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New perspectives on Sutton Hoo: the potential of 3-D graphics

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17.1 Introduction

The barrow cemetery at Sutton Hoo, near the town of Woodbridge in Suffolk, is known throughout the world for the discovery, in 1939, of a rich ship burial, generally accepted to represent the grave of an early East Anglian King, possibly Raedwald who died around 624–5 (see Bruce-Mitford 1975, Bruce-Mitford 1978, Bruce-Mitford 1983). The cemetery may originally have consisted of at least nineteen barrows, of which three had been trenched by Basil Brown in 1938 at the invitation of the landowner. In 1939 the rich ship burial was found in Mound 1 and excavation of the ship impression and the burial chamber proceeded during July and August 1939, immediately prior to the outbreak of World War II. The finds included gold and garnet shoulder clasps, a large collection of silver, a helmet, shield and sword.

Conservation, study and publication of the finds was achieved over the next 40 years, under the supervision of Bruce-Mitford. Further excavation between 1965–70 by teams from the British Museum revealed prehistoric features and traces of unaccompanied burials and cremations in the flat land between the barrows. In addition, Mound 1 was re-opened, enabling a complete plaster cast to be made of the ship impression.

A further major excavation campaign at Sutton Hoo commenced in 1983 under the direction of Martin Carver, in the hope of setting the earlier finds in a wider context (Carver 1983). This new attack on Sutton Hoo has so far

- established the extent of prehistoric settlement around the barrow cemetery;
- discovered and defined a flat Anglo-Saxon cemetery beyond the limits of the barrow area containing a number of bodies in a wide variety of dispositions; and
- re-opened Mound 2 where Basil Brown excavated a robbed ship burial, and established that Brown apparently followed the edge of a dinghy-shaped robber trench and that remains of a larger vessel may still be extant (see Carver 1986a).

Foremost amongst the aims of the current research project, however, is the desire to use the research project at Sutton Hoo as a laboratory and testing ground for the development of archaeological techniques, and advances have already been made in non-destructive survey (Royle 1985). Sutton Hoo offers a particular challenge to the excavator because of the nature of the surviving deposit. Traces of complex three-dimensional shapes have survived, representing ships, burial chambers, bodies and grave-goods. However, preservation is such that organic materials such as wood and bone invariably survive only as differential staining of the sand, perhaps with a slightly hardened or crusty exterior. Such features are difficult to excavate and frequently cannot be preserved intact as excavation proceeds. They then become a challenge for a conventional recording system which must attempt to allow reconstruction of a three-dimensional object from a series of 2-dimensional plans and sections. In other cases, features—such as the Mound 1 burial chamber—may have lost their original structure through the processes of post-depositional decay and disturbance. The challenge here is to reconstruct the original positioning of objects in the ground prior to collapse.

This paper will examine the rôle of computers, and in particular the application of three-dimensional graphics, in the generation and testing of hypotheses about Sutton Hoo. As is often the case, one of the initial benefits of computer modelling is to force the archaeologist to confront the existing data, and assess its value. Two aspects are highlighted. Firstly, our attention is directed towards what information is missing from previous work at Sutton Hoo. Secondly, this demonstrates what information should be recorded on the new excavations in order fully to exploit three-dimensional modelling.

The paper will be in four sections. Firstly we shall describe previous work on graphical modelling of Sutton Hoo. Secondly we shall discuss what the archaeologist may hope to gain from the application of computer 3-D graphics. We shall then describe the preliminary results of work in progress, and finally discuss some of the problems encountered so far.

17.2 Previous work

It is surprising that, during 40 years of study, no one has ever produced a three-dimensional reconstruction of the burial chamber with the objects placed within it. The 1939 excavations, whilst hurried, did provide records of the relative position of most of the 263 finds, although some individual relationships have been disputed (Carver 1986b). Nevertheless, the plan of the burial chamber does suggest aspects of the original disposition of objects.

Archaeologists have long appreciated the benefits of reconstruction drawings, although they have not always seen them as part of an hypothesis-testing process. Alan Sorrel's smoke-filled scenes have fired the imagination of the public, as well as providing measured reconstructions for a generation of archaeologists. Sorrell never produced a drawing of the burial chamber, but he did produce a view of the scene as the Sutton Hoo ship was hauled up from the Deben to be buried within Mound 1.

A cast of the ship was taken in 1967 but little reconstruction work has been attempted, with attention being focussed upon the objects themselves, rather than their relationships within a burial chamber.

