Modelling a new cam track for the Bowes Swan Automaton

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This document is based on the Masters thesis *'Analysis of historic evidence and modern data, leading to the design and prototyping of new parts, for the safe, fidelitous operation and longevity of the original mechanism',* carried out at West Dean College, 2009 and is now superseded by Matthew Read & Rachel Wicaksono (2023) Modelling a cam track for the *Silver Swan* automaton at Bowes Museum: a cross-disciplinary reflection on 'what things are', Journal of the Institute of Conservation, DOI: 10.1080/19455224.2023.2202411

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Fig.1. Cat. Ref. x.4653.a1/001

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Fig. 2. The Bowes Swan Automaton. Cat. Ref x.4653. Image courtesy of The Bowes Museum, Barnard Castle, UK.

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Table of Contents

Part 1

Part 2

Practical Work

The water bearing bar

Abstract

During a three-month conservation project of the automaton in 2008, twentieth century alterations were discovered that may be considered to threaten the operational safety of, and/or alter the visual experience and interpretation of, and/or impact on the integrity of the object.

The primary aim of this research was to investigate two of those areas. Primarily the zig-zag track that controls the rotation of the Swan's neck. Secondly, the relationship between the sub-automata swimming fish and the transverse water bearing bar that supports the stream of twisted glass rods on which the Swan appears to swim.

Through research, design and prototyping of new parts, the aim was to provide a perspective on the present physical and interpreted state of the object, and propose physical and theoretical solutions to the identified, perceived issues.

Physical prototyping of a new zig-zag track was carried out through the design, manufacture and operation of a test rig - Swanulator - with subsequent analysis of results and recommendations for implementing possible changes to the object.
A revised version of the transverse water bearing bar was proposed through analysis of extant material leading to a re-design.

The Swan is arguably mechanically complex. It has an equally complex history. This history stimulated considerations about wider professional practice issues, sometimes referred to as ethical considerations, relating to the on-going operation of the broader group of machines that includes the Swan; namely dynamic historic objects.

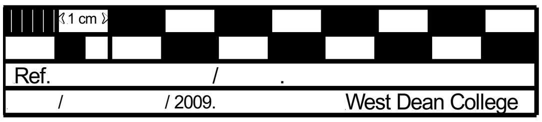

Fig. 3. Centimetre Scale as used in within this text

Part I of II.

Introduction

The Bowes Swan is a late eighteenth century, life-sized automaton in the form of a Mute Swan. The body, neck and head of the Swan are formed in chased, repoussé silver. In operation, the Swan appears to swim on a river or stream of contra-rotating twisted glass rods.
Hidden below the rods, within a metal framework or chassis, are three clockwork mechanisms or movements[1]. These mechanisms are a product of the eighteenth century clockmaking trade. The main mechanism causes the Swan to rotate and lower its neck, and to perform a display of 'preening', followed by the apparent trick of catching and swallowing one of the seven silver fish swimming in the stream below. The stream is driven by the second of the clockwork movements. The thirty-five-second-long performance is

1 In horology and clockwork the name Movement is given to the mechanism that powers the object. See Glossary for further details.

accompanied by twelve bells of music, the tune changing at the end of every cycle in an eight tune loop. The music being driven by the third of the movements.

It is believed that the Swan was created for James Cox, an eighteenth-century businessperson and exporter of british-made 'fancy goods'[2]. Although unsigned, the 'making' of the Swan is attributed to John Joseph Merlin.

Following a period in the late eighteenth century when the Swan was on display in the Museum of James Cox, London, it was bought and displayed by Thomas Weeks. Subsequently it was sold at auction in 1835[3]. The next known record of the Swan is its appearance on the stand of jeweller Harry Emmanuel, at the Paris exhibition, 1867.
Today the Swan belongs to the Bowes Museum, opened in 1892 in a purpose built French civic style building at Barnard Castle (fig.4.), County Durham. The museum and its collection were the work of John and Josephene Bowes,[4] collectors who saw the Swan in France and secured its purchase a few years later.[5]

Fig. 4. The Bowes Museum, Barnard Castle.[6] Image The Bowes Museum, Barnard Castle, UK.

Following storage during World War II, the Swan was returned to public display at the Bowes Museum. During the 1950's, 60's and early 1970's, the Swan underwent a programme of restoration, maintenance and repairs.[7]
One result of work carried out during this period, is that certain historic components were replaced with new ones that are believed to be of modified design.[8] These include parts of the multi-function cam known as the zig-zag track[9], which controls the rotation of the Swan's neck. During a conservation project that took place in 2008, the zig-zag track profile, and its proximity to one of the eighteenth-century neck operating levers was identified as having a potentially negative mechanical impact on the machine. It is arguably causing unnecessary wear, with the potential for further damage to other existing 18th century components. This could it is believed, in a 'worst case scenario', result in a catastrophic failure of one or more historic components. In its present configuration, the modified zig-zag track can and does occasional jam the entire main Swan driving mechanism, requiring intervention in order to be released. The redesign and prototyping of a new zig-zag cam is therefore the primary focus of this thesis.

