of target one kilometer north of the Nessie location.
- 11:45
  Found and identified target. It's a large rock. Broke off search to recover ROV and relocate to continue mowing the lawn.
- 12:00
  Reconsidering identification of wing-shaped target. After reviewing video and comparing to sonar target, we disagree with Phoenix. We don't think we found the target. We will go back and try again.

Tim Mellon watches the video monitors from the ROV as it inspects the "wing target." TIGHAR photo by L. Rubin.



A drawing of the object identified as the "wing target" doesn't look much like the sonar image. The box nearby appears to have been some sort of storage cabinet.

- 13:30

Launched ROV over *Norwich City* wreckage for third attempt to locate and identify the wing-shaped target.

- 15:00

Conclusive identification of wing-shaped target. It is not the feature identified by Phoenix but it is a section of *Norwich City* wreckage. Recovered ROV.

- 16:00

Launched ROV to continue mowing the lawn in the primary search area.

- 18:30

Recovered ROV after completing two lines – 1,200 to 600 feet. We only go up the hill because it's hard to see the surface going downhill. We are not searching the vertical cliff that goes from 600 feet up to 250 feet.

- 20:00

Launched AUV for all-night mission to re-survey the primary search area and collect side-scan data south of *Norwich City*.

End of Day Assessment

Both targets found and identified.

Two more search lines run.

8th Day On Site

Thursday, July 19 – Last Day

Objective:

Continue search operations

- 04:00

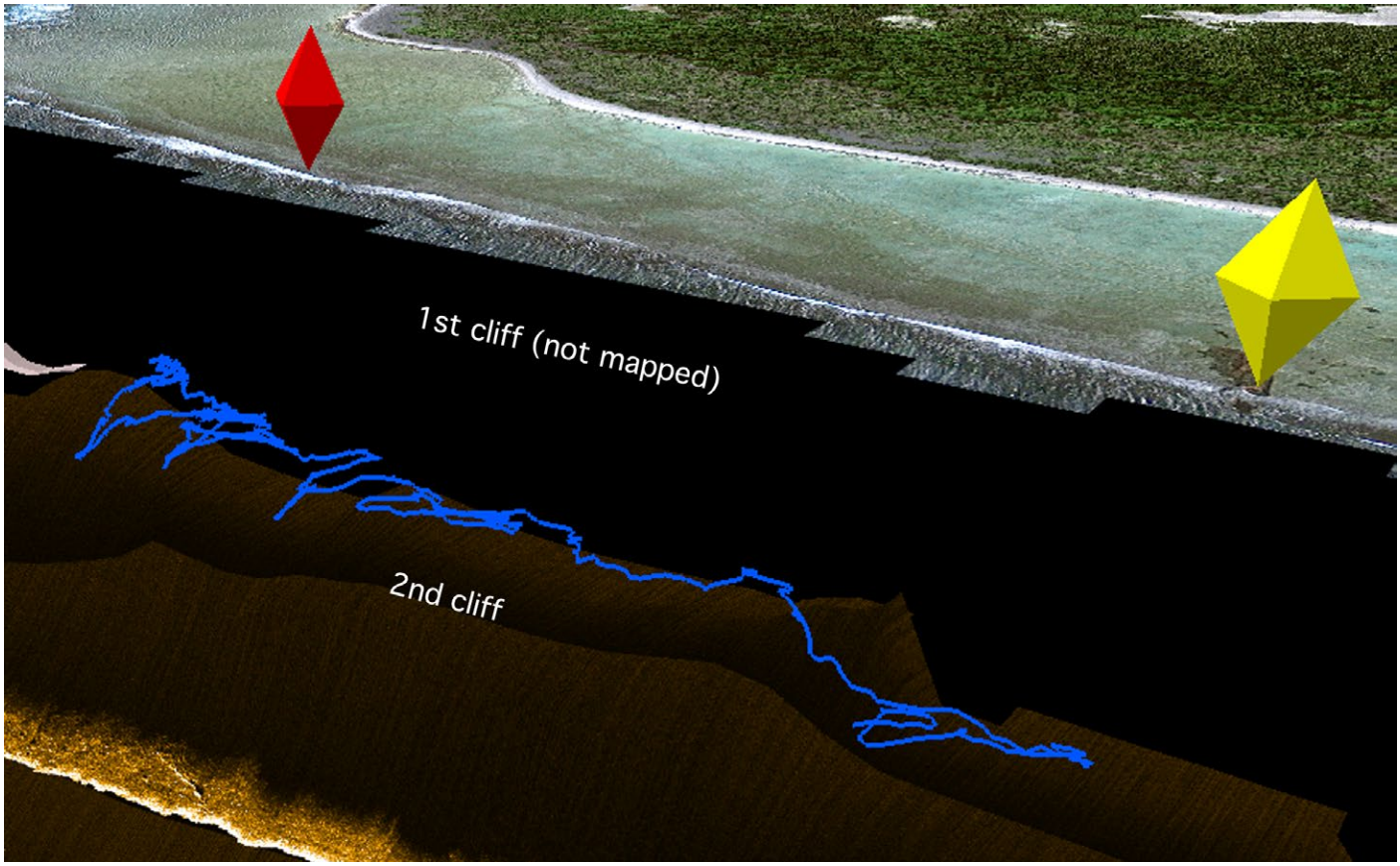
AUV finished search box south of *Norwich City*. Covered area almost to landing channel. Returned to the surface for re-programming for next mission. Phoenix unable to communicate with AUV for re-programming. AUV too close to the reef for *KOK* to execute recovery. Captain mustered all hands. Launched skiff to secure AUV and bring it out far enough from the reef for *KOK* to do recovery. AUV successfully recovered. The Captain is less than thrilled.

- 08:00

Amended ROV search technique for more efficient use of remaining time. "Mowing the lawn" by running lines west to east up the reef face from 368 meters (1200 feet) to 61 meters (200 feet) wastes time because most of the slope is too steep for anything to rest on. Better to search north to south at depths where the reef slope is mild enough for wreckage to stop descending.

- 08:30

Launched ROV for surface test run. Camera crew filmed from skiff.



ROV Dive 13 explored a relatively level area at the base of the first cliff.

- 10:30

Launched ROV for detailed inspection of intermittent ledges and "catchment" areas at base of first cliff – depth 61 to 91 meters (200 to 300 feet) – from Nessie south to *Norwich City.*

- 13:30

ROV recovered. Terrain in area covered was uneven and strewn with large coral boulders. Base of cliff undercut in several places forming large shallow caves. Ledges at base of cliff vary in width to a maximum of 30 meters (100 feet). Many coral plates with square edges. Numerous false targets. No man-made objects seen. Beyond the ledge, the reef slope drops at an estimated angle of 50° to 70°. In some areas, such as at main *Norwich City* wreckage site, slope moderates somewhat at depth of 305 meters (1,000 feet).

- 14:00

AUV data from last night processed. No targets of interest detected.

- 15:30

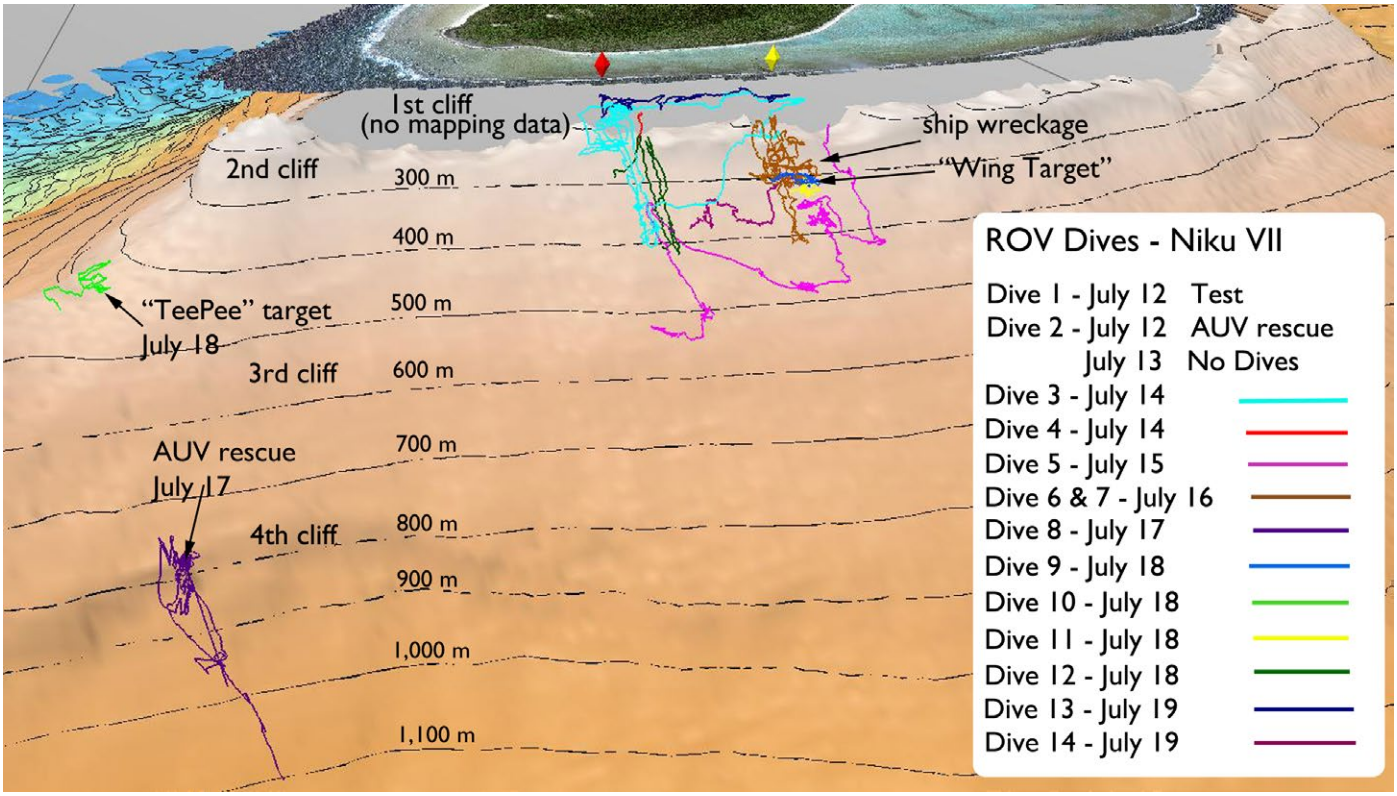
Launched ROV for inspection of reef slope from Nessie south to *Norwich City* at 305 meter (1,000 feet) depth.

- 17:19

Recovered ROV. Very little moderation in slope steepness along line until vicinity of *Norwich City* wreckage. Many coral plates with square edges. Numerous false targets. Fishnet/rope tangle on slope face at 900 feet at 274 meters just north of *Norwich City* wreck.

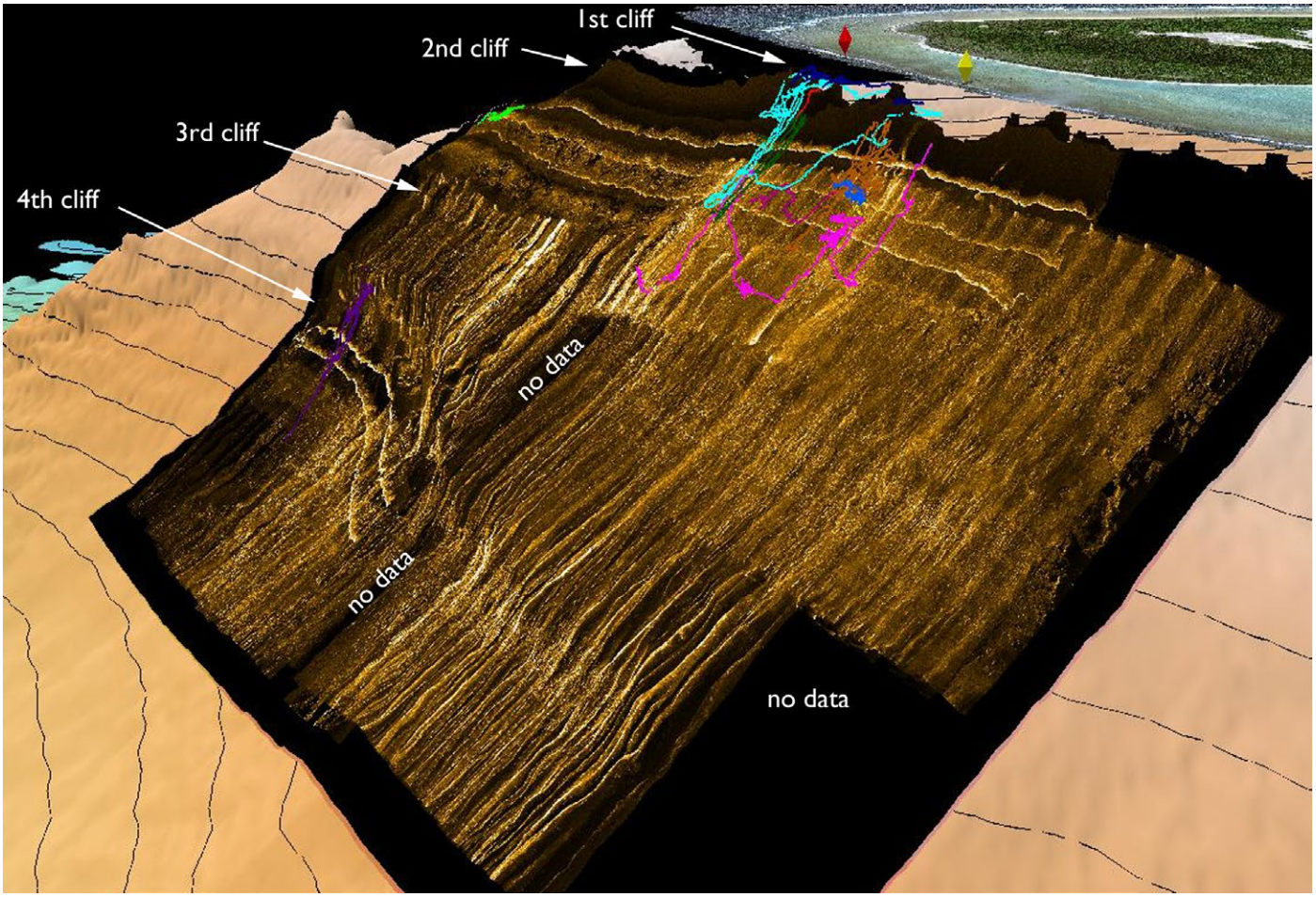
- 20:00

KOK collecting SeaBeam mapping data off southern side of island to fill gaps in data collected earlier. When complete we'll begin voyage back to Honolulu.



The color-coded lines trace the "snail trail" paths of the ROV on each of its dives.

This map combines data from all three technologies used during Niku VII. The underlying SeaBeam map is overlaid with the side-scan sonar data collected by the AUV and the ROV "snail trails." Note that some parts of the reef slope below the Bevington Object (red pyramid) were too steep for side-scan sonar coverage.



As *KOK* turned northward, recurring problems with the ship's propulsion system made it prudent to hold speed down to 7 knots for most of the voyage. Diamondhead slid past to starboard on July 29.

It had been a frustrating expedition. The original plan had called for 200 hours of searching - ten days of 'round-the-clock operations minus four hours each day for maintenance. Due to greater than anticipated transit times, we had only eight days – 192 hours – on-site during which we did 85.92 hours of searching – 53.36 hours of side-scan sonar data collection by the AUV, and 32.32 hours of visual searching with the ROV. Fifty-seven percent of the time spent on-site was non-productive due to accidents and equipment malfunctions. The net result is that we were able to examine only a small fraction of the area we had hoped to cover.

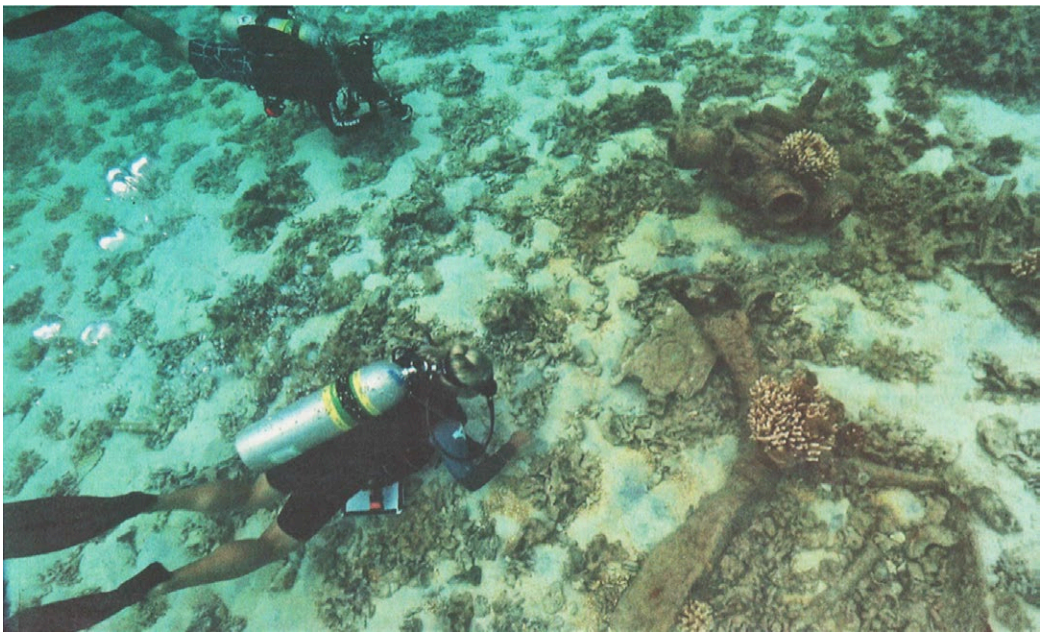
KOK's SeaBeam multi-beam sonar produced spectacular maps of the undersea topography that are a boon to the scientific oceanographic community and will be of great value in planning future searches. The AUV, however, did not produce reliable side-scan sonar data, was plagued with frequent malfunctions, and twice forced us to put the ROV at risk to rescue it from undersea entrapment. The ROV proved to be an effective search tool but the klugey HD video system did not give us the visual search capability we wanted and needed.

Niku VII was our first expedition dedicated solely to deep water exploration. We didn't get an airplane but we sure got an education. Niku VIII will benefit from the lessons we learned. ◆

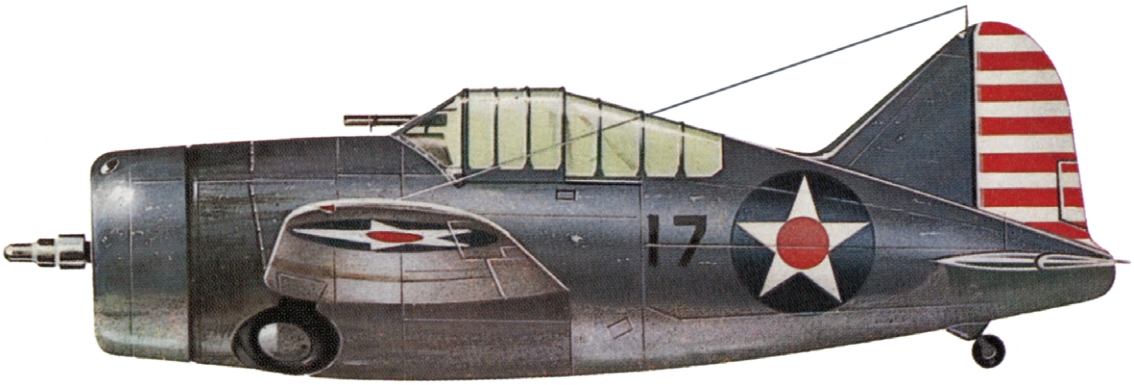
When you're looking for something, it's good to know what to look for. Aircraft in protected waters, such as this Douglas TBD-1 Devastator in Jaluit lagoon in the Marshall Islands, survive in remarkably good condition, but what does airplane wreckage look like after seventy-plus years in a high-energy coral reef environment? *(TIGHAR photo by W. Hoover.)*

Lessons From a Buffalo

In July 2012, while TIGHAR was searching the reef at Nikumaroro for the wreckage of NR16020, a NOAA Maritime Heritage team at Midway Atoll was documenting and identifying aircraft wreckage discovered in May. Just as Nikumaroro is now part of the Phoenix Islands Protected Area (PIPA), Midway is within the Papahānaumokuākea Marine National Monument. Both are UNESCO World Heritage Sites.



NOAA Maritime Heritage archaeologists documenting the propeller and engine from a Brewster F2A-3 "Buffalo." Open Boat Films/NOAA/Stephani Gordon.