Turning to the site itself, again very little modelling work has been attempted, although such work might be crucial to an understanding of the landscape context of the barrow cemetery. This was realised at an early stage by the current project and a full contour survey of the scheduled area was undertaken; over 10000 points were recorded by EDM. These were subsequently resolved into a contour survey at 10cm vertical intervals by Cooper, using a Ginosurf program by Ingram (Carver 1986c, Fig. 11).

Further 3-D manipulation and enhancement of these data would appear to offer the prospect for identifying hitherto unrecorded barrows and excavations. This takes us from the lack of previous attempts to reconstruct Sutton Hoo in 3 dimensions, to an examination of what might be gained though the attempt.

17.3 What the archaeologist hopes to gain

The benefits of applying 3-D computer graphical techniques to Sutton Hoo appear to lie in two main areas: archaeological, and general educational or public relations. Whilst the latter should not be underestimated in displaying the site to the public and getting visual images across it is the archaeological benefits which will principally concern us here. Four areas will be described:

- recording methodology;
- representation of recorded data;
- reconstruction of a static model; and
- simulation of a dynamic model.

17.3.1 Methodology of recording three-dimensional relationships

Analysing the structure of archaeological formations as they occur *in situ* is not simple. Apart from portable artefacts, the objects of archaeological enquiry (*e.g.* slight earthworks, collapsed buildings, rubbish pits, and so on) are not amenable to being moved around in order to obtain more informative views. With upstanding remains the observer is free to change views and viewing distances in order better to understand the form, scale and perhaps also the function of the thing being examined. In such circumstances we can, as it were, retrace our steps and have another look. This is not an option generally open to archaeologists, who are at the mercy of the amount of available light, its direction, and the vegetation cover, amongst other things. Excavators in particular are constantly confronted by the paradox that although archaeology is an observational discipline archaeologists only ever see a feature as a series of veneered surfaces. At any given time most of the entity is unobservable since outer, or upper veneers have been removed and subsequent veneers are still buried. In order to obtain a fuller understanding of these entities they must be reconstructed using the many details recorded from each of the observed constituent components. Ideally, since excavation involves the destruction of raw archaeological data, this form of investigation should be carried out to a level of precision which will ensure that every measurable detail recognised is committed to record in a form that will permit a complete three-dimensional reconstruction of the excavated area to be made at the defined level of measurement. With large data sets this process can be helped by harnessing the power of database systems used in combination with three-dimensional graphics.

Conventional archaeological recording systems use a combination of plan and section drawings to provide a record of interleaving three-dimensional deposits and features. Such records are incomplete as since they rely upon two-dimensional recording media they inevitably give an abridged record of the third dimension. Plans, for example, may be regarded as a number of horizontal slices through the ground which may be placed in a relative sequence. If they follow arbitrary spits then they literally are horizontal slices; if they follow the surface of contexts then a scattering of spot heights may provide some indication of general slope and surface topography of the layer. However, unless the layers or spits are recorded at minute vertical intervals it will not be possible to reconstruct the deposits at a later stage. Similarly, section drawings, unless undertaken at very frequent intervals across the site, only provide a series of single vertical slices.

Photogrammetric techniques do offer 3-D recording, but do not enable the archaeologist to distinguish between contexts as is required on a plan. Alternative methods would involve using a theodolite or EDM and taking readings across the surface of a context. At Sutton Hoo experiments have been undertaken using a theodolite and storing the *x-y-z* co-ordinates on hand-held Psion Organisers.

Another means of recording might be physically to digitise the surface of 3-D solids in situ. In order to record a context in 3-D it must be regarded as an irregular solid. In order to achieve a complete record of the context's shape then *x-y-z* co-ordinates would have to measured for every point on its upper and lower surfaces. Of course in practice the recording resolution will be determined by the resolution at which it will be necessary to manipulate the data. In practice, therefore, most archaeological features could be recorded, for example, on a regular 10cm grid, and since layer surfaces tend to consist of gentle curves rather than peaks and troughs a curve-fitting algorithm could be used to define the surface between adjacent points. For some contexts, such as the surface of bodies, a finer resolution may be required. Nevertheless it should be possible to determine the required sampling interval for any given class of context by measuring the difference in height between each point and the last for a number of sample contexts.