Brewster F2A-3 of Marine Fighter Squadron VMF-221 at Midway Atoll, February 1942. From Profile Publications #217, The Brewster Buffalo.

Led by Kelly Gleason, Ph.D., Maritime Heritage Coordinator and Archaeologist, the NOAA team was able to identify the debris as components from a Brewster "Buffalo" fighter of Marine Fighter Squadron VMF-221 lost in an accident on February 12, 1942. Most of the aircraft had been salvaged immediately after the accident, but the parts left behind and the official accident report tell a harrowing story.

Quite a Ride

The sun was already down as Marine 2nd Lt. Charles Somers returned to Midway from a routine two-hour patrol. A squall was pummeling the airfield with heavy rain and 40 knot winds as Somers lowered his wheels, lined up on the runway and began his landing approach. In the dark and the driving rain Charlie Somers got a bit too low and eight hundred feet from the runway threshold his propeller and landing gear snagged the ocean. The Buffalo pitched violently forward into eight feet of water, the nose striking the bottom as the aircraft flipped inverted. It must have been quite a ride. In the blink of an eye, Somers found himself upside-down underwater. Artifacts found by the NOAA team describe a desperate situation. The discovery of a shard of the thick bulletproof glass in front of the pilot suggests that the windshield shattered against the bottom. The control column was also found, so Somers may have had to detach it to scramble out of the cramped, inverted cockpit. Somehow he extricated himself and when the rescue party arrived they found a wet, undoubtedly embarrassed, and miraculously uninjured young Marine standing on the plane. None the worse for his dunking, Somers went on to a distinguished wartime career and retired as a Colonel.

From the wreckage found by the NOAA Maritime Heritage team it's apparent that the nose section of the aircraft – prop, engine, two cowling-mounted .50 cal machine guns and ammunition – was not recovered after the accident. Perhaps the weight was too much for the recovery gear available or maybe the nose was torn loose in the accident. In any case, what is remarkable is how little remains of what was once there.

- the light-weight aluminum cowlings are gone, apparently carried away by underwater forces.
- the prop has come off the crankshaft.
- most of the massive Wright R-1820 engine is missing.
- the guns, once together in the cowling, are more than ten meters apart.

The Midway site is not directly analogous to Nikumaroro. The Buffalo is in relatively shallow water (8 to 10 feet) on the reef flat far from the surf line at the reef edge. Although periodically subject to high-energy waves in storms, the site is well-protected compared to where the Earhart aircraft may have ended up. The available evidence suggests that the Electra was washed off the reef flat at Nikumaroro into the surf where it broke up and sank. If it came to rest in the relatively shallow water before the lip of the first cliff the wreckage was subject to forces far greater than anything the Buffalo experienced. It has often been said that "the engines have to be there" but based on the lessons of the Buffalo, that is not necessarily the case.

The good news is that the wreckage of the Buffalo is not difficult to see. There is little-to-no coral growth obscuring the shape of artifacts and the aluminum skin of the tail cone, which apparently tore loose as the plane flipped, looks remarkably pristine after more than 70 years in shallow salt water. One landing gear leg and wheel are present, ripped off

The WWII airfield on Eastern Island, Midway Atoll. The wreck site – although not shown for security reasons– is on the reef flat well inside the surf line.

The aluminum skin of the Buffalo's tail cone appears free of any significant coral growth or corrosion. NOAA/Cathy Green.

The tail cone was apparently torn loose as the aircraft flipped inverted. The tail wheel was found at the opposite end of the debris field. NOAA/Cathy Green.

in the crash, but the tire is gone. The rubber tail wheel, however, is there and shows little deterioration.

If the Buffalo is a reliable model, similar debris from the Electra in the shallow water off the reef edge at Nikumaroro should be readily apparent to scuba divers, but repeated searches have found nothing. Assuming that TIGHAR's hypothesis is correct, if anything of the Electra survives it is probably somewhere in the deep water beyond the first cliff. ◆

Most of the engine is missing. NOAA/Bert Ho.

The Buffalo's Wright R-1820-40 Cyclone, was similar in construction to the Electra's smaller Pratt & Whitney R-1340 S3H1 Wasp engines.

The propeller shows the effects of striking the bottom during the crash. NOAA/Bert Ho.

The Object Formerly Known as Nessie

A photographic image the size of a grain of sand may be the best stand-alone piece of evidence yet found to reveal the fate of Amelia Earhart. The nearly microscopic dot is in a wallet-size photo of Gardner Island (now Nikumaroro) taken three months after Earhart's aircraft disappeared. TIGHAR and U.S. Government photo analysts agree that the image seems to show the wreckage of a main landing gear assembly from a Lockheed Electra. There is only one possible source for such debris in that place at that time – Earhart's Model 10E Special NR16020.

The Bevington Photo measures 2.5 by 3.5 inches and is reproduced here actual size.

Origin of the Photo

In the early 1930s, His Majesty's Gilbert & Ellice Islands Colony had a problem. Since "the coming of the flag" in 1892, British administration had resulted in steady population growth. The amount of available land on the colony's low coral atolls, of course, remained unchanged and by 1931 over-population was at crisis level, especially in the Southern Gilberts. It was obvious that new land suitable for development must be found.[1] In September 1937 Lands Commissioner Harry Maude was directed by the Western Pacific High Commissioner to mount an expedition to determine which of the islands of the remote Phoenix Group might be suitable for colonization and settlement.[2] For an assistant, Maude recruited newly arrived Cadet Officer Eric R. Bevington.

Gilbert & Ellice Colony Lands Commissioner Harry Maude (center, hands on knees) and Cadet Officer Eric Bevington (to Maude's left) with the Gilbertese delegates.

From September 18 to October 31, 1937, sailing aboard the Royal Colony Ship *Nimanoa*, Maude, Bevington and 19 Gilbertese representatives inspected all eight islands of the Phoenix Group. Bevington kept a journal and took photos. The expedition spent three days at Gardner – October 13, 14, and 15 – and found the atoll suitable for future settlement. Bevington's journal is on the TIGHAR website at http://tighar.org/Projects/Earhart/Archives/Documents/Bevington_Diary.html.

1 *Of Islands and Men*, Harry Maude, Oxford University Press, 1968, p. 320.

2 Ibid, p. 321.

In 1939 Eric Bevington, by then a District Officer in the Gilbert & Ellice Islands Colony, sent his expedition journal and a collection of his photos home to his father in England. The negatives of the photos were destroyed when the Japanese invaded the Gilbert Islands in December 1941. Fortunately, Bevington and his family escaped to Fiji. The only surviving prints of the photos Bevington took during the 1937 expedition remained with his father until Bevington retired and returned to England many years later.

What we now call The Bevington Object is a tiny feature in one photo among two hundred fifty-three pictures in the collection of a minor British colonial official. Is this incredibly small speck in an impossibly obscure photograph the long-sought conclusive proof that the Earhart/Noonan flight ended on Gardner Island? Is there other evidence that supports the idea that an object in that place at that time might be wreckage from the Earhart aircraft? What can experts see in such a tiny picture that allows them to identify it so specifically? Do we have to take their opinion on faith or can we see this landing gear wreckage for ourselves?

The Plane on the Reef – Evolution of a Hypothesis

The Bevington Object may be the best stand-alone piece of evidence yet found to reveal the fate of Amelia Earhart – but it does not stand alone. It fits perfectly into the puzzle picture that has gradually come together during a quarter century of TIGHAR research.

First Hints: The 1989 and 1991 Expeditions

During the course of TIGHAR's first two expeditions to Nikumaroro we found aircraft artifacts in the island's abandoned village. The Gilbert and Ellice Islanders who lived on the atoll from 1939 to 1963 used salvaged aircraft parts to make fishing lures, combs, and other small items. During the island's period of habitation, no aircraft were lost or even damaged there. Where did the aircraft parts come from?

Most of the bits and pieces found in the village are too generic to be traceable to any particular aircraft type but the handful that bear part numbers are from a Consolidated B-24 Liberator bomber, possibly one that is known to have crashed on Canton Island, about 200 miles away, in 1944. A few aircraft artifacts found in the village, however, do not seem to match any WWII type and appear to be consistent with components of a Lockheed Electra.

Combs fashioned from aircraft aluminum found in the abandoned village on Nikumaroro.

The Lockheed Vanishes

The more we learned about the island's documented history and the more time we spent exploring the island ourselves, the more we came to believe that there was little or no chance that there was an undiscovered airplane wreck lurking in the bush. This presented an interesting conundrum. The radio distress calls heard for several nights following Earhart's disappearance on July 2nd could only be sent if the aircraft landed safely but the failure of the U.S. Navy aerial search one week later suggested that, by July 9th, the aircraft had somehow disappeared. How could that be?

From almost the beginning, one possibility seemed obvious. The following is from an article in *TIGHAR Tracks,* Vol. 5, No. 4, November 1989:

> The broad, flat expanse of hard coral which surroundsthe island's shore dries at low tide to provide a very attractive surface upon which to make a forced landing. However, a disabled aircraft on that reef-flat would, at high tide, be partially afloat in 3 to 4 feet of water. Over a period of a few days tidal cycles would move the aircraft inexorably toward and ultimately over the edge of the fringing reef. From there it's a steep plunge to depths of 2 to 4 thousand feet.


Nikumaroro is surrounded by a broad, flat reef that dries at low tide.

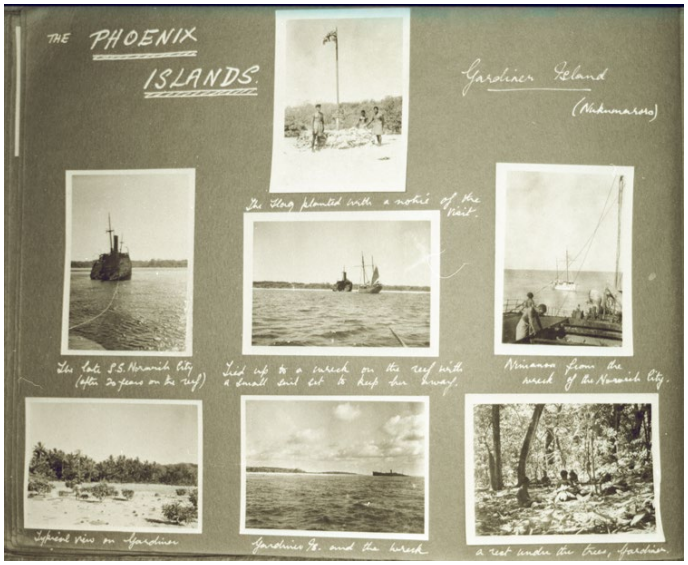
But where on the atoll's roughly ten miles of reef might it have happened and, if the plane went over the edge and sank in deep water, how did the people who later came to the island end up with pieces of it? Or was there some other explanation for the radio signals and airplane parts? The puzzle was becoming more puzzling.

Bevington Photo: First Iteration, 1992

We first became aware of Eric Bevington's photos when, on January 22, 1992 TIGHAR President Pat Thrasher and I visited Eric and his wife Enid at their retirement cottage in the south of England. The purpose of the visit was to interview Bevington about his participation in the 1937 expedition and learn whether he had seen anything unusual on Gardner. A day shy of his 80th birthday, he was a gracious and charming host, eager to help us in any way he could and delighted to compare notes about our mutual experiences on Gardner Island, but he was highly skeptical of the idea that Earhart had landed there. (A DVD of our videotaped discussion "An Interview with Eric R. Bevington," is available in the TIGHAR Store.)

Eric and Enid Bevington, January 1992.

During the visit, Bevington brought out the album of photographs he had sent home to England in 1939. Pat asked if she might take photos of the pages in the album. Eric readily agreed and gave TIGHAR permission to reproduce his photos. Pat took copy-photos with a Nikon 8008 SLR camera fitted with a Nikon 30/70mm zoom lens and a Nikon Speedlight SB-24 flash. She laid the album on a coffee table and hand-held the camera to photograph each of the pages. We were, of course, especially interested in the fifteen photos taken at Gardner Island during the 1937 expedition. Four of the pictures gave us our first look at the



The page from Bevington's album that includes "Gardiner Island and the wreck."

S.S. *Norwich City* shipwreck as Earhart may have seen it. One photo, labeled "Gardiner (sic) Island and the wreck" provided an excellent profile view of the ship. Neither we, nor Bevington, noticed the tiny dot near the left hand edge of the picture.

Cropped Out

Upon returning to the U.S. we developed the film and made prints of the more interesting photos. Because our primary interest at that time was the condition of S.S. *Norwich City* in 1937, I made an 8 x 10 inch print of "Gardiner Island and the wreck" and, to enlarge the ship, I cropped out the left hand portion of the frame, thus removing the unnoticed anomaly from view. It would remain hidden for the next eighteen years.

1995: The Lockheed Reappears

As TIGHAR's investigation of the Earhart disappearance continued, we encountered more information that supported the theory that the aircraft had been landed somewhere on the reef and was subsequently washed over the edge. In 1995, after seeing a television documentary about TIGHAR's work, Dr. John Mims, a retired physician in Tuscumbia, Alabama, contacted us with a story from his time as a Navy PBY flying boat pilot during WWII. Assigned to Patrol Aircraft Service Unit (PATSU) 2-2 based at Canton Island, Ensign Mim's flew regular re-supply runs to the Loran navigations stations in the Phoenix Chain from December 1944 to February 1945. On one visit to Gardner Island the settlers proudly showed him a large fish they had just caught. Mims was astonished to see that the hook in the fish's mouth was crudely fashioned from aircraft aluminum and the "leader" on the fishing line was clearly an aircraft control cable. As Mims described in a March 1995 letter:

> I asked the native about the hook and leader, and he promptly informed me that it came from a wrecked plane that was there when he arrived some (?) three years earlier (apparently no one lived on the island prior to 1941). He said the plane was much smaller than mine. The question arose at the time about Amelia Earhart, but we knew that she had a flight plan for Baker Island [sic], which was several hundred miles to the north where a small runway was present. Also, we had no knowledge of any plane lost at that location.
>
> As I got to know these people they started giving me gifts in exchange for the things I would take to them. They showed me crude knives made from aluminum by grinding it with seashells and sand. At the present time I still have some jewel boxes and outriggers with inlaid diamond, heart, and star-shaped pieces of aluminum that they said came from the wrecked plane.

Ensign Mims in 1944.

Dr. Mims in 1995.

Carved wooden boxes inlaid with metal "from the wrecked plane."

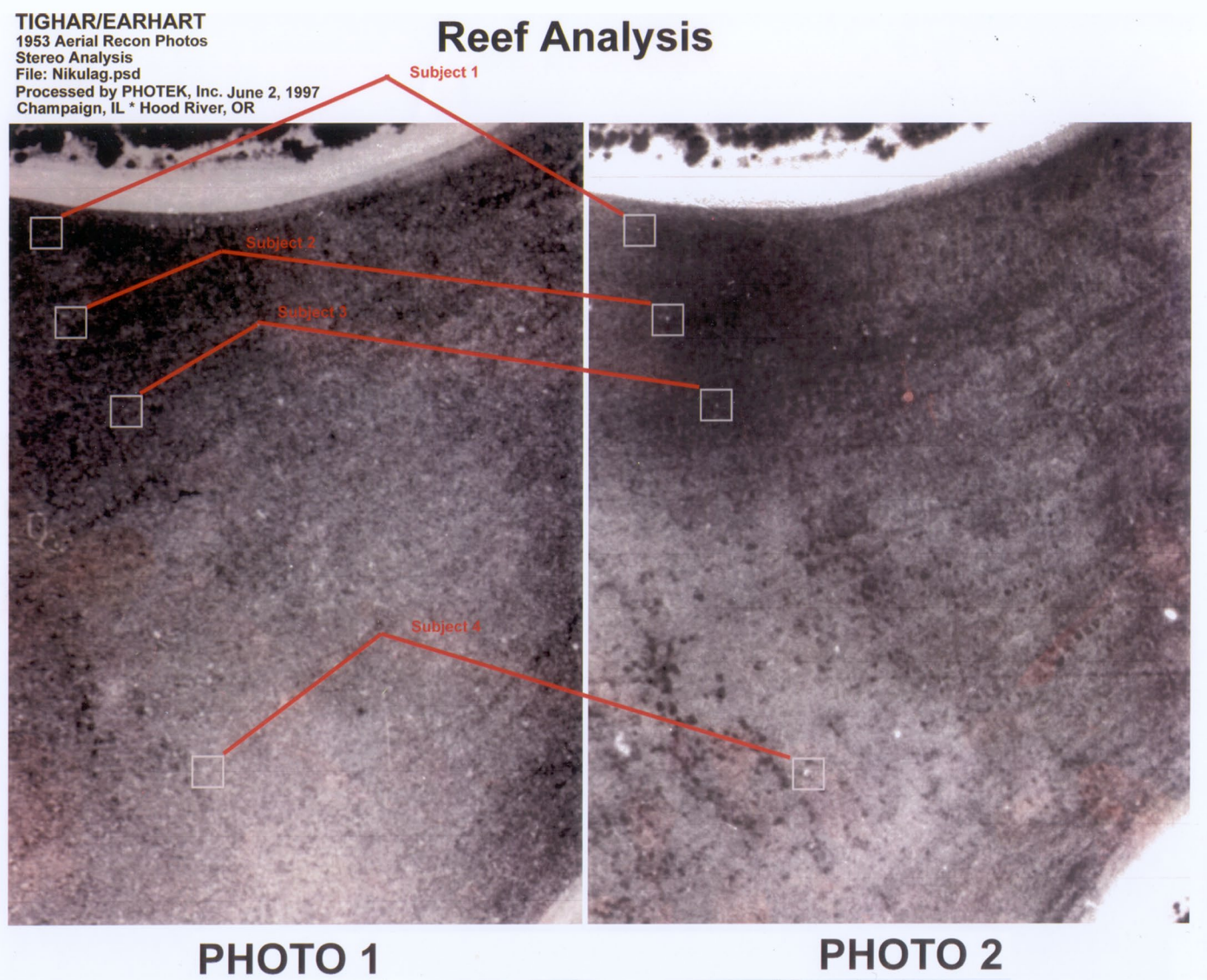
Dr. Mims let us remove one of the inlaid pieces of aluminum and have it tested. It's 24ST ALCLAD, the kind of aluminum sheet used in the construction of Earhart's Electra – and virtually every WWII American aluminum aircraft – but Mims was on Gardner before the locals had access to WWII wrecks.

Dr. Mims' story was fascinating and supportive of our hypothesis, but it was still just a story, an anecdotal recollection that may or may not be accurate, and we still had no idea where on the reef the plane may have landed.

1997: Wreckage on the Reef

Our lucky break came at the end of the 1997 expedition. During an unscheduled stop at Funafuti Atoll we met former Nikumaroro resident Tapania Taeke who told us of seeing aircraft wreckage on the reef near the main lagoon passage in the 1950s. When we got home we asked forensic imaging specialist Jeff Glickman if he could find corroboration of her recollection by examining aerial mapping photos taken in 1953. Jeff was able to find four light colored objects, possibly aluminum, on the reef surface in the area described by Tapania.

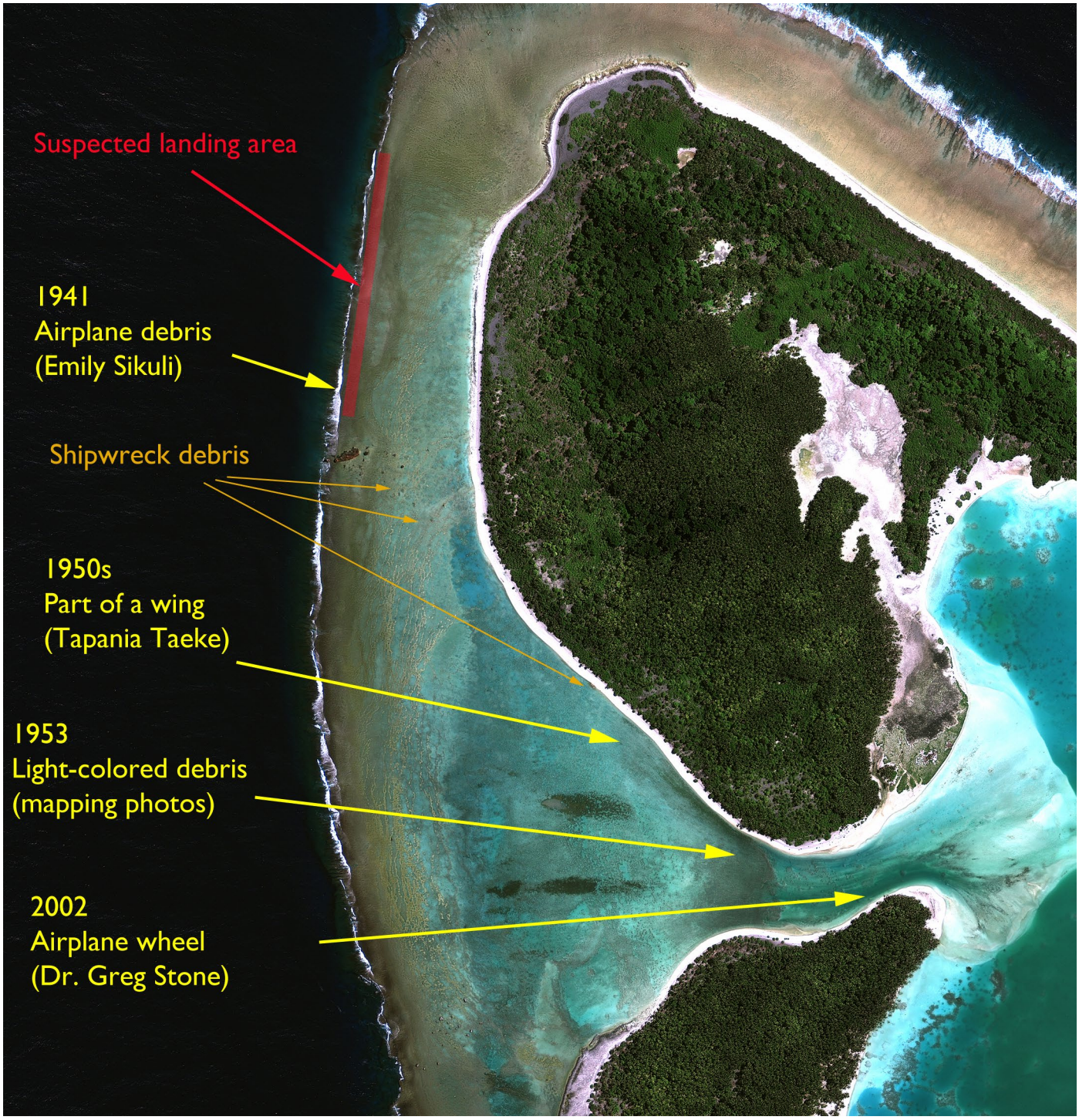
If there was aircraft aluminum near the main lagoon passage, where did it come from? Debris from the shipwreck is distributed on the reef surface to the southeastward. If the objects in the 1953 photos were aircraft debris, the aircraft must have broken up somewhere to the northwest. For the first time we had a general impression of where the plane may have landed. As research continued, a picture began to emerge.



Light colored objects appearing in two 1953 aerial mapping photos.

- In 1999 we interviewed a woman in Fiji who had lived on Nikumaroro as a teenage girl in 1940 and '41. Emily Sikuli described rust-colored metal debris on the reef edge that her father told her was part of an airplane. On a map of the island, she marked a spot north of the shipwreck.
- In 2001, we inspected that part of the reef at low tide and found it to be suitable for landing an aircraft like the Electra.
- In 2002, marine biologist Dr. Greg Stone reported seeing what appeared to be an airplane wheel near the shore in the main lagoon passage. When we got there to check it out in 2003, storm activity had swept it away.
- In 2007, we surveyed the height of the reef surface to find out how water levels at various states of the tide in July 1937 correlate with reported post-loss radio signals from the Electra. Analysis based on that data revealed that, almost without exception, the credible signals were heard at times when the water level on the reef was low enough to permit Earhart to run an engine to keep the batteries charged.

By the time preparations were underway for the 2010 expedition, we had a string of anecdotal, photographic and analytical data suggesting that Earhart had landed the Electra on the reef somewhere north of the shipwreck and sent radio distress calls for several nights until rising tides washed the aircraft over the edge where it broke up in the surf.



By January of 2010 the available evidence pointed to a relatively safe landing on a smooth stretch of reef north of the shipwreck, the subsequent break up of the aircraft in the surf, and the eventual distribution of some of the wreckage southeastward.

As part of the preparations for the Niku VI expedition in May and June of 2010, we put together a collection of all of the historical aerial photos of Nikumaroro and sent it to all of the expedition team members. On March 17, 2010 Arthur Carty suggested:

> … since Jeff [Glickman] looked at some of these pictures quite a while ago, have there been any significant advances in photo/image processing tools or software that would justify taking another look at some point?

Jeff replied,

> Yes, there have been advances that warrant looking at the images again.

Fortunately, Jeff didn't limit his review to the aerial photos and he already had the negatives of the 1992 Bevington copy photos. On April 1, 2010 he called me and asked, "What's the thing sticking up out of the water at the left hand side of Bevington's photo of the western shoreline?" I looked at

The full-frame 1992 copy photo. "What's the thing sticking up out of the water…?"

my copy of the photo (forgetting that it had been cropped) and replied that I didn't see anything. Jeff then sent me a scan of the full frame image derived from the copy negative.

There was something there – no doubt about it – but what could it be?

- A flaw in the photo? Jeff said no.
- A coral block thrown up onto the reef surface by a storm? No. Wrong shape and too complex.
- *Norwich City* debris? Too far from the shipwreck and in the wrong direction.
- Airplane wreckage? Maybe.

When something seems too good to be true, it usually is. The more exciting a new piece of evidence looks, the more caution is warranted. All we knew for certain was that we had an unknown something sticking out of the water. With tongue firmly in cheek, I dubbed it "Nessie."

Nessie

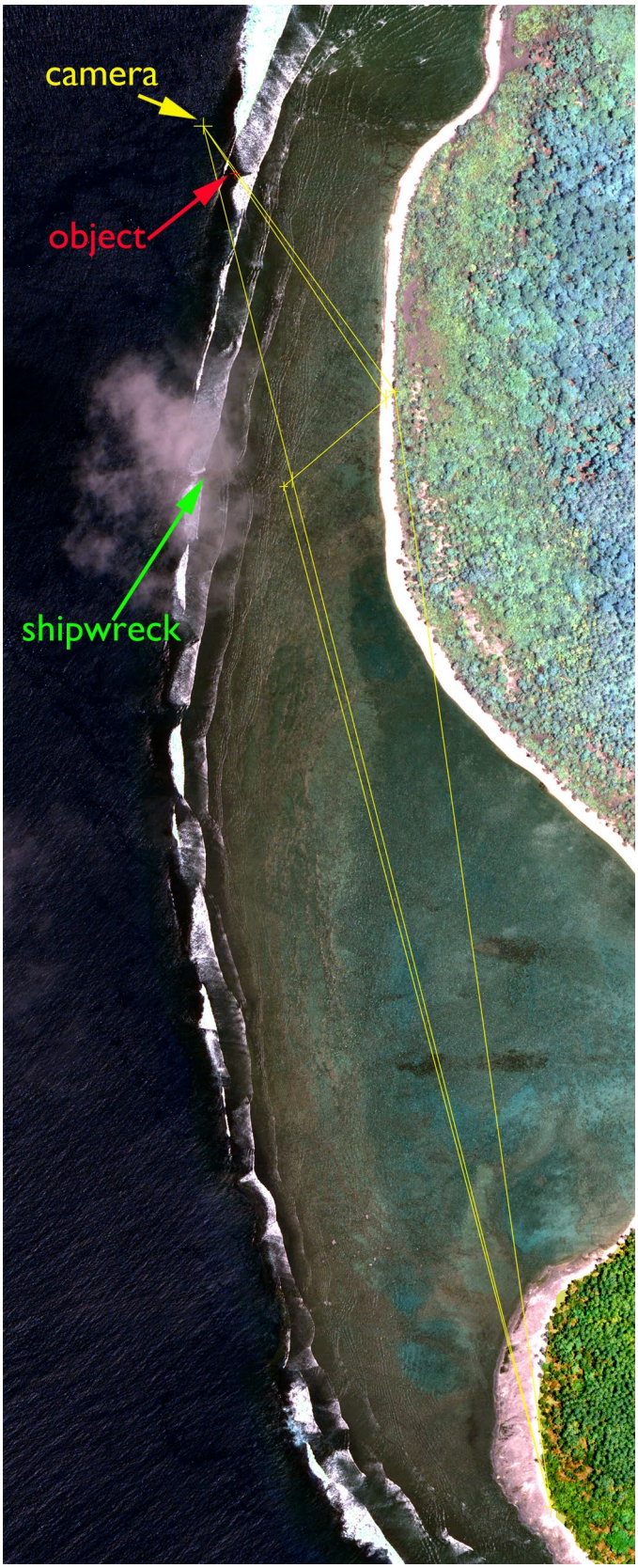
Jeff calculated the object's position by triangulating features that are identifiable in both the 1937 photo and in a modern satellite image of the island. With the ship of known dimensions providing a convenient scale, Jeff was able to place Nessie 416 meters – about a quarter of a mile – north of the shipwreck and at the very edge of the reef flat. It was the same spot Emily Sikuli had marked on our map eleven years earlier.

Could this be the "part of an airplane" Emily's father pointed out to her in 1941? Emily had given us a simple sketch of what she saw, a long shaft with a small round thing on the end. Enlarging the copy photo of Nessie as much as possible resulted in a fuzzy image that didn't look like Emily's sketch but did seem to resemble the main landing gear assembly of a Lockheed Electra standing upright on the reef. How could that happen? We wondered if perhaps a wheel had dropped into a groove in the reef surface and become jammed there. The force of the surf might then have torn the aircraft free and into the ocean, leaving the landing gear assembly behind.

Second Iteration

Nessie clearly had the potential to be an extremely important piece of evidence but, just as clearly, we needed something better to work with than the casual 1992 copy photo.

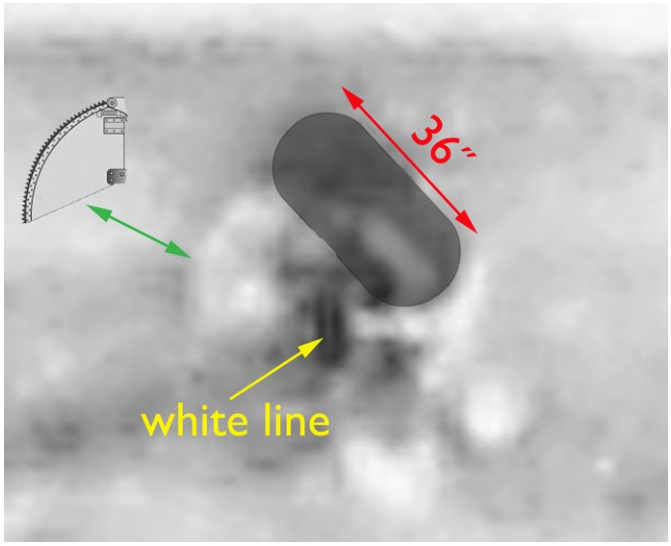
Before his death in 2004, Eric Bevington donated his papers and photos to the Bodleian Library of Commonwealth and African Studies at Rhodes House Library, Oxford University, England. Within a week of Jeff Glickman's discovery of Nessie we ordered a scan of the photo from Rhodes House. The best the library could do was 600 dpi, but the new image revealed far more detail and a very different picture of the object. It no longer suggested an intact landing gear assembly standing upright but rather a jumble of wreckage made up of distinct and measurable components – but did those components match the size and shape of anything on a Lockheed Electra?



By identifying features visible in both the 1937 photo and a modern satellite image, Jeff Glickman was able to triangulate the position of the camera and the object.

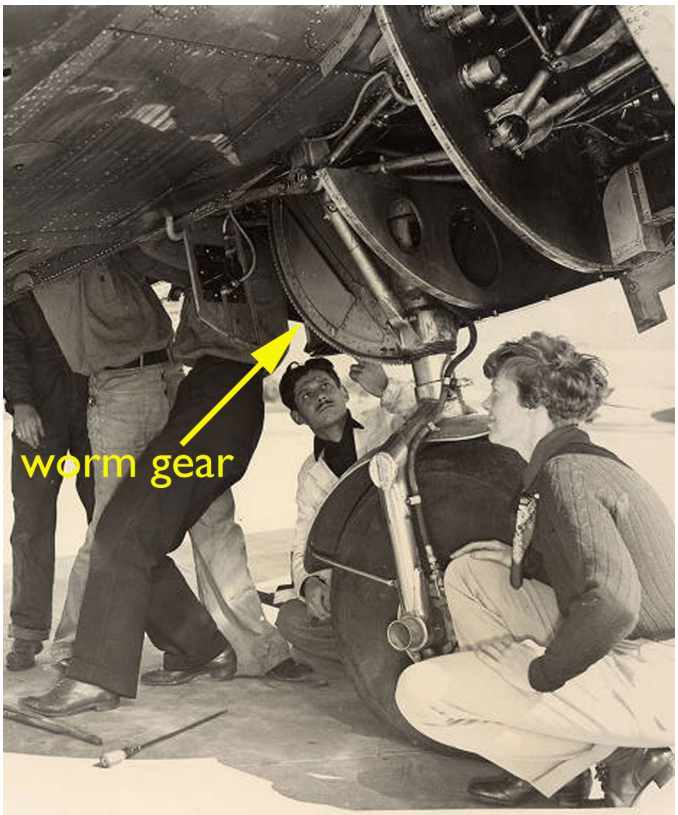
The 600 dpi scan of Nessie.

Using data TIGHAR had collected from Lockheed c/n 1052 at the New England Air Museum in Windsor Locks, Connecticut, Jeff was able to match the size and shape of components of the Electra landing gear to specific elements in the new scan of Nessie.



Elements in the scanned image resembled components in the landing gear of Earhart's Electra.

The first item of interest was that the diameter of what might be a tire appeared to be roughly 36 inches – the Goodyear Airwheels on Earhart's Electra had a diameter of 35 inches. The second item of interest in the new image was a fine white line on the central dark area. The line is an illusion caused by image processing software in the scanner but the fact that the scanner put a line there suggests a cylindrical shape consistent with a landing gear strut. A third item of interest was a light colored section on the left side of the strut-like area. The size and shape was similar to the worm gear on the landing gear of Lockheed Electras — or rather, some Lockheed Electras. (See "Part No. 40776" page 45.)



The first 55 Lockheed Electras featured Lockheed Installation 40650, a main landing gear assembly that featured a heavy steel "worm gear" as part of the retraction mechanism.

The Niku VI expedition departed for Nikumaroro on May 17, 2010, six weeks after Jeff first discovered Nessie and less than a month after we received the new scan from England. If Nessie was landing gear wreckage that was still on the reef edge three months after the plane was washed into the ocean, the jammed-in-a-groove theory still seemed like the best explanation, but was there a groove in that location and, if so, was there any chance that some part of the object was still there? At low tide on May 27 Gary Quigg and I

went to the GPS coordinates calculated from Jeff Glickman's placement of Nessie. We didn't expect to find surviving debris on the reef surface, and we didn't, but we did confirm that there is a deep natural groove in the reef surface in that location.

TIGHAR's Gary Quigg beside the reef groove at the Nessie location, May 27, 2010.

Art Carty and I again inspected the area on June 8. Although the sea was relatively calm on both occasions, the slippery reef surface and the force of the tidal surge made it difficult to remain standing. The constant patrol of sharks was a reminder that falling on the sharp coral and floundering around in the surf would not be a good idea. An inspection of the groove itself was out of the question.

By the end of the Niku VI expedition we had found nothing to disqualify the hypothesis that the object in the 1937 photograph was landing gear wreckage jammed in the reef. So far, so good, but failure to disqualify is not the same as confirmation. Further research was clearly indicated. To better evaluate whether the shapes visible in the photograph matched the components of Electra landing gear, Jeff wanted hands-on, in-person familiarity with those components. So, in September 2010, Jeff Glickman and Niku VI expedition veteran Karl Kern paid a call on Lockheed Model 10A constructor's number (c/n) 1011, the eleventh Electra built, at the Pima Air & Space Museum in Tucson, Arizona. The measurements and photographs they took reinforced Jeff's opinion that Nessie was the wreckage of Lockheed Electra landing gear, but in reporting his findings he had one request.

"Don't call it Nessie."

"Why not?"

"Because that name trivializes it, and this is not a trivial piece of evidence."

Forensic imaging specialist Jeff Glickman with Lockheed Electra c/n 1011 at the Pima Air and Space Museum, September 2010.

In twenty years of working with Jeff Glickman I had never known him to be so sure of anything as he was about this photograph. If he was right, we not only had photographic proof that the Electra had been there but we also knew where the plane went over the reef edge and, therefore, where we should look for the rest of the wreckage. That was too many eggs for one basket. We needed an independent expert opinion. With the help of Dr. Kurt Campbell, Assistant Secretary of State for East Asia and the Pacific Islands, we were able to get photo analysts from the Imagery Center of the State Department's Bureau of Intelligence and Research to examine the photo. On November 16, 2011 I sent a confidential report to TIGHAR's board of directors.

> On Monday I had a meeting in Washington at the State Dept. Bureau of Intelligence and Research regarding the Nessie photo. I had sent them the hi-resolution version and asked them to evaluate it. At the meeting were three photo analysts. The senior analyst is about my age. He had a 20 year career in photo analysis with the USAF before coming to work at the State Department and is experienced in finding aircraft wrecks through photo analysis. The other two analysts looked to be in their early 30s.

"My colleagues and I have spent time with this photo and have also done some background research. We feel that what you have here may well be what you think it is - the landing gear of a Lockheed Electra."

They see the same things in the photo that Jeff Glickman sees - the strut, the mud flap, the worm gear, possibly the tire. What puzzles the senior analyst is that the assembly seems to be not only damaged but upside down. "The gear cannot still be attached to the airplane or we'd see more of the plane. If it's detached from the plane, why is the heavy side up?" He is under the impression that the tire end of the assembly would be heavier than the attach-point end. I don't think so. That worm gear is heavy and I think the tire would be buoyant - not buoyant enough to keep the whole assembly afloat, but enough to account for the assembly being upside down when it gets jammed in the reef.

He said, "In this business we have three levels of certainty - Possible, Probable, Confirmed. That this photo shows the landing gear of a Lockheed Electra is somewhere between Possible and Probable."

The principal reason he was that cautious was not anything about the photo but the fact that we don't have the original negative. "What are the chances that the print you photographed was made from a negative that had been doctored sometime between the time the photo was taken in 1937 and when you photographed the print in 1992?"

(Subsequent research has shown that the original negative was destroyed when the Japanese invaded Tarawa in December 1941. The prints in the album and the journal of the trip to Gardner in 1937 survived because Bevington had sent them home to his father in England in 1939.)

About the project in general, the senior analyst had this to say:

"You have a strong circumstantial case. You're not trying to sell anybody a bill of goods. You're doing good work but you've chosen a tough mission." His only criticism of TIGHAR is that we call the anomaly Nessie. "You're selling yourself short. Nessie was a fraud."

Regarding attribution, he said,

"What we've given you is our opinion as private individuals. The U.S. Government does not offer opinions on things like this. If the people I work for knew I was even talking to you about this they would have a fit."

This presented something of a quandary. We had independent support for Jeff's findings from an unimpeachable source, but we weren't going to get a written report and we couldn't even talk about it publicly – and they didn't like the name Nessie either. Still, it was good to know we were on the right track.

Third Iteration

When you're on the right track, it's important to keep moving along that track. What more could we learn from Nessie – or (ahem) the Bevington Object? The 600 dpi scan done in 2010 was a big improvement over the casual copy-photo taken in 1992 but, as Jeff Glickman explained,

"When images are taken at a lower resolution, curved edges have the appearance of being sharp and are straight due to aliasing by the image sensor. This illusion is further exacerbated by image processing software in the scanner which attempts to increase the local contrast at these aliased edges."

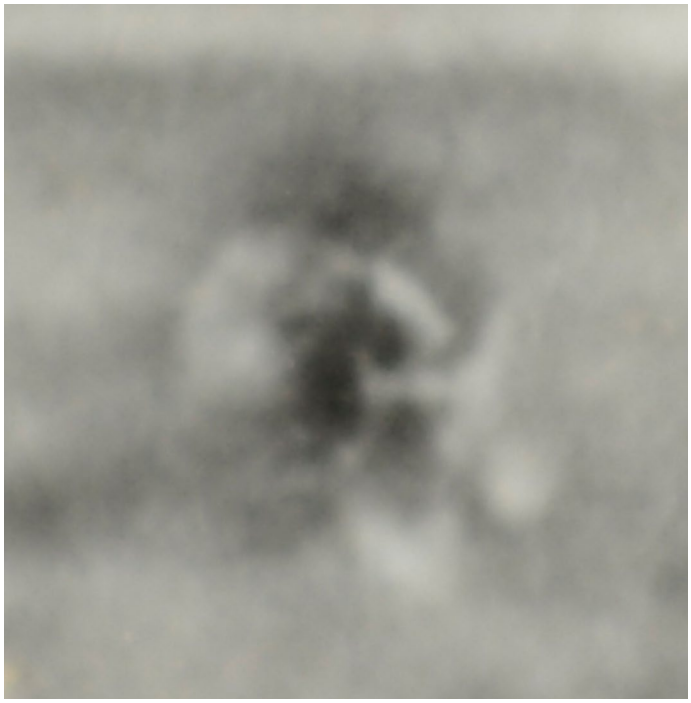
What we needed was the best possible copy of the original print and the only way to get it was to go to Oxford ourselves. On April 26, 2012, with the full cooperation of the Oxford University Rhodes House Library, Jeff Glickman used a state-of-the art Nikon D800 camera with a Nikon AF-S DX Micro-NIKKOR 40mm f/2.8G lens and a Sigma EM-140 ring light to take copy photos that provide sixteen times better spatial resolution than the 600 dpi scan. A short video of our trip to Oxford is on the TIGHAR Youtube channel at http://www.youtube.com/watch?v=Zcqb26Lz6V8&feature=plcp.