17.3.2 Representation and manipulation of recorded data

Having recorded 3-D data in this manner, computer manipulation becomes essential in order to use them. This does allow techniques of image enhancement to be applied, including simulated low-level lighting etc. It should also be possible to manipulate contexts on the VDU screen—not just as boxes in a stratigraphic matrix, but as solid objects with length, breadth and depth—and to examine the relationship between them. Of course there are limits as to the number of contexts which could successfully be displayed on the screen at one time, whether a wire-frame or a solid model was utilised.

17.3.3 Reconstruction of static model

The next stage would be the reconstruction of a static model of features, such as a burial ship, or chamber grave, from the amalgamation of the low level 3-D data. For the existing data at Sutton Hoo this requires interpolation of missing points, and the application of high technology to low technology data. As will be discussed later, in general it appears that the information recorded in 1939 is not sufficient to allow this sort of manipulation, without a high degree of interpolation.

17.3.4 Simulation of dynamic processes

The ultimate aim, and the most difficult to achieve, is to turn the static model into a dynamic one in order to understand the processes of deposition and disturbance. Martin Carver has suggested that the relationship of the objects within the burial chamber should allow some reconstruction of the sequence of collapse (Carver *pers. comm.*). In fact one is here taking the final position of the objects within the chamber, as revealed in 1939, and trying to understand what forces may have operated upon them to produce that position, and hence working back to their original position within the burial chamber. The computer provides an ideal tool with which to investigate alternative hypotheses for the collapse sequence, combining graphical modelling with physical laws.

17.3.5 Preliminary investigations

Computer graphics have a potential role in almost every aspect of the archaeological endeavour. The growing interest in terrain-modelling is a development with major implications for the analysis and presentation of topographic data. Certainly, this is true of the Sutton Hoo project. Graphics are being used with mixed success as exploratory tools.

17.4 Preliminary results of work in progress

17.4.1 The topographic data

There are said to be at least nineteen barrows within the Sutton Hoo burial complex. However, three of them—Mounds 15, 17, and 18 respectively have not been fully defined. The existence of these mounds was only suspected in recent years, in the course of the intense activity of archaeologists on the site in the latest Sutton Hoo campaigns. Apparently, these mounds have been seen on occasion, under exceptional lighting conditions, but they have not yet been isolated or recorded.

Several thousand spot-height readings were taken from the surface of the cemetery at the start of the present campaign. It can been seen that the density of spot-height readings is by no means uniform (Fig. 17.1). In fact the surveyors have obviously decided to take a greater number of readings from the surfaces of the more obvious earthwork features, such as the mounds and anti-glider trenches, than elsewhere. Ironically, it is precisely in those areas which are now thought to contain other, but topographically less distinct mounds, that the density of data points is least great! These levels were available as digital data, and had been computer-contoured in 1984 (Carver 1984, p. 1). The contour plan, although good, still masks quite a lot of interesting detail.

More of the information held in these readings could be assessed if the readings were presented in a three-dimensional form. The simplest method is simply to place a marker on the data point and display three-dimensionally. Colour can also be used to provide useful visual clues. For instance, we have used colour as a simple height-cuing device with bands of colour referring to a different range of height values. Most of the mounds show up fairly clearly. These data were displayed three-dimensionally on an IBM 5080 graphics device. With this unit one can dynamically clip the z-buffer, or, in other words, one can effectively shear away slices of the displayed image in the z-direction. This is a very effective device for showing any local topographic discontinuities. The ease with which the user can clip-away slices of the display is increased if the z-readings have been accentuated (Figs. 17.1 & 17.2).

Exaggerating height readings is itself another obvious and fairly commonplace technique for improving the definition of these features. Enlarging the z-values in the Sutton Hoo data by a factor of ten brings out further details about the site. In particular small islands of points representing as yet unidentified mounds have been revealed

However, with devices like the 5080, one also has access to full 3-D real-time graphics facilities which give the laboratory archaeologist the great added advantage of being able to simulate the aerial archaeologist, and 'fly' over the site and look for informative views. The attraction of this approach is that one is not constrained by seasonal lighting conditions which may be simulated if necessary. Without being able to demonstrate this point without the

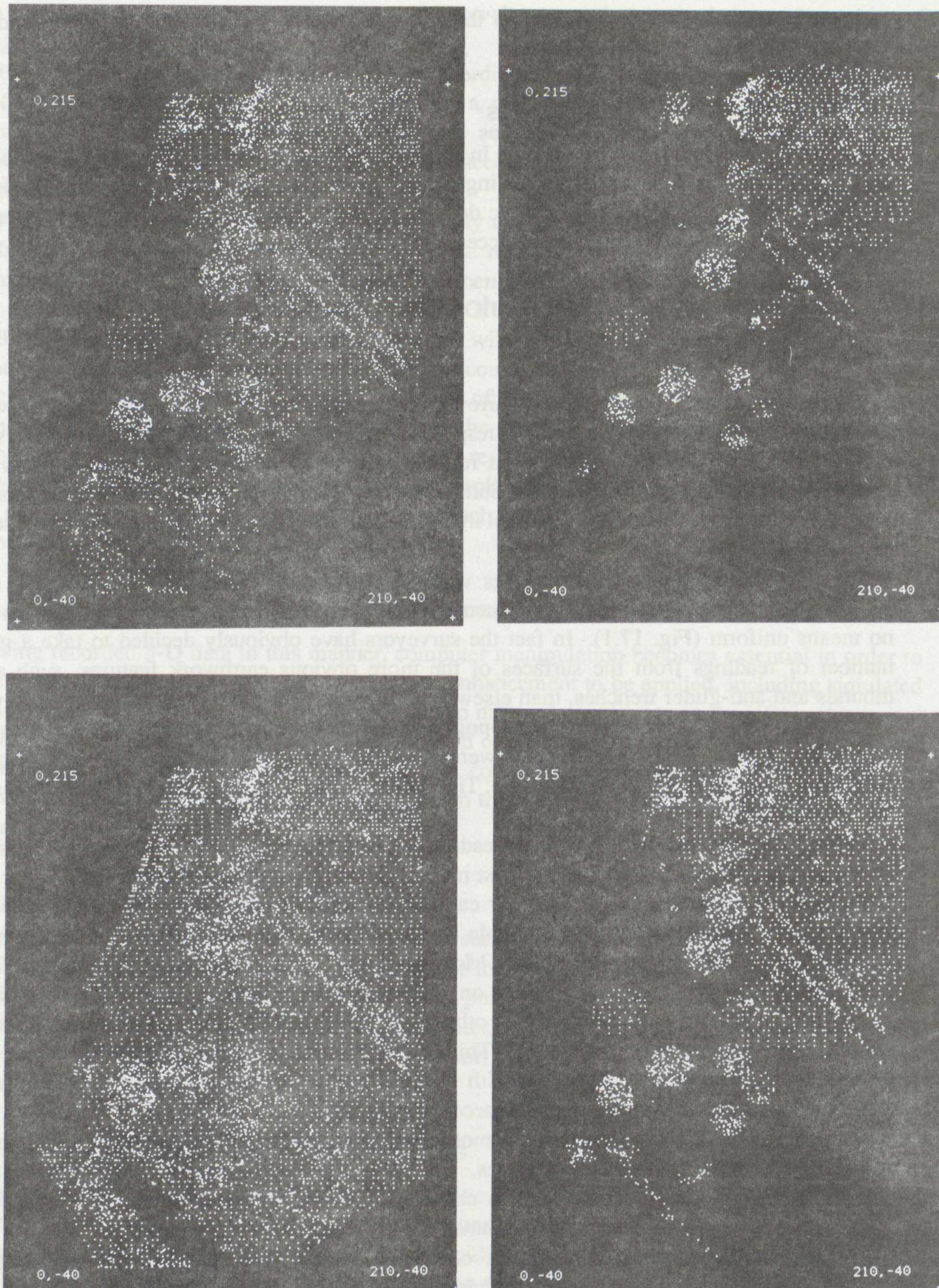

Fig. 17.1: Views showing where the Sutton Hoo spot height readings were made, with the lower readings being systematically sliced away