Jeff Glickman at Rhodes House Library, Oxford University, England, April 26, 2012.

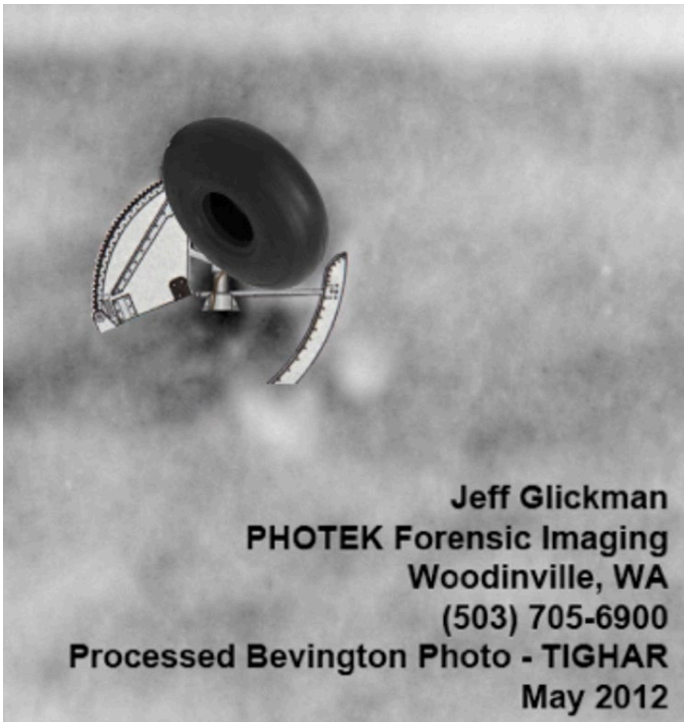
The resulting image is a bit counterintuitive. As Jeff explained:

"While the eye reads the D800 photograph as being less sharp, this is because the curves and the correct levels of contrast in the photograph have been preserved. This preservation provides the higher resolution necessary for more complete photointerpretation."

The new image confirmed what we had deduced from the earlier iterations. Discernible elements in the object match the shape and dimensions of components in the main landing gear of Earhart's Lockheed Electra – but the components are not oriented in the way they would be in an intact assembly. If this was Electra landing gear, it was the jumbled wreckage of Installation 40650, as it should be if our hypothesis is correct. The next job was to sort out the jumble and see if it was reasonable that a landing gear assembly could end up looking like Nessie – sorry – the Bevington Object.



The max-resolution image of the Bevington Object.



Initial parsing of the Bevington Object.

Jeff Glickman's initial parsing of the image, as presented at TIGHAR's Earhart Search 75 symposium in Washington on June 2, 2012, postulated that the strut was intact but partially submerged and the tire/wheel separated from the fork. An abbreviated video of Jeff's presentation is on the TIGHAR Youtube channel at http://www.youtube.com/watch?v=iLxjEU1VJHA&feature=plcp.

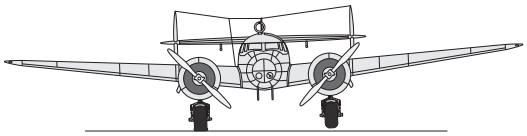
It seemed like a reasonable interpretation except that it was difficult to understand how the tire and wheel could separate from the fork and remain with the rest of the assembly.

In September 2012 I stumbled upon a brief clip of old newsreel footage in the 2010 Discovery Channel special "Finding Amelia" that I had not previously noticed. The film was shot at Luke Field following the accident that ended Earhart's first world flight and showed two Army officers crouched over the Electra's right main landing gear. Although not mentioned in the extensive U.S. Army accident report, it was apparent from the clip that the entire landing gear assembly had separated from the airframe – and it looked startlingly familiar. Further research was clearly needed.

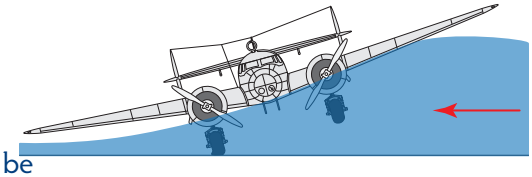
The clip in the Discovery Channel show was only three seconds long and did not show the entire landing gear but there was enough of it visible to reconstruct what had happened.

The Luke Field Ground Loop

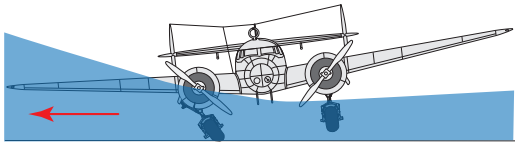
From the statement of 1st Lt. Donald D. Arnold, Air Corps, Engineering Officer, Hawaiian Air Deport, Luke Field, T. H.:



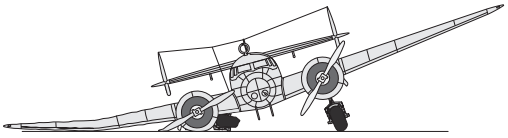
1. Before the airplane had reached the halfway mark on the field the right wing seemed to drop slightly lower than the left and the airplane made a slow even forty-five degree turn to the left.



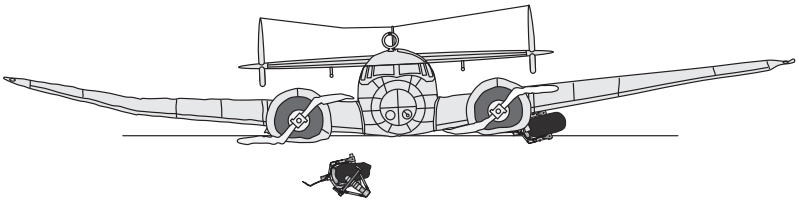
2. Suddenly, the airplane was seen to be veering to the left with increasing rapidity as in the initial stage of a ground loop; as it swung it tilted with the outer (i.e. right-hand) wing almost scraping the mat.



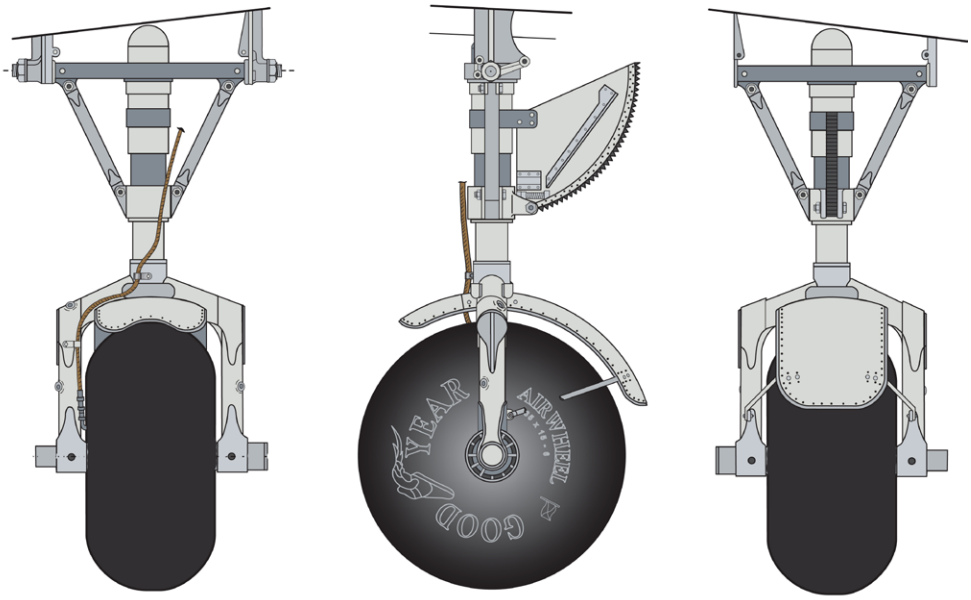
3. The right hand landing gear suddenly collapsed followed by the other and the airplane slid in an abrupt left hand skid on its belly.



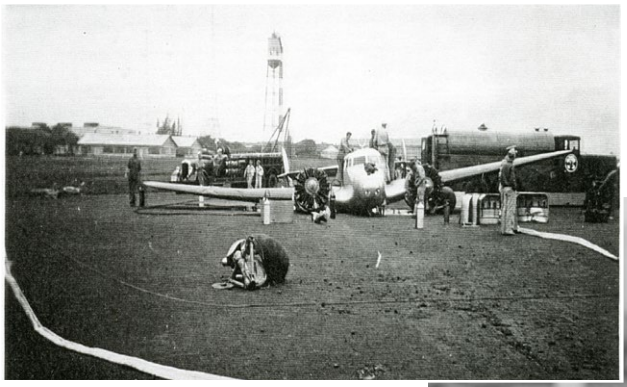
4. Half way between the center of the runway and the Navy side I saw a long streak of flying sparks under the airplane, followed instantly by the sound of grinding metal. The airplane instantly dropped on its belly and slid to a stop, right side up, but headed in the direction from which it had come.



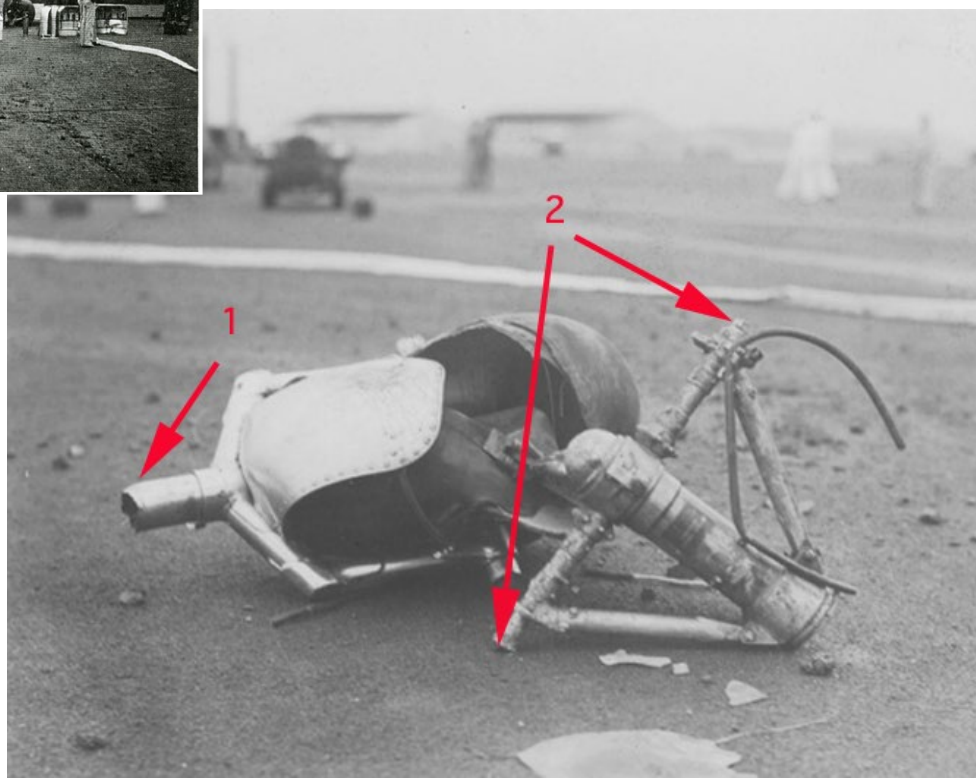
With a real-life model of how the landing gear on NR16020 could fail, the Bevington Object seems to pop into focus. The distinctive shapes of the tire, fork , and worm gear are clearly visible to the untrained eye. These three elements in the image are the right color, shape, and dimensions, and in the correct proportion to each other, to be the Goodyear Airwheel; Lockheed Part No. 40776 Fork, landing gear; and Lockheed Part No. 41065, Gear, worm – components of Lockheed Installation 40650. The assembly appears to have failed in much the same way it did in the Luke Field accident.



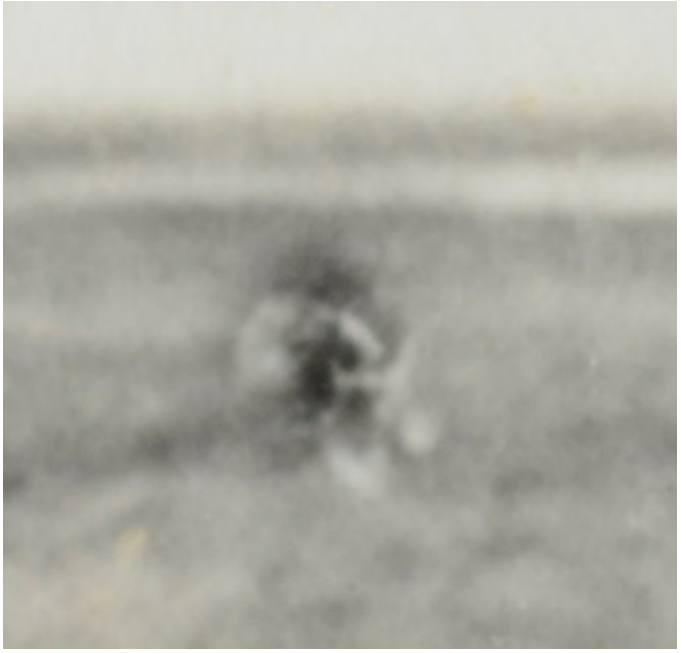
Front, profile and rear views of Lockheed Model 10 Landing Gear Installation 40650.

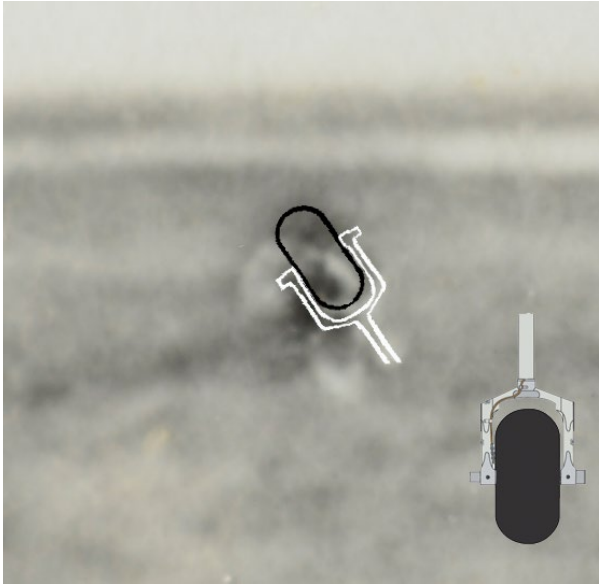


A photograph taken by Gerald Berger, the Navy mechanic who drove the crash truck at Luke Field, shows the mangled wreckage of the right main landing gear assembly where it lay after separating from the airframe during the crash. TIGHAR photo courtesy of G. Berger.

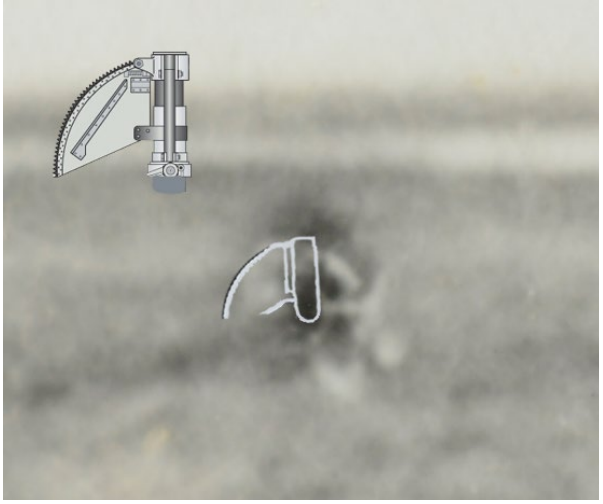


It appears the shaft of the oleo strut (1.) failed, dropping the full weight of the aircraft onto the upper part of the strut which separated from the airframe at the attach points (2.). The broken-off lower section rotated as it collapsed and the tire was torn open by the worm gear. San Diego Air & Space Museum.





The distinctive shape of "Lockheed Part No. 40776 Fork, landing gear" had been there all the time but we hadn't recognized it. The tire remained on the axle just as it did at Luke Field.



The upper part of the oleo strut appears to be inverted and, in this case, "Lockheed Part No. 41065, Gear, worm" does not appear to be inside the tire. Part of the worm gear may be underwater.

The curved light-colored shape may be part of the fender.

The identifiable elements in the Bevington Object are consistent in size, shape, and color with the components of the landing gear of Earhart's Electra and are distributed in much the same way they were in the Luke Field accident.

The statistical probability of an unknown object that is not the wreckage of Electra landing gear having all of the quantifiable characteristics present in the Bevington Object is vanishingly small. The fact that the object is in the area where abundant other evidence had already led us to conclude the aircraft was landed adds a further level of likelihood that the object in the photo is what it appears to be: a photo of wreckage from NR16020 on the reef at Gardner Island in October 1937. ◆

Part Number 41065

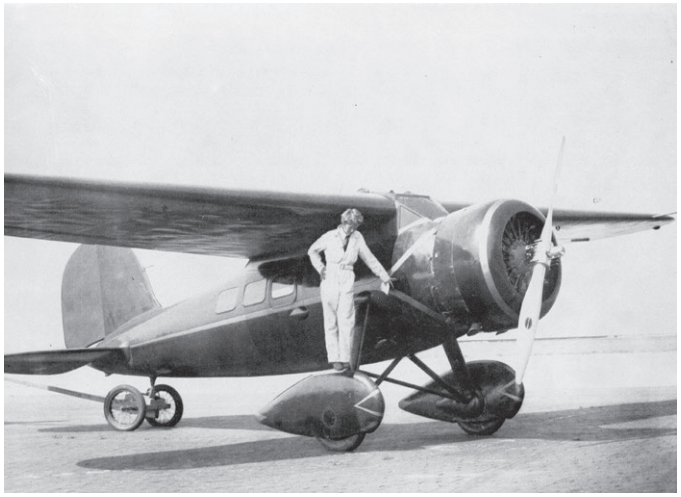
Revised and reprinted from the October, 2011 edition of *TIGHAR Tracks*.

As explained in "The Object Formerly Known As Nessie," one of the elements that appears to be identifiable in the Bevington Photo is part of the retraction mechanism listed in the Lockheed Model 10 Parts Catalog as "Part Number 41065, Gear, worm." If our identification of the part is correct, its presence in the photo guarantees that the wreckage on the reef in the 1937 photo is specifically from the Earhart aircraft.

In 1936 Lockheed made a major change in the landing gear retraction mechanism of the Model 10. Earhart's Model 10E Special, delivered on July 24th of that year, was the last of only 54 Electras built with the original system – Lockheed Landing Gear Installation 40650.[1] When you know what to look for the change is easy to spot, but it took a bit of research to piece together how and why the modification was made.

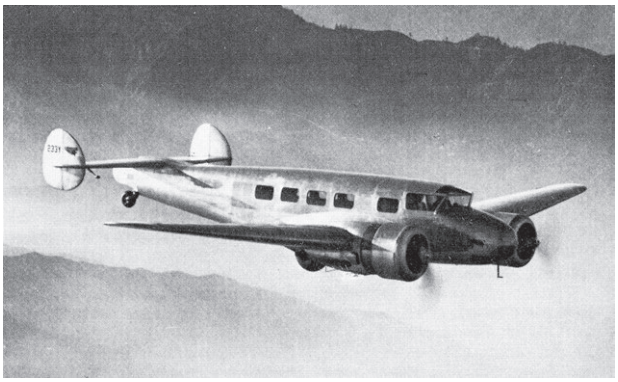
New Company, New Star

Introduced in 1934, the Model 10 was the tenth design marketed by Lockheed. Like the earlier Model 5 "Vega," Model 8 "Sirius," and Model 9 "Orion," the new design was named for a star, in this case "Electra," the "lost star" of the Pleiades cluster in the constellation Taurus. Despite the appearance of continuity, this was a new Lockheed Aircraft Corporation and the new airplane was a radical departure from previous designs. Lockheed had built its reputation on fast single-engine airplanes with sleek molded-plywood bodies and cantilevered wooden wings designed by Jack Northrop and flown by customers with names like Post, Earhart, Lindbergh and Kingsford-Smith. However, fame proved to be no antidote to the Great Depression and on June 16, 1932 the doors of the Burbank factory were closed.