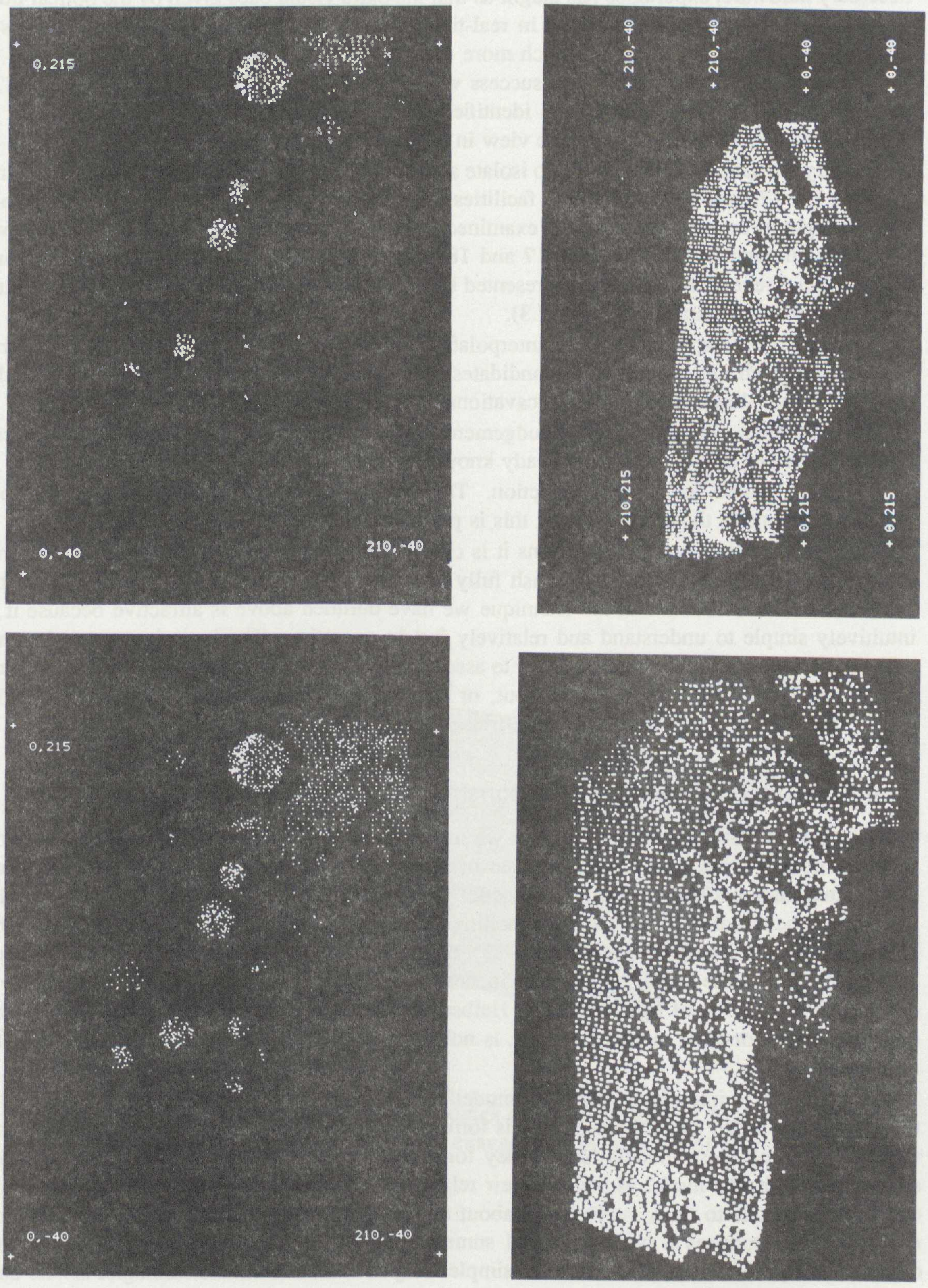

Fig. 17.2: Views showing where the Sutton Hoo spot height readings were made, with the lower readings being systematically sliced away *continued*

necessary hardware, experience has taught us that the extra visual cues given by the optical flow, caused by moving around the model in real-time, enables us to detect discontinuities, caused by changes in relief for example, much more quickly than through a series of static views. A similar approach has been used with success with other surveys (*e.g.* Reilly & Halbert 1987). Once an interesting feature has been identified, one can then think more about how best to display the point of interest in a static view in the more conventional modes of publication.

Recently we have been attempting to isolate some of the more ephemeral mounds, particularly Mounds 15, 17, and 18, using these facilities. The readings in the areas where the mounds were thought to be were isolated and examined separately using the technique outlined above. In the area thought to hold Mounds 17 and 18, this combination of colour-cuing, scaling and z-clipping did reveal two mounds, represented by only three or four readings, quite well. Could these be Mounds 17 and 18? (Fig. 17.3).

Certainly, other experiments with interpolated terrain models indicate other small features in the area which are also possible candidates. However, some of these features may be the remains of spoil-heaps from earlier excavations.

At the moment, we are reserving judgement about these mound-like features until we can establish whether any of them are already known to be something other than barrows.

Mound 15 has so far escaped detection. There is in fact one unusual reading at the spot where the mound is thought to be, but this is probably an erratic.

From these preliminary investigations it is clear that a greater density of readings will have to taken in the problem areas if we wish fully to define all the topographical features present. We think we have shown that the technique we have outlined above is attractive because it is intuitively simple to understand and relatively fast in operation. The investigator can interact with the data quickly, allowing him or her to assess rapidly whether a particular area is interesting or requires further work to be carried out, or whether more data needs to be collected. The same principle applies to the use of wire-framed terrain models.

17.4.2 Work on the computer reconstruction of the Mound 1 burial

Initially, one of our main hopes was that we might able to produce a computer reconstruction of the famous Mound 1 ship burial. It had been hoped that once a computer model had been constructed attempts could be made to model various post-depositional processes such as the collapse of the burial chamber. Solid-modelling, for instance, has been used to effect at with the temple precinct at Roman Bath (Smith 1985), the bath house at Roman Caerleon (Zienkiewicz 1986, back cover), the Saxon Minster at Winchester (Colley & Todd 1985) and an early medieval chapel site on the Isle of Man (Reilly & Halbert 1987). Stonehenge has also been prey to the computer animators; the model, however, is not particularly accurate as it was built as part of a fine art piece.

The approach is interesting since the modeller can create a series of images which can be transferred to a video and animated. In this form one can create a video tour of the model. The value of building these models is that they force the archaeologist to define explicitly every single element in the model as well as their relationship to other associated components. This exercise forces one to think very clearly about the data, and from that point of view it is very rewarding. It produces a working visual summary of the state of our understanding of the object of study; moreover, even the most simple insights will help the archaeologist isolate and examine more closely those areas where evidence exists to resolve particular problems. They also allow the public to assimilate a great deal of information rapidly and with little apparent

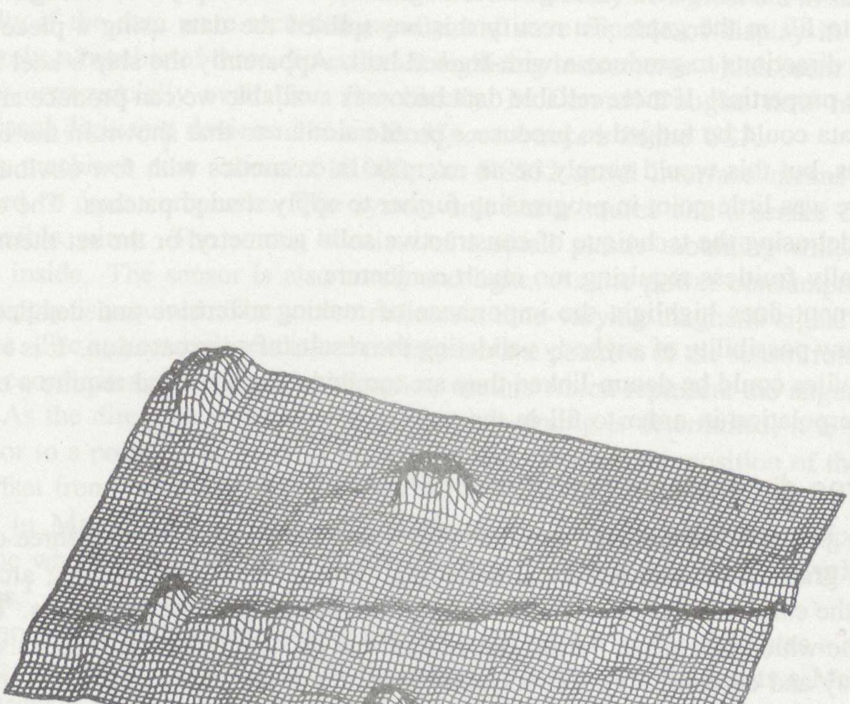

Fig. 17.3: Terrain model based on readings taken in the area of Mounds 17 & 18
Height readings have been exaggerated by a factor of four.

effort. Furthermore, they are not like artists' impressions which tend to have foliage, smoke, or a wall conveniently hiding a problematic area!