The Vega in which Earhart flew the Atlantic was typical of the classic Lockheed designs of the late 1920s and early '30s.

Just five days later Lockheed Aircraft Corporation was reborn, its assets purchased by a group of investors for $40,000. A new design team headed by Lloyd C. Stearman began sketching out an all metal, ten-seat, single-engine airliner until the primary investor and new Treasurer, Robert Ellsworth Gross, convinced them that the future of commercial sales was in multi-engine aircraft. A second engine was added and the new Lockheed company's first offering was an all-metal, twin-engine, low wing monoplane with retractable landing gear.[2]

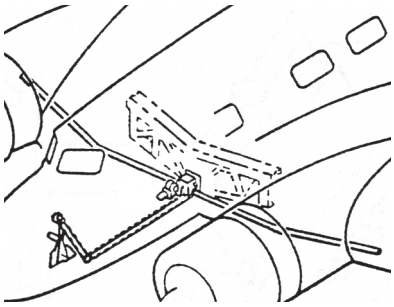


Introduced in 1934, the first Electra – c/n 1001 – featured the then-fashionable forward slanting "Fokker style" windshield.

The Flying Cement Mixer

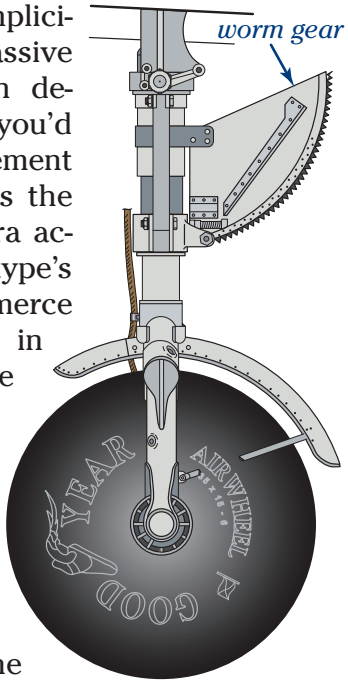
Like the rest of the airplane, the system devised for retracting the wheels was straightforward and robust. Steel drive shafts extended out from a centrally mounted electric motor and transmission. A "worm" on the end of each shaft engaged the cogs of a steel "worm gear" – Part Number 41065 – bolted to the rear of each landing gear

strut. When the shaft rotated, the worm walked the worm gear and the attached strut and wheel rearward and upward into the engine nacelles.



As illustrated in the Model 10 Maintenance Parts Catalog, the Electra's retractable landing gear was driven by steel shafts that extended out from an electric motor and transmission mounted on the girder-like main beam.

The price of simplicity was weight. The massive "worm gear" has been described as "something you'd normally see on a cement mixer" and its bulk was the cause of the first Electra accident. On the prototype's final Bureau of Air Commerce certification test flight in August 1934 one of the wheels failed to extend for landing. Apparently one of the drive shafts was not up to the task. Lockheed test pilot Marshall "Babe" Headle made a successful one-wheel landing but the cost of repairs was a blow to the struggling young company.[3]



Landing Gear Installation 40650

Learning from Junior

Despite some birthing pains, the Model 10 was well received and by the end of 1935 nearly fifty Electras had been delivered to airlines such as Northwest, Pan American, Eastern, and Delta.[4] Hoping to expand on the success of the basic Model 10 formula, Lockheed entered a Bureau of Air Commerce design competition for a small twin-engine transport to serve feeder lines. By scaling down to a shorter fuselage with accommodation for six, rather than ten, passengers while keeping the same 450 HP engines, the Model 12 "Electra Junior" (there was no Model 11) would be faster and have better over-all performance than the Model 10, but weight reduction would be key. In the end, the Model 12 weighed in

In this photograph the worm gear can be seen on the left main landing gear strut of Earhart's Electra.

a full 18% lighter than its big sister, aided in large part by a new, lighter, faster landing gear retraction system.[5] Instead of the clunky worm gear, the Electra Junior's landing gear featured an articulating "knuckle" that was hinged in the middle and jack-knifed forward as the wheel was pulled up and back.

The Model 12 Electra Junior was smaller, lighter and faster than its big sister.

Babe Headle made the first takeoff in the prototype Model 12 on June 27, 1936, three days before the Bureau of Air Commerce competition deadline. The new design clocked a top speed of 225 mph at 5,000 feet and delivered a cruising speed of 213 mph (compared to 202 mph and 190 mph for the Model 10A) and won the Bureau of Air Commerce competition.[6] Adapting the new retraction system to the Model 10 was a no-brainer and, beginning with constructor's number (c/n) 1056 – a Model 10B delivered to Chicago & Southern Airlines – Landing Gear Installation 45100 replaced 40650 on all subsequent Electras.

In this photo of Lockheed Model 10A c/n 1130, under rebuild at the National Museum of Naval Aviation, the "new" retraction system – Installation 45100 – is clearly visible.

Lockheed test pilot Marshall "Babe" Headle with Amelia Earhart. "You see Amelia? We got rid of that heavy worm gear mechanism like the one on your airplane and replaced it with this new drag strut system." Ironically, the Electra in the photo is Model 10A c/n 1060, registered VH-UXH and destined for Guinea Airways in Lae, New Guinea.

Earhart's Model 10E Special, c/n 1055, was the last airplane built with the old worm gears.[7] It is a bit surprising that the system was not upgraded when the airplane was in the shop for extensive repairs following the Luke Field debacle but that was probably because time and money were in short supply. Photos of NR16020 in Lae, New Guinea leave no doubt that the airplane still had the 40650 system when it disappeared.

If we have a photo of a worm gear on the reef at Gardner Island (now Nikumaroro), what aircraft could it be from? Of the fifty-four Electras that had worm gears, only two airplanes ever traveled west of California. Model 10A, c/n 1034, was delivered to the Mesta Machine Co. in Pittsburgh, PA in August 1935 and, at some later time, was sold to Qantas Empire Airways in Brisbane, Australia. That airplane was destroyed in a crash near Charlville, Queensland in February 1949.[8] The only other candidate is Amelia Earhart's Model 10E Special, c/n 1055, and the wreckage on the reef can only be from that aircraft … unless somebody misplaced a cement mixer. ◆

Notes

1 Lockheed Model 10 Maintenance Parts Catalog – 1939.
2 Francillon, René. *Lockheed Aircraft since 1913*, Naval Institute Press, 1987.
3 Emmert & Larkins. "Lockheed's Model 10 Electra" in *Journal of the American Aviation Historical Society*, Summer 1978.
4 *Ibid.*
5 Francillon.
6 *Ibid.*
7 Lockheed.
8 Emmert & Larkins.

In Lae, New Guinea Fred Noonan assists with maintenance on the left engine propeller hub of NR16020. The bottom edge of the worm gear is clearly visible on the rear side of the left main landing gear strut.

THE DOGS THAT DIDN'T BARK

Scotland Yard detective: "Is there any other point to which you would wish to draw my attention?"

Holmes: "To the curious incident of the dog in the night-time."

Detective: "The dog did nothing in the night-time."

Holmes: "That was the curious incident."

"Silver Blaze," *The Memoirs of Sherlock Holmes,* by Sir Arthur Conan Doyle, 1894.

Just as important as the numerous pieces of archival, photographic and artifact evidence that point to the Earhart/Noonan flight having ended at Gardner Island (now Nikumaroro) are the people and events that might have discovered the fate of the lost flyers – but didn't. These are the dogs that didn't bark and they provide us with as many clues about what happened as do the dogs that did.

July 1937

For the first five nights after Earhart disappeared the dogs were fairly baying at the moon. Scores of radio signals believed at the time to be distress calls sent from the missing aircraft were heard by professional operators, licensed amateurs, and ordinary people listening on their home sets. The first week of the U.S. Navy's search was based on the theory that the calls were genuine and were being sent from one of the islands in the Phoenix Group. USS *Colorado* steamed south from Pearl Harbor with orders to search the reefs and islands but by the time the battleship reached the area, the signals had stopped.

Radio signals believed to be from the lost plane were heard for the first five nights after the Electra disappeared.

The dogs were silent when three aircraft from USS *Colorado* searched Gardner Island on the morning of July 9. The naval aviators saw nothing of Earhart's plane or its wreckage, but the Senior Aviator noted "signs of recent habitation." He didn't know that the island had been uninhabited since 1892.

October 1937

Led by Lands Commissioner Harry Maude and Cadet Officer Eric Bevington, a British expedition to evaluate the Phoenix Islands for future settlement spent three days, October 13-15, at Gardner Island three months after Earhart disappeared.

The object on the reef north of the shipwreck, visible in a photo taken by Eric Bevington in October 1937, appears to be the wreckage of one of the Electra's main landing gear assemblies.

One of the fifteen photographs Bevington took during their visit appears to show a separated landing gear assembly from Earhart's Electra on the reef about a quarter mile north of the shipwreck (see "The Object Formerly Known As Nessie," p. 30) but this piece of debris went unnoticed at the time and, once again, the dogs didn't bark.

November/December 1938

On November 30, 1938 a ten-man team arrived at Gardner Island to map the atoll and lagoon as part of the New Zealand Pacific Aviation Survey. The next day a Supermarine Walrus launched from the cruiser HMS *Leander* took aerial photos of the island. In those photos no aircraft or aircraft debris are apparent on the reef or in the water. The

This December 1, 1938 aerial photo clearly shows the shipwreck on the reef but the object in the 1937 Bevington Photo is not discernible.

object in the October 1937 photo is either gone or hidden by the surf.

While the New Zealanders were there, and totally unrelated to their survey, the Phoenix Islands Settlement Scheme (PISS) got underway when, on December 21, Harry Maude returned with an eight-man work party of Gilbertese laborers to start clearing land for a village on the south side of the main lagoon passage. The reports and correspondence related to that work mention nothing about aircraft wreckage.

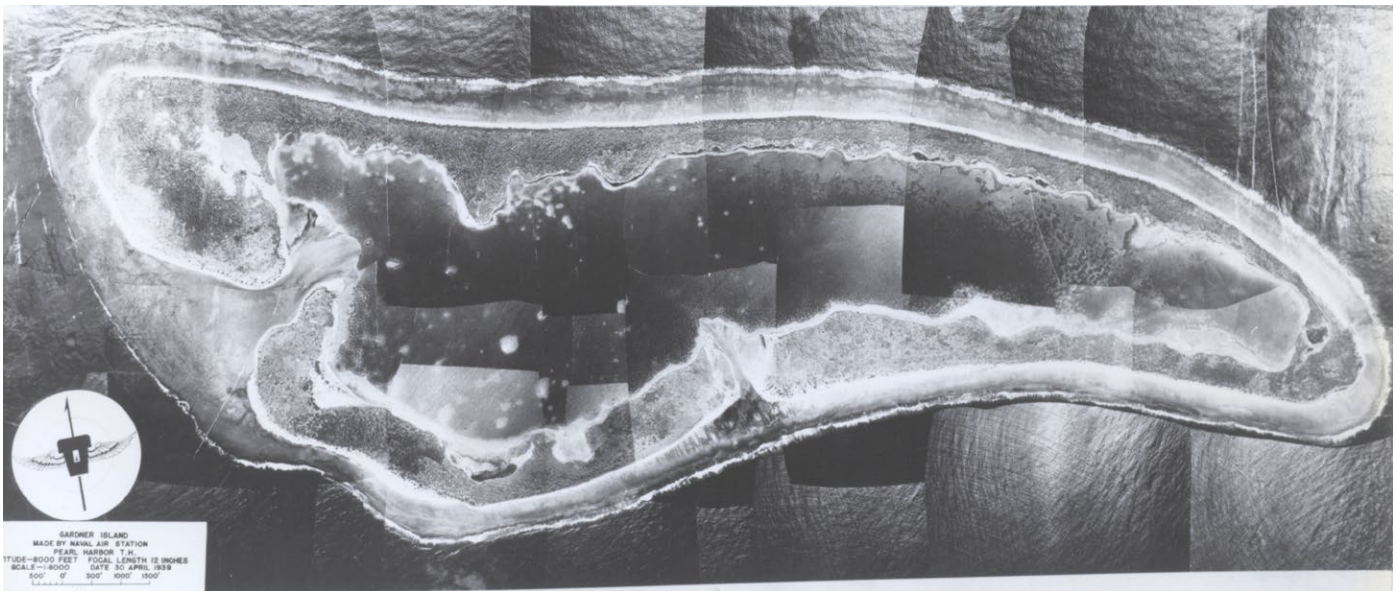
1939

The New Zealand survey party completed its work and departed on February 5, 1939. Their purpose had been to determine whether the island was a good prospect for the construction of an airfield. It wasn't, but the lagoon was judged to be suitable for seaplane landings. No aircraft debris was reported.

Clearing and construction of the village continued and, on April 28, the families of the Gilbertese laborers arrived – twelve new settlers. Two days later another aerial photographic survey of the island was flown, this time by the U.S. Navy as part of a Pacific islands strategic survey. A Grumman J2F "Duck" supported by the seaplane tender USS *Pelican* took photos for a mosaic of the entire island. No aircraft wreckage is apparent in the photo-mosaic but the photography was from high altitude.

On June 17, the arrival of more settlers brought the island population to fifty-eight (sixteen men, sixteen women, eleven boys and fifteen girls). In November a U.S. Navy team mapped the island and lagoon while the survey ship USS *Bushnell* took depth soundings in the surrounding waters. Through all this activity the dogs remained silent. No one seems to have noticed any airplane wreckage.

This photo mosaic of the island was created from high-altitude aerial photos taken on April 30, 1939. The individual images used to create the mosaic have not been found.



1940

The biggest dog who didn't bark was Gerald Gallagher, Officer in Charge of the Phoenix Islands Settlement Scheme. On September 23, 1940, soon after his arrival as the resident British colonial administrator on Gardner Island, Gallagher reported the discovery of a castaway's partial skeleton which he suspected was "just possibly that of Amelia Earhardt (sic)." Gallagher, a licensed pilot himself, was certainly aware that Earhart had vanished in an airplane and yet, in all of his correspondence with British officials, not once did he mention anything about an aircraft – no wreckage, no search for wreckage, not even speculation about what might have become of her plane. It could be that he knew the U.S. Navy's search had concluded that the plane had gone down at sea and assumed that if Earhart and Noonan had ended up on Gardner they arrived by liferaft. In any case, if there was an airplane wreck at Gardner in 1940 it seems likely that nobody knew about it yet – or at least didn't mention it to Gallagher.

Gerald B. Gallagher , Officer in Charge, Phoenix Islands Settlement Scheme, in his residence on Gardner Island 1940 or '41.

1941

In 1999, then age 76, former island resident Emily Sikuli told us of seeing a rusty strut-like object on the reef edge north of the SS *Norwich City* wreck. The location she marked for us on a map is virtually the same place where debris appears in the 1937 Bevington Photo.

Emily Sikuli in 1999.

Her father, Temou Samuela, told her the object was part of an airplane. Temou, the island carpenter, was bought to Gardner from Funafuti in the Ellice Islands in January 1940. With him came his family, including seventeen year-old daughter Segalo. In November 1941, Segalo left to attend nursing school in Fiji where she used an English first name and eventually married to become Emily Sikuli.

Emily/Segalo was on the island from January 1940 until November 1941. Gallagher was on the island from September 1940 until June 1941. He returned in September gravely ill and died within days. If Gallagher didn't know about the airplane debris and Emily did, the wreckage she described may have been discovered sometime in the five month period between Gallagher's departure in June and Emily's departure in November.

1944/45

For the first two years following Gallagher's death and the outbreak of war in the Pacific, British administration of the Phoenix Islands settlements was almost non-existent. The island had no resident European and visits by the District Officer, based at Canton Island two hundred miles away, were brief and rare. In July 1944, construction began on a U.S. Coast Guard Loran station at Gardner's southeastern tip. Construction was completed in September and the station went on the air in December. Coast Guard, and later U.S. Navy, PBY flying boats from Canton regularly resupplied the unit's twenty-five personnel with mail and perishables.

Ensign John Mims

Between December 1944 and February 1945 Ensign John Mims, assigned to Patrol Aircraft Service Unit (PATSU) 2-2 based at Canton Island, made eight trips to Gardner as co-pilot of U.S. Navy PBY-5 BuNo 08456. On one of those visits the settlers proudly showed him a large fish they had just caught. Mims was astonished to see that the hook in the fish's mouth was crudely fashioned from aircraft aluminum and the "leader" on the fishing line was a control cable from an aircraft smaller than a PBY. As Mims wrote in a March 1995 letter to the Smithsonian National Air & Space Museum:

> I asked the native about the hook and leader, and he promptly informed me that it came from a wrecked plane that was there when he arrived some three years earlier (apparently no one lived on the island prior to 1941).[1]

The first work party of the Phoenix Islands Settlement Scheme arrived in December 1938 so Mims' supposition that his informant arrived with the first settlers was incorrect, but the story does corroborate 1941 as a probable date for the discovery of airplane debris. When asked where the wreck was located Mims' informant just shrugged. Apparently by 1944 the wreck had either disappeared or whatever wreckage had washed up had been salvaged.

In addition to heavy-duty fishing tackle, Mim's saw the islanders on Gardner using

> …crude knives made from aluminum by grinding it with seashells and sand. At the present time I still have some jewel boxes and outriggers with inlaid diamond, heart, and star-shaped pieces of aluminum that they said came from the wrecked plane.[2]

TIGHAR had one of the inlays tested. It's aircraft–grade aluminum.

Ensign Mims was puzzled by what he had seen and the story he had been told. He couldn't imagine where an aircraft at Gardner in 1941 could have come from unless…. When he returned to Canton Island he asked the District Officer if the British had lost a plane at Gardner.

> He replied that no British planes had been there and neither had the Americans lost any planes there. I asked him if this could be a part of Amelia Earhart's plane and he said it could well be, but he had little interest in a story of a lost pilot since the war was in progress. Also, he joked that the woman was American and that the 4th of July and Thanksgiving with the Americans was about all the American history he could take.[3]

Coast Guardsman Glen Geisinger was stationed on Gardner from late 1945 until the closing of the Loran station in May 1946. Like Mims a year earlier, Geisinger bought or traded for carved wooden boxes and model canoes that featured metal inlays said by the islanders to have come from "the downed plane that was once on the island."[4]

During later war years, American servicemen bought or traded for carved wooden items inlaid with metal said to be from "the downed plane."

The stories told by Emily Sikuli, Dr. John Mims, and Glen Geisinger are anecdotal recollections of events in the past. They may or may not be accurate but they are independent – in that each had no knowledge of the others when they told their story – and yet their stories are mutually corroborative and consistent with the photographic evidence in the Bevington Photo.

It appears that during the early war years – 1941 to 1943 – when the island had little contact with the outside world, the wreckage of an airplane, or pieces of wreckage from an airplane, became accessible to the islanders. Some, if not all, of the island people knew about the discovery of a skeleton rumored to be that of the famous American Amelia Earhart, but no one seems to have connected that event with "the downed plane."

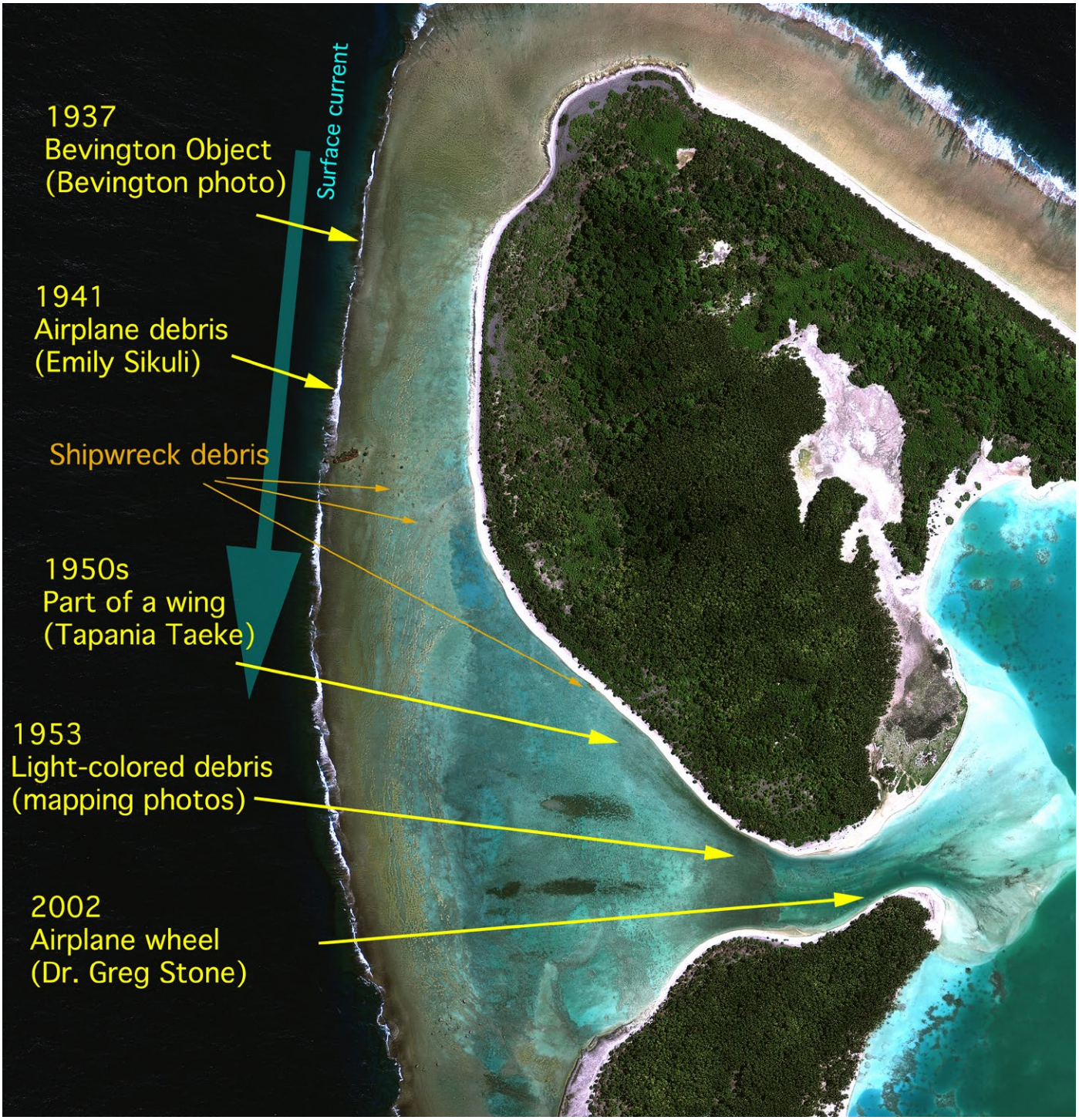
The curious now-you-see-it-now-you-don't nature of the airplane wreckage continued. No reports have come to light for the period 1944 to 1952, but forensic examination of aerial mapping photos taken in 1953 shows what appear to be four pieces of light-colored metal, perhaps as much as two meters on a side, on the reef near the entrance to the main lagoon passage. Several former island residents describe seeing airplane wreckage on the reef and on the beach in that area later in the decade.

1 Letter to Smithsonian National Air & Space Museum, March 1995
2 Letter to Smithsonian National Air & Space Museum, March 1995
3 Letter to TIGHAR, March 2000
4 Telephone conversation with Glen Geisinger 8-23-2001

Perhaps the most compelling aspect of the entire body of photographic and anecdotal evidence is how, each time wreckage is reported, the location is further south – as it should be based on the known environmental forces and as demonstrated by the distribution of *Norwich City* debris.

There is even some indication that debris from the aircraft may continue to move from the ocean, onto the reef, and into the lagoon. In 2002, during a marine biology expedition by the New England Aquarium, Dr. Greg Stone saw what appeared to be an airplane wheel stuck to the reef surface near the southern shore of the main lagoon passage. It hadn't been there during TIGHAR's expedition the year before and when TIGHAR came back to look for the wheel in 2003, it was gone, but it was also clear that, in the interim, the west end of the island had been pummeled and over-washed by severe storms.

All of the barking and non-barking from 1937 to the present tells a story that, if we can learn how to interpret it correctly, should tell us where and how to search for whatever wreckage still survives.



Introduction

The available evidence suggests that Amelia Earhart landed her Lockheed Electra on a particular section of the reef at Gardner Island (now Nikumaroro) and sent radio distress calls for several days before the aircraft was washed into the ocean leaving her and her navigator to survive as castaways on the uninhabited, waterless atoll. It's a hypothesis with a broad base of anecdotal and photographic support, but for it to be true the reef must be smooth enough and long enough to land on. Also, the reef must have been dry enough to permit a successful landing during the time Earhart could have arrived. Furthermore, for the radio signals to be genuine, the times of the credible signals must coincide with times when the water level on the reef was low enough to permit Earhart to run an engine to keep the the batteries charged. Those are specific, quantifiable, physical values that are not easy to determine for a location as remote as Nikumaroro and a point in time 75 years in the past. Bob Brandenburg's paper describes how we did it and what we discovered.

Time & Tide

Bob Brandenburg
TIGHAR #2286R

The Electra Landing Area

Pilots experienced in aircraft with tires similar to those on the Electra inspected the western reef during TIGHAR expedition Niku IIII[1] in September 2001. They found the surface dry at low tide, and suitable for landing the Electra in a strip (see photo previous page) about 50 meters wide,[2] bounded by the seaward edge of the reef, extending north from the wreck of the SS *Norwich City*, a ship that went aground there in 1929. They estimated the Electra could land safely with up to 0.15 meter (6 inches) of water on the surface. The reef immediately shoreward of the landing area was found too rough for landing, but suitable for taxiing the plane.

Tide Computation Considerations

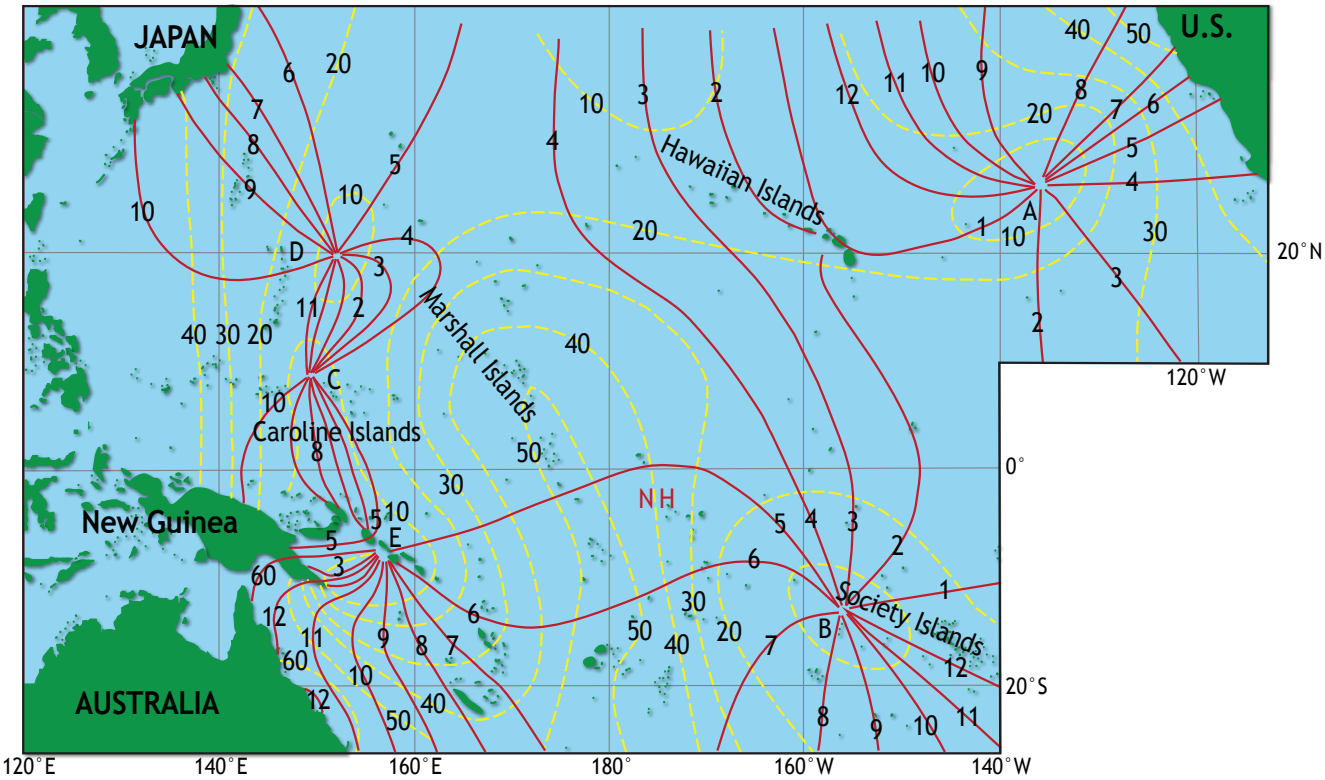
Tide tables are published for many places, and give tide height versus time of day. Tide height is the sum of the heights of harmonic constituent tides,[3] which are functions of harmonic constants derived from time series of hourly tide observations for at least 29 days. However, tide tables have never been published for Niku, and TIGHAR collection of the data needed for deriving harmonic constants would not be practicable. A feasible alternative would be to use a tide reference station for which July 1937 hindcasts are available, and find Niku tides by offsetting reference station tides, by an amount based on statistical correlation of tides at both places. This would require far fewer Niku tide observations than for deriving harmonic constants.

Tide Reference Station Selection

Hull Island (4°30´S, 172°10´W),[4] 143 nautical miles (nmi) east of Niku (4°40´S, 174°33´W), is the nearest island, and was selected as the tide reference station. Hull Island tide predictions and hindcasts are available from the UK Hydrographic Office (UKHO).[5]

The selection of Hull Island was informed by the work of Luther and Wunsch[6] on central Pacific harmonic constituent tides. Figure 2 is their chart of the lunar semi-diurnal (M2) constituent, the principal component of the Hull Island tide;[7] the solid curves are cotidal lines,[8] and the dashed curves are co-amplitude lines.[9] The chart is annotated for this paper to show the locations of Niku (N), and Hull (H), which are on about the same cotidal line, and slightly different co-amplitude lines, suggesting near-synchronous tides of similar heights.

Figure 2



Niku Tide Observations

Hull Island tide tables were used during Niku IIII to test the tide synchronicity suggested by Figure 2. Tides in the landing area were observed to occur at approximately the times predicted for Hull Island. Tide heights were not measured because it could not be assumed that the reef surface height, and thus tide height, everywhere in the landing area would be the same as at a single measurement point; and making concurrent measurements at multiple locations would not be practicable. Moreover, walking on the reef there is hazardous except near low tide. Post-expedition analysis of *Norwich City* engine photos found that the lowest tide during Niku IIII occurred at the time of lowest astronomical tide at Hull Island, confirming that Hull and Niku tides are synchronous.

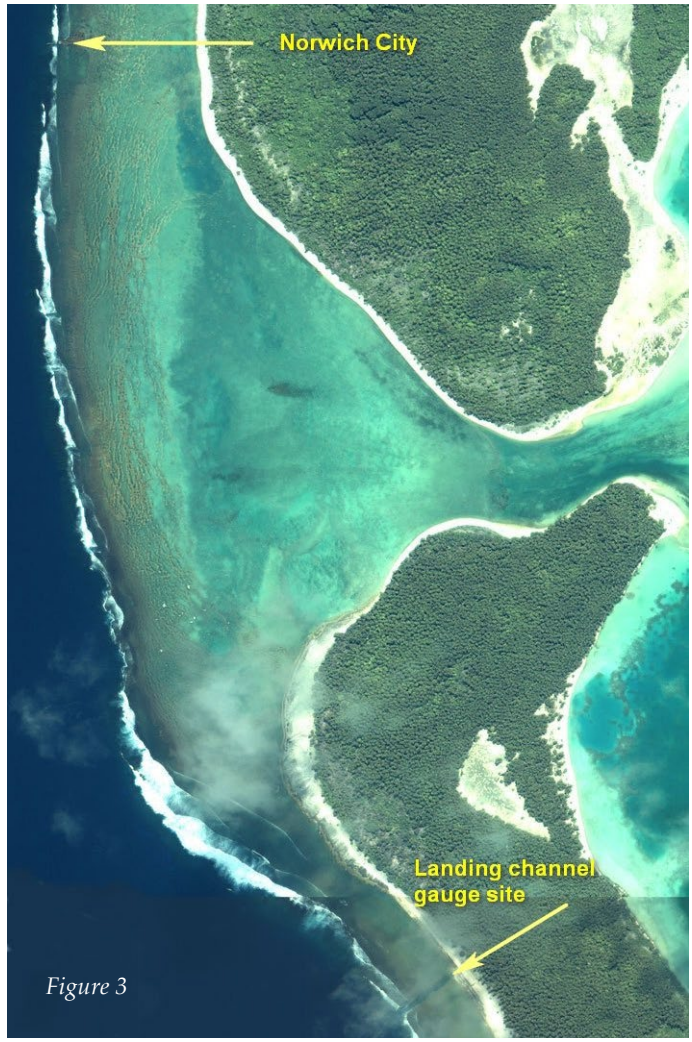


Figure 3

It was decided that future expedition tasking would include data collection for correlating Niku tides with Hull Island tides, using a tide gauge at a convenient location, and a leveling survey to measure landing area reef heights relative to the gauge site. The collected data would be used in deriving an algorithm for offsetting the Hull Island tide to find the tide in the Electra landing area. The boat landing channel through the southwest reef (Figure 3) was selected as the gauge site; a gauge there could be read from the expedition ship's boat while carrying personnel to and from the island. Several tide heights were measured by hand at the gauge site during Niku IIII, near low tide, to confirm time agreement with Hull Island tide.

A float-type tide gauge was installed at the landing channel site during expedition Niku Vp in 2003.[10] However, it was found during post-analysis that the data collected were unusable, due apparently to anomalous gauge behavior not evident in the field. A second attempt, with a pole-type gauge during expedition Niku V in 2007,[11] was successful.

Tide Correlation

The landing channel tide heights collected during Niku IIII and Niku V were correlated with Hull Island tides by linear least squares regression (figure 4), yielding correlation coefficient r = 0.981, and regression line (Equation 1):

$$T_C = 1.156T_H - 0.6098$$

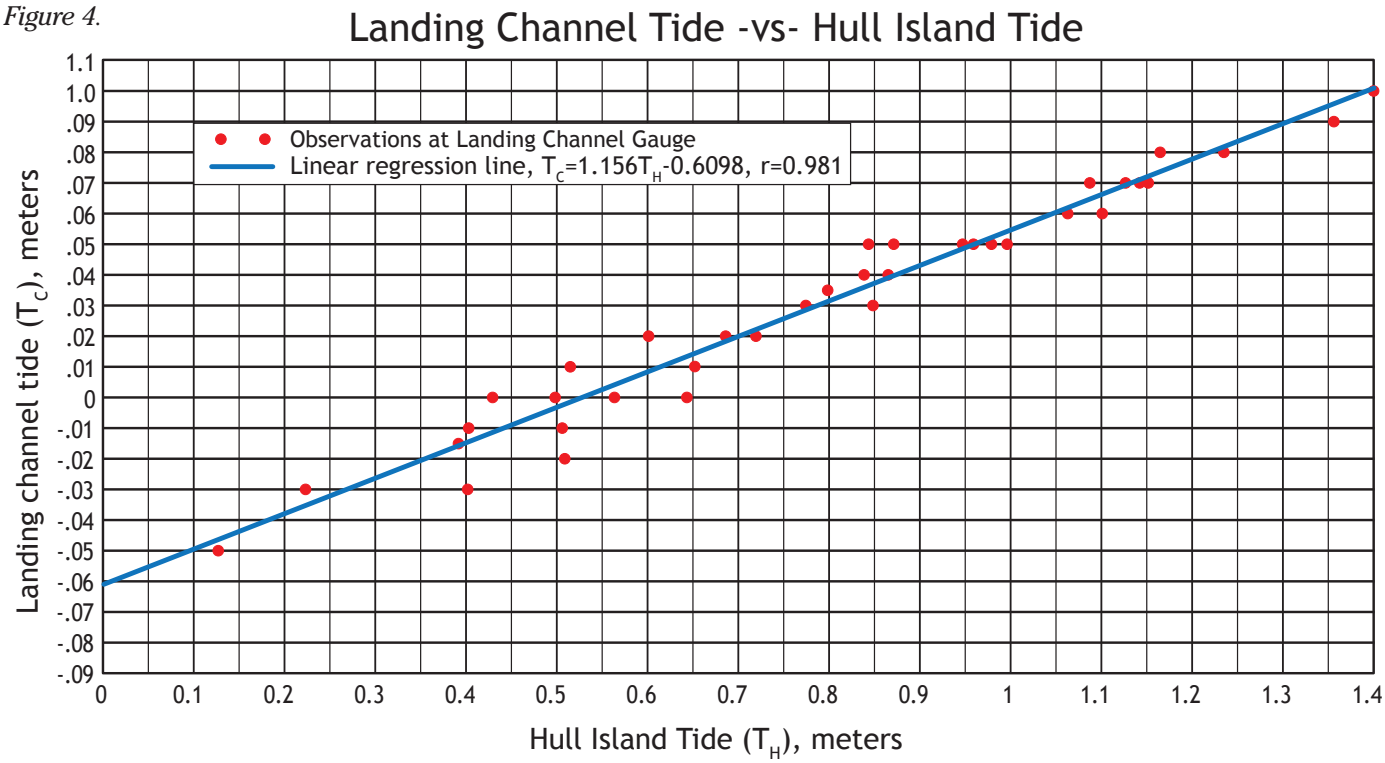
where T_C and T_H are the respective heights, in meters, at the landing channel and Hull Island. See Figure 4, next page.

Surveying the Reef

A leveling survey[12] during expedition Niku V measured Electra landing area reef heights relative to the landing channel gauge site. The survey was done in two phases because the landing channel site is not visible from the Electra landing area.

In phase 1, the survey instrument was sited on the southwestern shoreline, at a location with concurrent sight lines to the landing channel gauge site and a point, designated survey point A, at the *Norwich City* wreckage. The reef surface at point A was found to be 0.21m lower than at the gauge site, there-

Figure 4.



fore the point A tide is 0.21m higher than at the gauge site. Applying this difference to equation (1) gives the point A tide (TA), in terms of the Hull Island tide (equation 2):

$$T_A = T_C + 0.21 = 1.156T_H - 0.6098 + 0.21 = 1.1560\,T_H - 0.3998\text{m}$$

In phase 2, the instrument was sited on the shoreline east of the *Norwich City,* and reef heights relative to point A were measured. The results are shown in figure 5.