Attempts were initiated to build a computer reconstruction of the Mound 1 burial published by Bruce-Mitford 1975). Progress toward an accurate model has been slow. The main reason is that the published accounts, plans and profiles do not provide sufficient detail from which to work out the actual dimensions of the formations found. Moreover, key information such as scales and datums is missing on several plans. We can, however, report the small progress that has been made so far. Work on the reconstruction began with the boat. The published report provides a number of plans and elevations from which to extract measurements. The first stage was to digitise the published profiles. These profiles are, it turns out, hypothetical reconstructions of the excavators. When the 1966 expedition went back to the site which had been reburied in the war, distortions had already occurred. The readings as they are are certainly not sufficiently dense to use the spot method used on the cemetery data. The simple skeletal wire-frame is nowhere near good enough. There is simply not enough information for the mind to fill in the gaps. To rectify this we splined the data using a piece-wise cubic spline in both directions to produce a wire-framed hull. Apparently the ship's keel has unusual hydrodynamic properties! If more reliable data becomes available we can produce an interesting model. The data could be fudged to produce a profile similar to that shown in the line-drawing reconstructions, but this would simply be an exercise in cosmetics with few obvious analytical benefits. There was little point in progressing further to apply shaded patches. The construction of a solid model using the technique of constructive solid geometry, or the set-theoretic, model would be equally fruitless requiring too much conjecture.

The experiment does highlight the importance of making extensive and detailed records if there is to be any possibility of anybody validating the results of an excavation. It is apparent that even if the profiles could be datum-linked they are too widely spaced and require a considerable amount of interpolation in order to fill in the gaps.

17.4.3 Three-dimensional digital recording

Happily much greater success can be reported with regard to the application of three-dimensional digitising and graphics to archaeological recording. One of the most pressing archaeological challenges of the current Sutton Hoo excavations is the recording of the flat graves. The aerobic, acid soil regime which prevails at Sutton Hoo means that all buried organic materials are subject to intense decay and corrosion. Fortunately, however, the decay products of such materials are themselves visible. Hence, even when buried human remains contain only a little bone they can still be excavated as three-dimensional silhouettes. These three-dimensional silhouettes are known euphemistically as *sand men*. In fact, the Sutton Hoo sand men survive in the form of a series of concentric jackets of discoloured sand marking decay horizons. It has been hypothesised that some of these horizons are the remains of flesh or clothing contours, but most often they are thought to represent the outer bone casing. In one case one of these outer jackets was removed to revealed the silhouette of the bones (Andrew Copp, *pers. comm.*). A thickening of the decay contours around the hands and faces in particular has been observed (Carver 1986c, p. 27). In order to investigate the theory that some of these decay horizons from the bodies are the product of different organic jackets of material it is would be useful to have accurate and precise three-dimensional records of the relevant surface contours. Clearly, it is vital to be able to record this information precisely so that it might more easily be judged what exactly these decay products represent and why it should be that they are found where they are.

Traditional recording methodologies are considered to be inadequate by the excavators. The colour-coded plans only provide two-dimensional records which omit the volumetric information which may be important. The taking of spot-heights using staff and levelling device is time consuming and cannot cope with re-entrant features. Existing skeletal charts are also insufficient because they do not cater for the inclusion of this vital information recording these other surface contours. Photogrammetry is one method of recording these details, and the technique has been used successfully to extract the three-dimensional surface contours of the so-called *Lindow Man—Peat Marsh* (Lindsey 1985). Jim Hooker has attempted to extract three-dimensional information about the sand men from stereo-pairs, but the results so far are not very satisfactory (Hooker 1986). The approach has many attractions, but it is weak when it comes to recording re-entrant features which cause blind spots in the photographs. Optical contouring techniques also suffer from the same shortcoming.

The provision of an instrument which could be used to probe into such recesses, measure them, and record them in three-dimensions would obviously be a great aid in such circumstances, especially if the data were recorded rapidly and were capable of display in three-dimensions. Fortunately, a number of three-dimensional digitising instruments which seem to fit these criteria are now commercially available. Specifically, McDonnell-Douglas now manufacture three-dimensional digitising devices, known as *3Space trackers* in the USA.