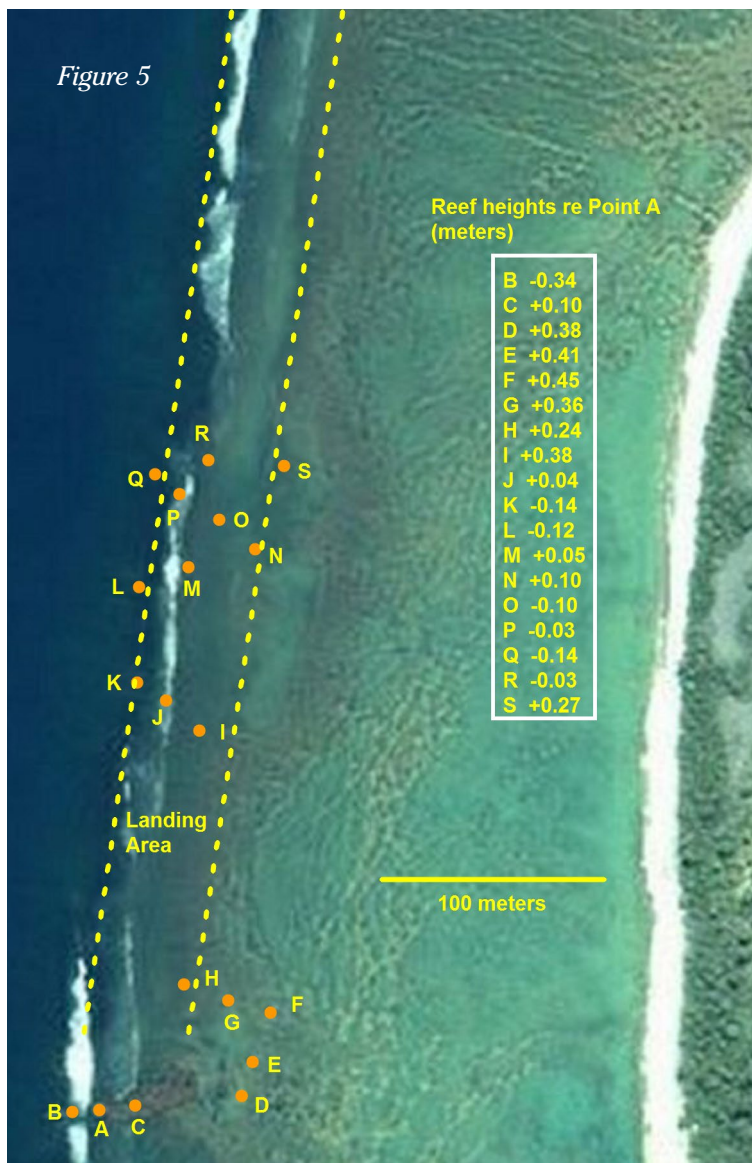


Figure 5

Hindcasting Tides in the Electra Landing Area

The tide height at a given point in the Electra landing area for a given date and time is found by solving equation (2) for the tide height at point A, and applying the reef height differential for the point of interest. For example, the reef surface at survey point I is 0.38m higher than at point A, hence the tide level at point I is 0.38m lower than at point A (Equation 3):

$$T_I = 1.156T_H - 0.3998\text{m} - 0.38\text{m} = 1.156T_H - 0.7898\text{m}$$

Testing the TIGHAR Hypothesis

The TIGHAR hypothesis[13] – that Earhart landed her Lockheed Electra 10E on the western reef of Niku on 2 July 1937, and sent radio signals[14] from there until 8 July 1937, when tide

and surf forced abandonment of the aircraft[15] – relies on three implicit assumptions, each requiring satisfaction of a tide-governed constraint:

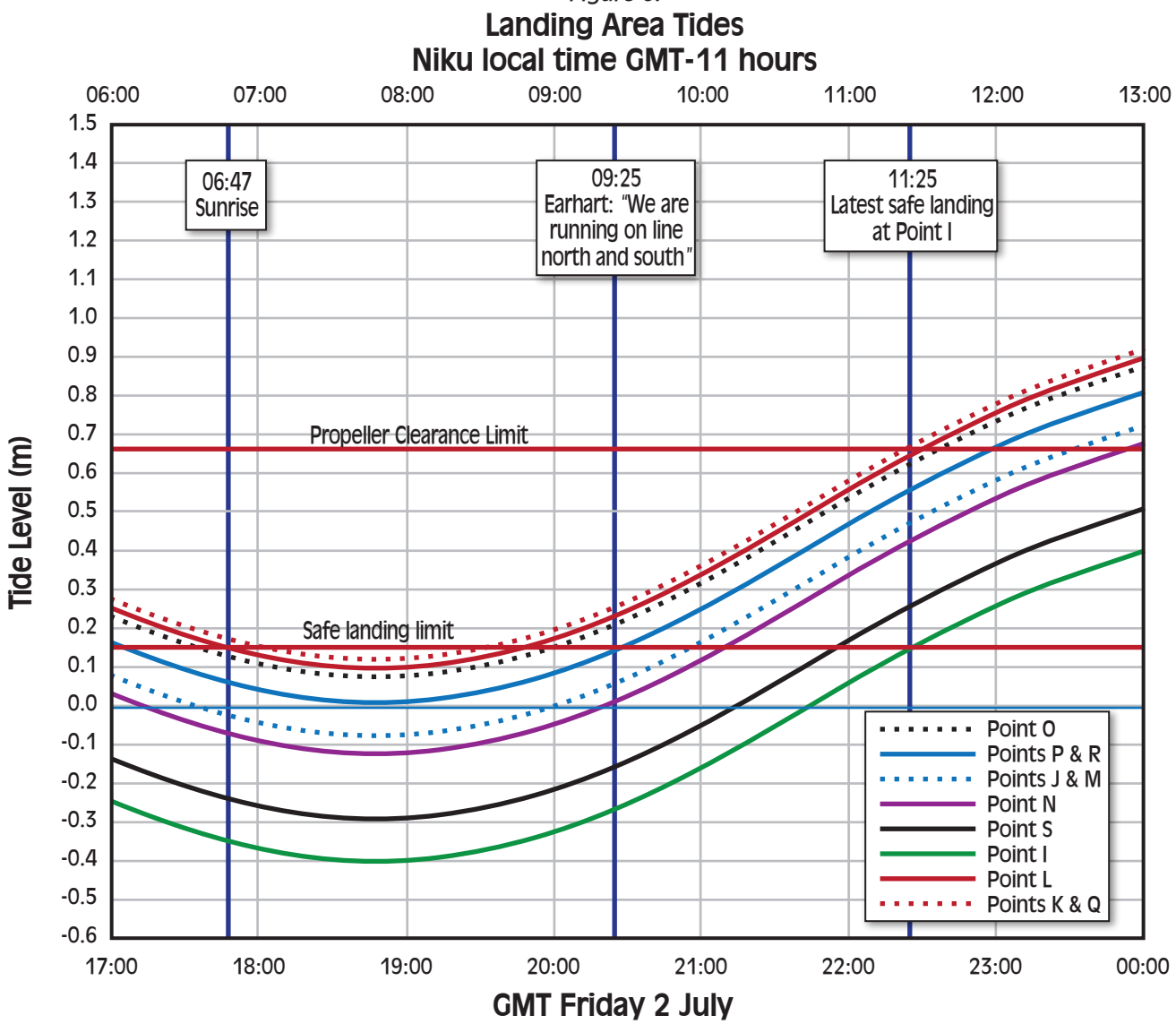
- the plane landed before the tide exceeded the 0.15m safe landing limit;
- the plane was parked where the radio transmitter was not subject to tidal flooding;
- tide allowed operating the plane's engine-driven generator for radio transmission and battery charging.

The hypothesis was tested with respect to each constraint, in the context of a northbound landing approach over the *Norwich City* wreck, as was flown by a helicopter[16] simulating an Electra landing during expedition Niku IIII. The hypothesis would be confirmed only if it was possible for all three constraints to have been satisfied, and would be false otherwise.

Time Zones. Niku local time is GMT-11 hours for this analysis, to agree with the UK Hydrographic Office zone time for Hull Island tides. Local time on the Coast Guard cutter *Itasca*, at Howland Island, was GMT-11.5 hours.[17]

The Landing Time Constraint. Figure 6 shows the tide versus time at each surveyed point in the Electra landing area the morning of 2 July 1937.

Figure 6.



The tide in the landing area was low at 07:43 Niku time and rising when the *Itasca* heard Earhart at 08:55[18] (09:25 Niku time), say "We are running on line north and south." Points S and I were above water then, and the tide was at or above the safe landing limit at points K, L, O, P, Q, and R. The limit subsequently was reached at Points J and M (09:52); point N (10:06); point S (10:55); and point I (11:25).

Table 1 shows landing times for various enroute speeds, given the 09:25 distance from Howland, if the Electra was on the 157°/337°[19] line of position through Howland Island. The times include a 15-minute search for a landing place after arriving overhead Niku.

Table 1

09:25 Niku Local Time		Landing time vs. Electra enroute speed			
Dist (nmi) Howland	Dist (nmi) Niku	87 kts (100 mph)	104 kts (120 mph)	113 kts (130 mph)	130 kts (150 mph)
0	350	13:41	13:01	12:45	12:21
20	330	13:27	12:50	12:35	12:12
40	310	13:13	12:38	12:24	12:03
60	290	13:00	12:27	12:13	11:53
80	270	12:46	12:15	12:03	11:44
100	250	12:32	12:04	11:52	11:35
120	230	12:18	11:52	11:42	11:26
140	210	12:04	11:41	11:31	11:16
160	190	11:51	11:29	11:20	11:07
180	170	11:37	11:18	11:10	10:58
200	150	11:23	11:06	10:59	10:49
220	130	11:09	10:55	10:49	10:40
240	110	10:55	10:43	10:38	10:30
260	90	10:42	10:31	10:27	10:21
280	70	10:28	10:20	10:17	10:12
300	50	10:14	10:08	10:06	10:03
320	30	10:00	9:57	9:55	9:53
340	10	9:46	9:45	9:45	9:44

Entering the speed columns of Table 1 with the limiting safe landing time at a point in the usable set (J, M, N, S, and I) gives the distances from Howland and Niku from which it was possible to arrive and land safely at the point. A single case is sufficient to show that it was possible to satisfy the landing time constraint: Earhart could land safely at point I before 11:25 if her 09:25 distance from Howland was at least 120 nmi, depending on enroute speed. This result is consistent with radio signal propagation analysis[20] suggesting Earhart likely was between 80 and 210 nmi from Howland at 09:25.

Figure 7 (next page) shows a possible scenario for landing at point I before 11:25, with touchdown at point I, followed by roll-out and taxiing to a parking place somewhere upslope where the transmitter would be dry and the engine-driven generator could be operated. The feasibility of the taxi, parking, and engine-operation components of the scenario, in relation to tide, is examined in the next section.

The Radio Transmission Constraints. The two post-arrival tide constraints – parking where the transmitter would not be subject to tidal flooding, and allowing operation of the plane's engine-driven generator – are interrelated, and will be treated together in this section. These constraints are illustrated[21] in figure 8 (next page).

The ***dry-transmitter constraint*** was due to the transmitter location, on the cabin floor behind the auxiliary fuel tanks, 0.9m above ground when the plane was parked.[22] Neither the cabin nor the transmitter was watertight, so if the tide height exceeded 0.9m sea water would enter the transmitter,[23] rendering it inoperable thereafter.

Figure 7.

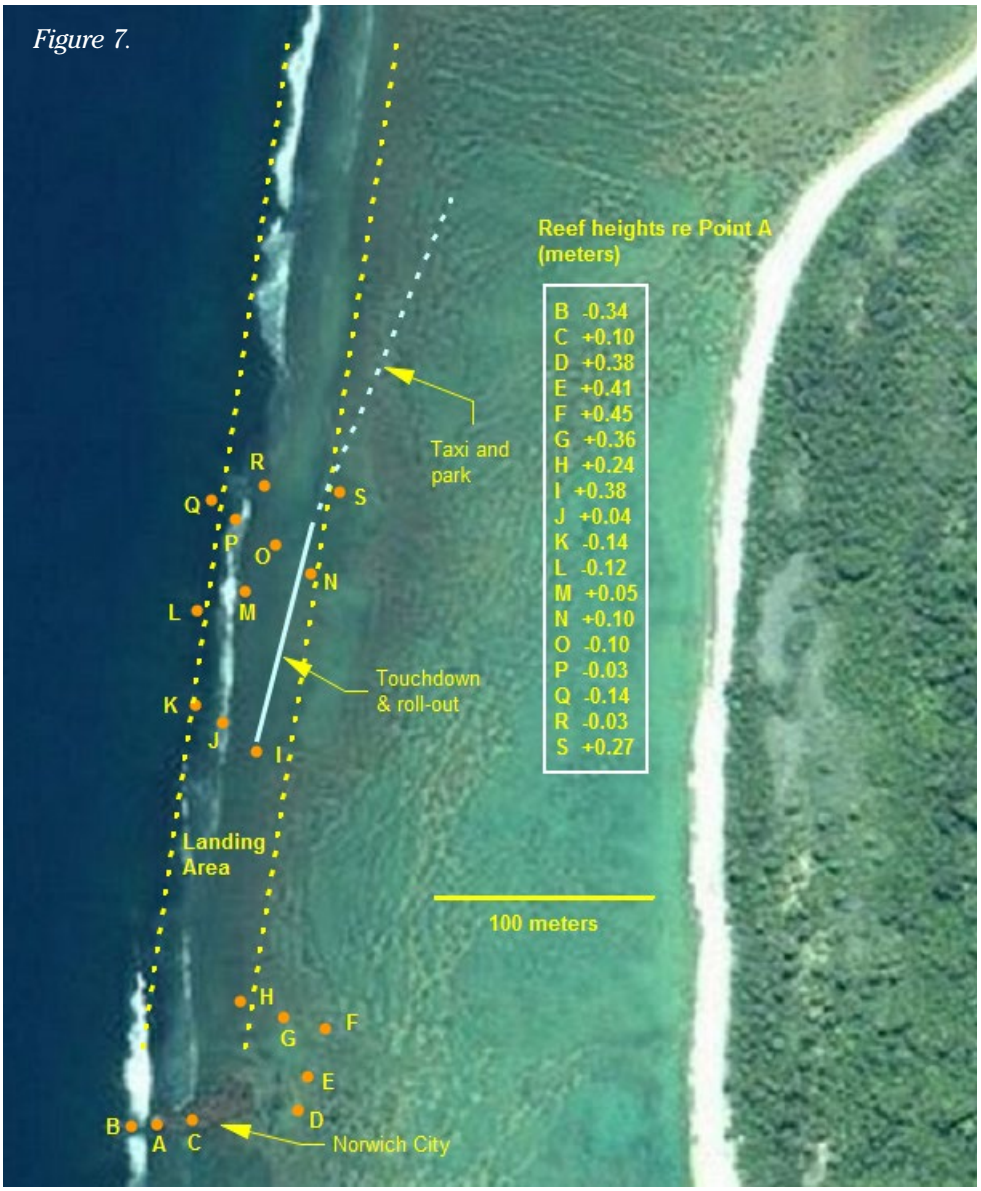
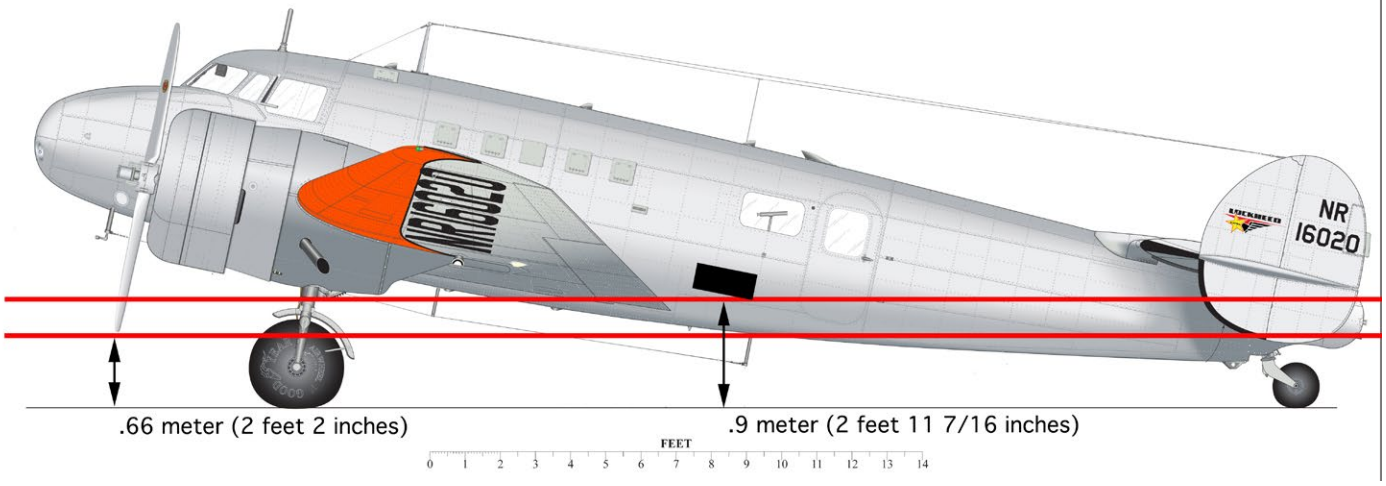


Figure 8.



The actual Electra parking location is unknown, but the reef height there required by the dry-transmitter constraint can be derived. The highest Hull Island tide during the period 2-8 July was 1.5m, at 0545 (GMT-11) on 7 July. The landing area point A tide at that time is given by Equation 2:

$$T_A = 1.156T_H - 0.3998m = 1.156 \times 1.5m - 0.3998m = 1.334m$$

Therefore, in order for the tide at the parking place not to exceed 0.9m, the reef height there must be at least 1.334 - 0.9 = 0.432m greater than at survey point A. This is just 0.052m greater than at point I, and 0.162m greater than at point S.

At least one credible radio signal[24] was heard each day during the period 2-8 July 1937, suggesting the plane was parked where the transmitter was dry and operable. The reef height at survey point F – 0.45m greater than point A – shows it was possible for the required height to be found upslope of the landing area. The reef slope indicated by the survey data suggests the required parking area height could be found within 50 meters shoreward of the landing area. Clearly, Earhart had no way of knowing the reef height anywhere, but she could have found a suitable parking place merely by taxiing as far upslope as the reef surface permitted. Therefore, the evidence supports a conclusion that it was possible to satisfy the dry transmitter constraint by taxiing as shown in Figure 7.

The ***engine operation constraint*** was due to the Electra's propeller ground clearance, 0.66m (26 inches),[25] the low point of the arc described by the propeller tips during engine operation when the plane was taxiing or parked. Engine operation with a tide level above 0.66m would result in propeller impact with water, causing catastrophic engine damage.

Taxiing to the parking place after landing was possible only if the tide level was below the propeller clearance limit. The tide (Figure 6) was below the propeller clearance limit at points J, M, N, S, and I until well after 11:25, so it was possible for the plane to taxi in the landing area, and to a parking location upslope.

As in the case of taxiing, operation of the engine-driven generator for radio transmission and battery charging was possible only when the tide level at the Electra parking place was less than 0.66m.

The relationship between tide and radio transmissions evaluated as credibly having been sent from the Electra at Niku[26] is illustrated in Figures 9 through 14, which show the tide curve for each day 3-8 July 1937, with the dry transmitter and the propeller clearance limits, at any location where the reef height exactly satisfies the dry transmitter limit. If the plane was parked where the reef surface was higher, the tide curves would be correspondingly lower on the respective plots. Credible radio signals are shown as green bars; signal details are in the signal catalog.[27]

With the exception of one signal on 4 July (Figure 10), when the tide level was just at the propeller clearance limit, and two signals on 5 July (Figure 11), when the tide was at or above the propeller clearance limit, all credible signals were heard when the tide level was below the limit. Those signals could have been transmitted on battery power, without operating the engine-driven generator. However, if the plane had been parked where the reef height was only 0.1m higher than required for the transmitter to be dry, the tide would have been below the propeller clearance limit for those signals, allowing engine operation. The evidence supports a conclusion that it was possible to operate the engine-driven generator for radio transmissions, and between transmissions for battery charging.

Conclusion

Application of tide hindcasting has shown that it was possible for Amelia Earhart to land her Lockheed Electra 10E on the western reef of Niku on 2 July 1937, and send radio signals from there until 8 July 1937. If future research requires hindcasting tides at reef locations other than those discussed herein, the only additional information needed would be the results of a leveling survey to find the associated reef surface heights. ◆

These illustrations plot the credible post-loss radio signals against the tidal rise and fall of the water level on the reef for July 2-8, 1937 for anywhere the reef surface is 0.43m higher than reference point A. The Electra, parked at such a location, could transmit as long as the water level did not exceed the "Radio transmitter dry limit" and could run an engine any time the water level was not above the "Propeller clearance limit." Note that the water level is never high enough to flood the transmitter. The credible radio signals occur almost exclusively during hours of darkness at Nikumaroro and only at times when the water level is low enough to permit engine operation to keep the batteries charged.