These machines cost about £10,000; An RS232 serial interface means that they can be connected to most computers. The system-unit has a source and a sensor connected by 3m-long flexible wires. The source consists of a small plastic moulding which has small coils epoxied inside. The sensor is also small and light. As the power consumption is 60 watts, a mains supply is required. The source radiates a time-varying magnetic signal which the sensor measures. The system-unit sends to the computer the position of the sensor relative to the source in *x-y-z* coordinates, and also three direction vectors which represent the angular position of the sensor. As the direction in which the system is pointing is determined, it is possible to attach the sensor to a pointing or probing instrument and calculate the position of the tip of the probe as an offset from the sensor-unit itself.

Early in March 1987, a visit was made to the bitterly-cold Sutton Hoo excavations to determine whether the *3Space tracker* represented in practicable terms a workable tool in field situations.[1]

The most immediate consideration for using the device in the field was a suitable hardware configuration and power supply. For the purposes of the first field tests a McDonnell-Douglas *3Space tracker* was used in conjunction with an IBM XT with a 10 Mb hard disk. A portable Honda EM650 petrol-driven generator provided the necessary power.

Unfortunately, no sand men could be examined in context at the time of our visit. However, a number of resin moulds taken from specimens which had been excavated earlier were available for experiments. Without going into details, it was necessary to provide a rigid, stationary, and non-conductive platform on which to set the transmitting device as a datum. The was done using a combination of perspex panels and plastic clamps.

The initial objective was to obtain a sufficiently dense concentration of surface-point readings which would allow a detailed three-dimensional computer model of the specimen to be created. Since a potentially infinite number of possible surface points were available for measurement it was obvious that only a sample of points could be taken. The simplest rationale for obtaining

[1]None of the work with the 3Space tracker could have been undertaken without the expertise of Andrew Walter (IBM UK Scientific Centre). We would like gratefully to acknowledge his considerable contribution to the success of the experiments.

the required sample of points was to take readings from the surface of the mould at intervals along transects. It was estimated that the taking of readings at roughly 1 cm intervals along transects set about 2.5 cm apart would in general be sufficient to record the microtopology of the surface of the sand man examined. However, readings were taken at much closer intervals in places where the slope of the surface changed rapidly. Re-entrant features, such as the underside of the chin, often necessitated a higher frequency of readings to be taken. Readings could be taken at intervals of about a second, and a total of 3, 319 readings were taken.

The recorded points were subsequently examined on an IBM 5080 real-time graphics unit. It turned out that the density of points was so great that the shape of the sandman could be analysed simply by representing each three-dimensional reading by a dot. Feature enhancement was improved by drawing lines through the points forming each transect.

The aesthetic appeal of the representation can also be modified by the application of pseudo-illumination. The model is greatly simplified and ignores effects like shadowing or the residual illumination due to light bouncing back from other surfaces and so on. Even so the legibility of the image, in terms of how well it conveys the information embodied in the model, has been improved immensely. The application of this principle to the computer-model brings out details around the rib-cage area for instance.

Not only can we accurately a complex shape record in three-dimensions, it is also possible to display and analyse the data in real-time. Detailed computer models can be made onto which one can map additional information obtained—decay products for instance. Here again image enhancement techniques may prove useful.

The adoption of this technology carries major implications for field methodologists. By applying these techniques we are adding whole new dimensions to the data being collected. In order to avoid the 'Garbage-In-Garbage-Out' syndrome archaeologists must ensure that their data are collected in meaningful ways so that it may be meaningfully analysed and displayed. We think it has been demonstrated that the device works in principle and is a viable tool, but the would-be surveyor is confronted with the problem of where to make measurements.

With composite objects there is the problem of defining sub-components, and then deciding whence to take measurements. How many points are necessary in order to record the full three-dimensional shape of a given object? In a complex free-form object, such as the decay products of a human body, which is perhaps wearing clothes, how does one go about making sure that the various elements of the object are distinguishable? These are just some of the unanswered questions that need to be thoroughly investigated.

17.5 Overall conclusions

The work on the graphics was begun only a very short time ago and the early results are mixed. The experiments involving three-dimensional recording and display are probably the most exciting development to date. The analysis of the surface topography of the cemetery also promises more interesting results. It is already clear that the taking of further spot height readings will be necessary in the areas where the new mounds are suspected. Work on the reconstruction of the ship-burial will continue. It may be possible to resolve the problem with the ship's profiles using information gleaned from other sources. We will in any case turn our attentions next to the burial chamber itself.

Finally, the presentation of the site to the public and professionals alike will hopefully involve much more advanced graphical techniques. The modelling in particular represents an interesting challenge and it is anticipated that the current excavations will provide the necessary information in the appropriate detail.

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