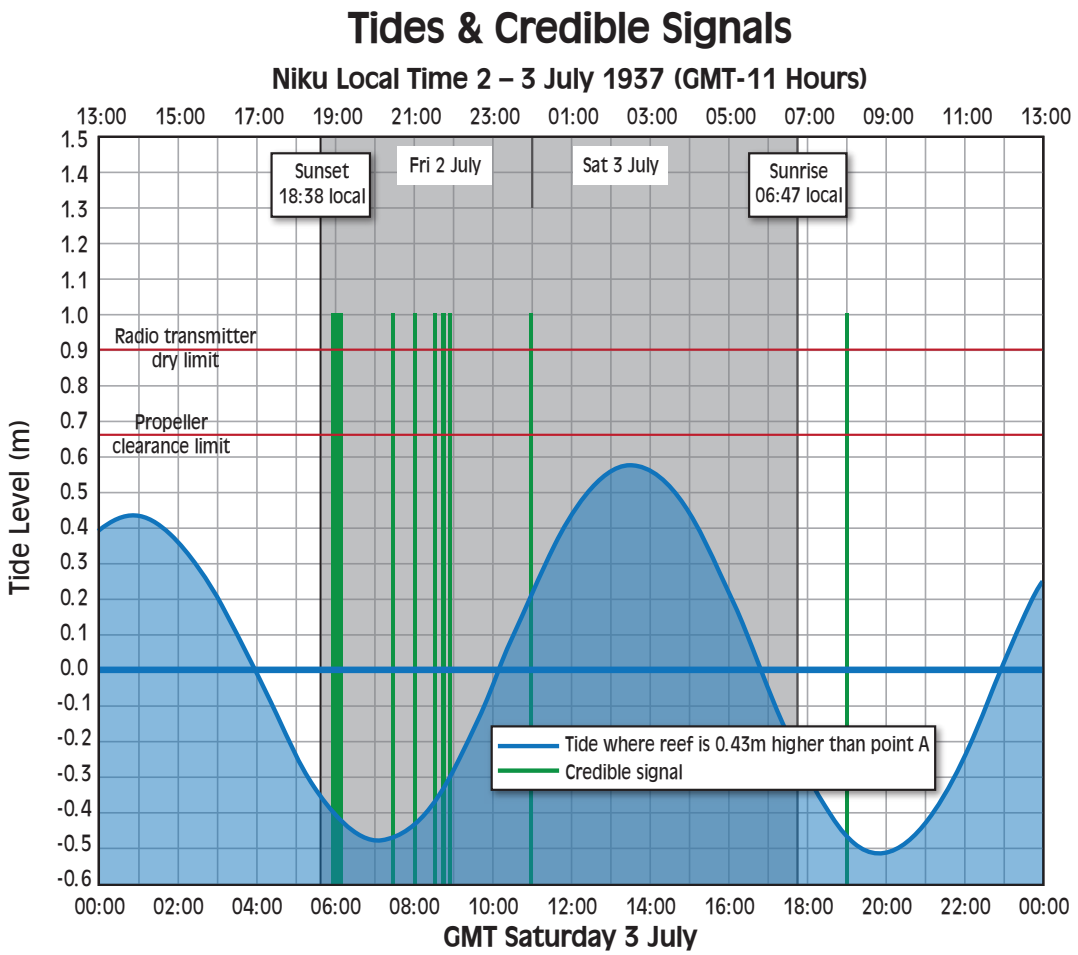


Figure 9

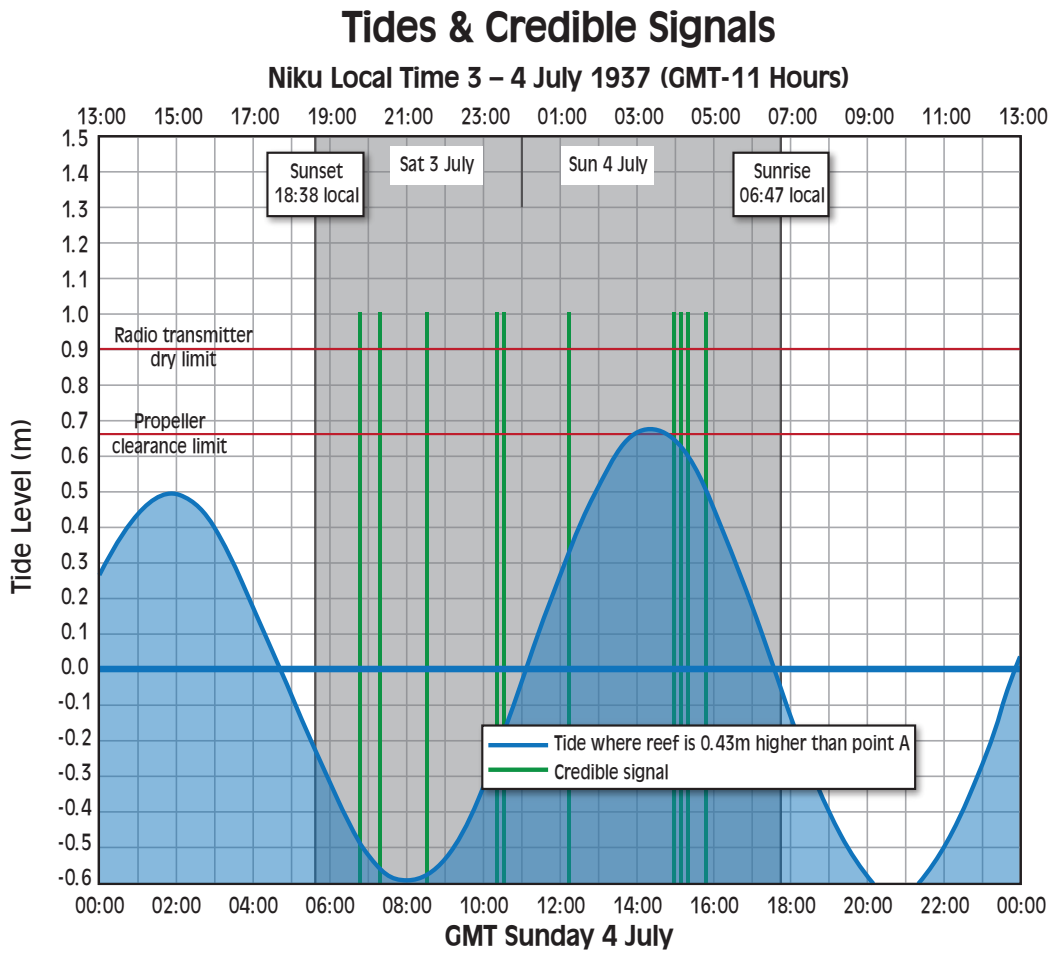


Figure 10

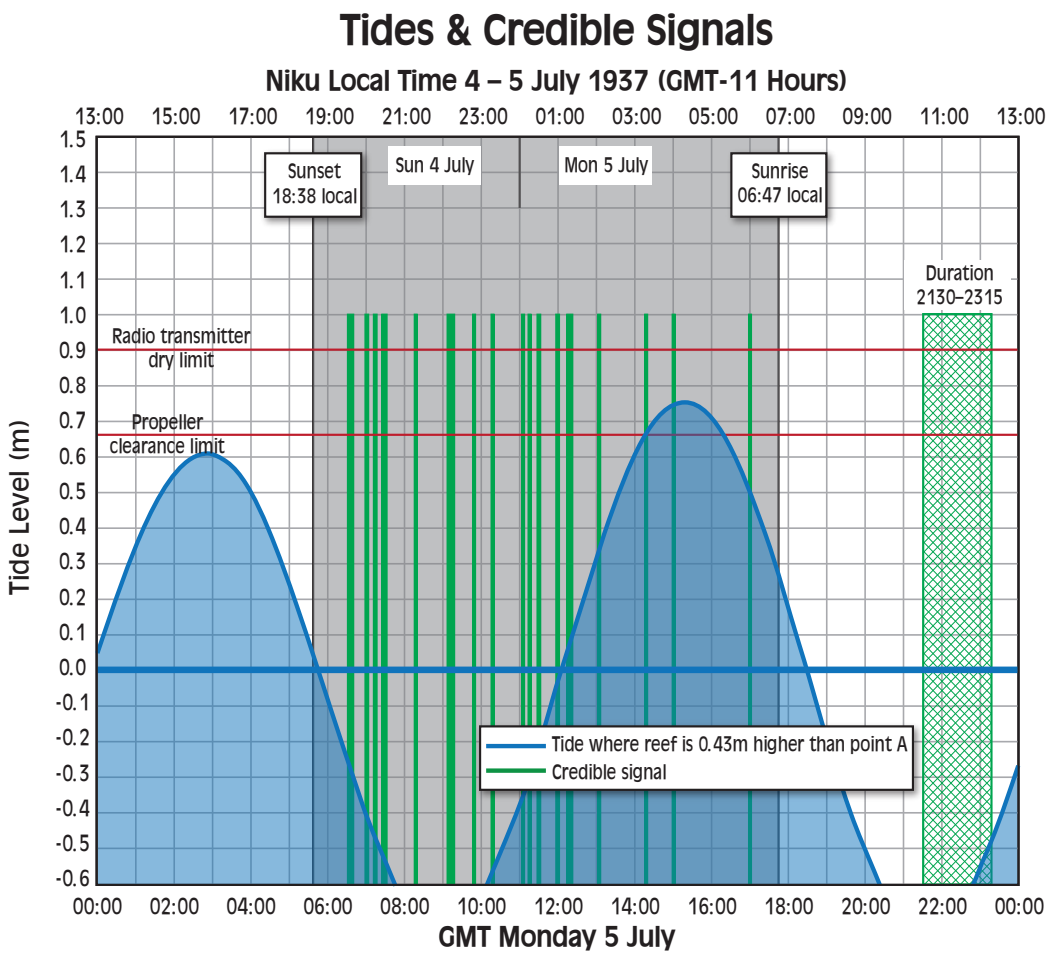


Figure 11

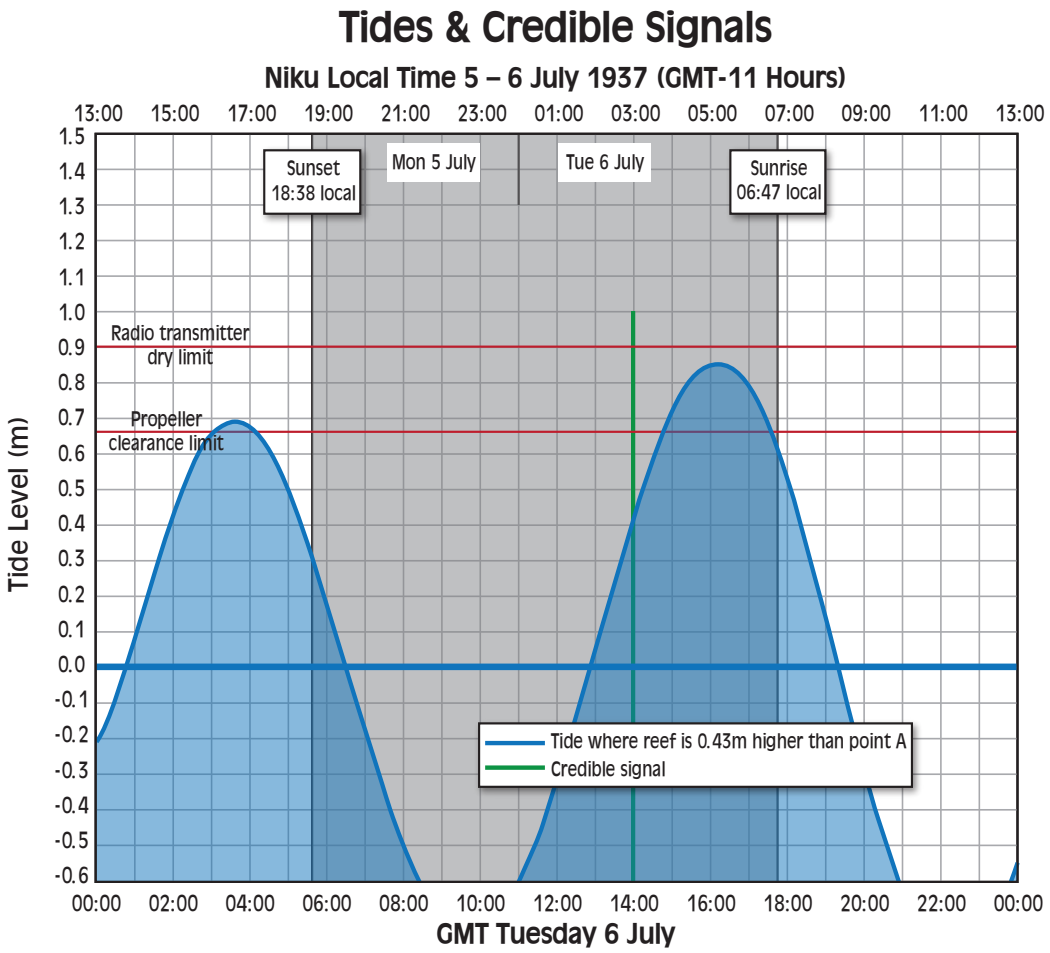


Figure 12

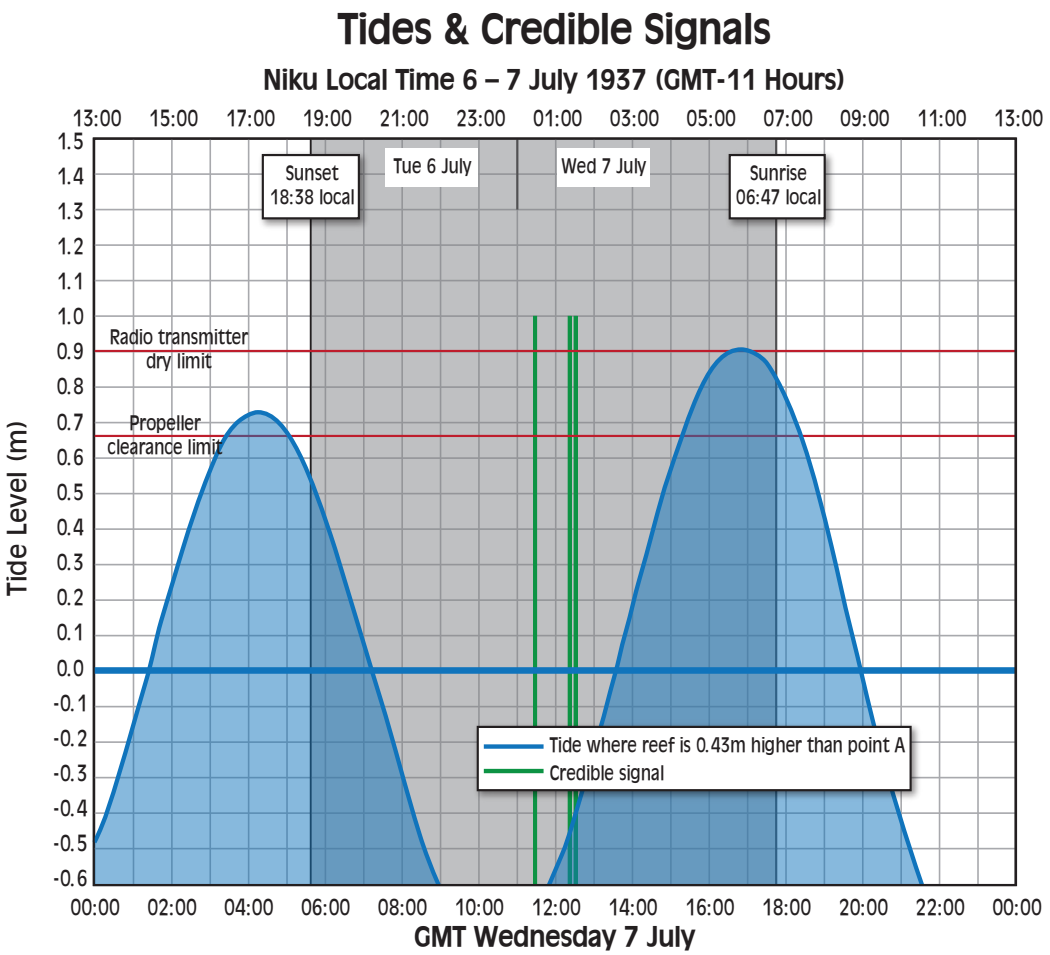


Figure 13

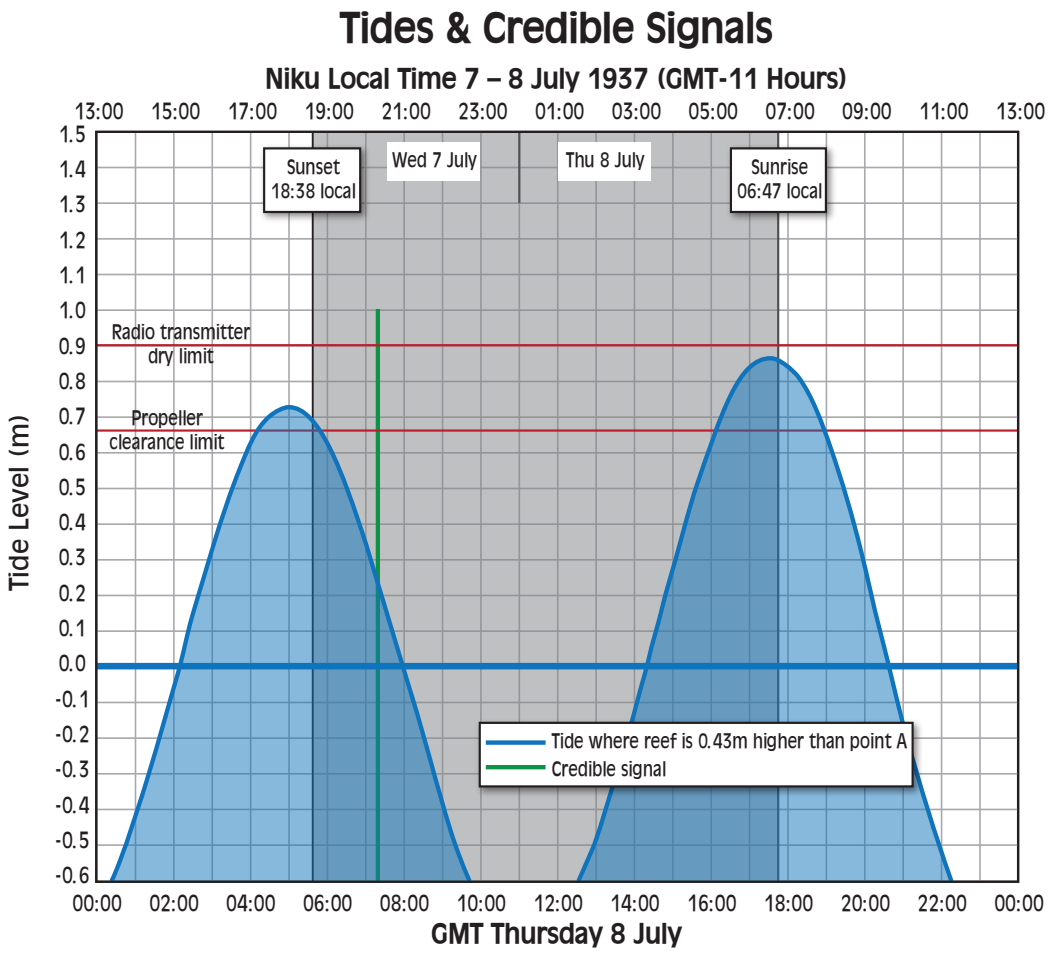


Figure 14

Notes

1 tighar.org/TTracks/2001Vol_17/1707.pdf

2 Ric Gillespie, TIGHAR Executive Director, personal correspondence.

3 Schureman, Paul. 1941. *Manual of Harmonic Analysis and Prediction of Tides*, U.S. Department of Commerce, Coast and Geodetic Survey, Special Publication No. 98. Washington: U.S. Government Printing Office, reprinted 1958 with corrections.

4 British Admiralty chart 184, "Plans of the Phoenix Islands," November 1991.

5 easytide.ukho.gov.uk. UKHO tide tables give the times and heights of low water and high water. Heights at intermediate times for TIGHAR research were computed by the author, using cosine interpolation.

6 Luther, Douglas S., and Carl Wunsch. 1975. "Tidal Charts of the Central Pacific Ocean." *Journal of Physical Oceanography* 2 (April): 222-230.

7 Luther and Wunsch, Table 1. The M2 tide accounts for 56% of the composite tide at Hull Island.

8 High water occurs simultaneously everywhere on a co-tidal line. Each line shows the Greenwich epoch (G), the phase lag in solar hours to high water after moon passage over the Greenwich meridian.

9 Amplitude (half the tide range), shown in centimeters, is the same everywhere on a co-amplitude line.

10 tighar.org/Publications/TTracks/2003Vol_19/NikuVp.pdf

11 tighar.org/Publications/TTracks/2007Vol_23/2303.pdf

12 With a Sokkia SRX Total Station, courtesy Instrument Sales & Service Co., Wilmington, Delaware.

13 tighar.org/Projects/Earhart/Overview/AEhypothesis.html

14 tighar.org/Projects/Earhart/Archives/Research/Research-Papers/Brandenburg/signalcatalog.html

15 tighar.org/Projects/Earhart/Archives/Documents/Lambrecht's_Report.html. USS *Colorado* aircraft did not see the Electra during an aerial search of Niku on July 9.

16 Video CD, "An Aerial Tour of Nikumaroro," narrated by Ric Gillespie, available at tighar.org/store.

17 Time Zones section of the Jacobson Database at tighar.org/Publications/Books/FindingAmeliaNotes.

18 tighar.org/Projects/Earhart/Archives/Research/Bulletins/49_LastWords/49_LastWords.html.

19 "The 3105 Donut" tighar.org/publications/TTracks/2008Vol_24/1008.pdf.

20 Ibid.

21 Courtesy Ric Gillespie.

22 William F. Harney drawings of Earhart's Electra, TIGHAR.org/store.

23 Suggested by Ric Gillespie, personal correspondence.

24 See footnote 14.

25 Harney drawings of Earhart's Electra.

26 See footnote 14.

27 See footnote 14.