The second component under investigation, also altered during the period 1968-72 is the transverse water bearing bar which forms part of the mechanism operating the stream of twisted glass rods on which the Swan appears to swim. Alterations to the water bearing bar result in an element of the automaton - the seven swimming fish - operating in a restricted

2 Smith, R. (2008) The Sing-Song Trade: Exporting Clocks to China in the Eighteenth Century. Antiquarian Horology (March 2008) pp. 629-658.

3 Christies auction catalogue. (May 26, 1864). Lot 184.

4 Bowes Museum Website. www.thebowesmuseum.org.uk

5 Bought by John Bowes for 5000 Francs in 1872/3

6 Image with kind permission of the Bowes Museum. http://www.thebowesmuseum.org.uk/

7 Bowes Museum catalogue entry ref: x.4653.

8 We know these components are later replacements due to the materials they are made from, the style of fixings and the fact that many of them are signed.

9 Made circa 1968-1972.

rather than 'sporting' manner as described in a nineteenth century document[10]. This changes the visual performance, and therefore perception/understanding/interpretation of the object. Aesthetics are of course an inextricable part of the performance of such a machine, however there was not perceived to be the same level of urgency as less physical impact is apparent than attributed to the re-design of the zig-zag cam. Therefore, although considered from a hypothetical point of view rather than physical prototyping, the re-design of the water bearing bar was a secondary focus in this research.

Fig.5. Seven Silver Fish sub-automaton.

The conclusion of this paper will aim to provide the basis for a practical proposal for physical alterations to the Swan that may enable it to be operated in a relatively safe state.

A Description of the Mechanism of the Swan and How it Works

Overview

The Bowes Swan has three driving mechanisms, one for the musical element, one for the water element, and one for the combined operation of the neck and swimming fish elements. The latter, the main driving movement, including the multi-function cam that operates the Swan's neck will be described first. A description of the music operating mechanism is omitted due to its lack of direct relevance to this project and the fact it is a slightly modified 'standard' clock motor of the period.

A Description of the Performance of the Swan

When played, the Swan turns to look to its left, then to its right, where it lowers its head and appears to preen its feathers. It then raises its head, turns again to the front then back to the centre, where it lunges for one of the seven silver fish swimming in the stream below. As the lunge takes place, the fish dart away from the Swan's head. At that very moment, a fish hidden within the Swan's bill is ejected to near the tip of the beak; it appears to have been caught by the Swan. The Swan then raises its head with the fish on view and 'fighting'

10 Forster and Sons (1834) a catalogue of the Valuable Property forming the late Mr. Weeks' Museum.

to be free. The Swan looks around, the fish is then swallowed and the performance comes to an end. The whole performance takes approximately 35 seconds.[11]

A Description from the catalogue of James Cox's Museum, 1773 and 1774.

A Swan as large as life. It is made of silver, the plumage finely copied, and the whole so nicely, closely, and artfully imitated, as at a distance to deceive the most accurate observer. It is represented as upon the water, and is fill'd with mechanism, communicated even to the bill; it turns its neck in all directions, extending it backwards and forwards, and moving round on each side to the very tail, as if feathering itself; during the playing of the chimes, that are heard from beneath, it beats time with its bill, to every note of the music, and as the tunes change from swift to slow, or from slow to swift, its motion changes with surprising exactness. This Swan is seated upon artificial water, within the most magnificent stand ever made, and is reflected by mirrors, which produce the appearance of several Swans. Under the seat is a rock of christal [sic] , finely constructed and ornamented, it is mechanically set in motion, to represent the flowing down of water, which is also reflected by mirrors, as to multiply the appearance of water works in different directions. The rock likewise is embellished with a profusion of jewellery, and other elegant designs. Above the mirrors is a costly dome of great magnitude, on the top of which is a rising sun, that terminates the whole, and makes it near eighteen feet high. The rays and points of the Sun seem to extend from a body of fire in the center [sic], and this piece is so astonishingly executed, that many illustrious personages who have seen it, even in its unfinish'd state, have pronounced it rather the creation of absolute magic, than the production of human mechanism'.[12]

It is reasonable to conclude from the above description that the Swan was originally part of a much larger construction. An artist's impression of the Swan in its original setting was published recently[13].

From the catalogue description and artist's impression it is apparent that what now may be considered the front of the Swan, was originally the back.[14] The temple would almost certainly have hidden the winding-up and initiating operation.
To the eighteenth-century audience, the Swan almost certainly appeared in an 'S' shape; the neck and head facing to the right of the audience. Today, in its glass showcase, not only can the Swan be viewed from 360 degrees, but the side from which the Swan is wound and set going is regarded as the front, i.e. with the head and neck on the audiences' left, appearing as a '2' shape. The winding and initiating process is now a promoted element of the show.

It is not known what happened to the temple, other than the last known description of it was in a auction sale catalogue entry of 1834 *'a magnificent temple, or canopy'*.[15]

For a more detailed early history of the Swan including the history of restoration, maintenance and repair, 1780 – World War II, and the history of the Swan including the

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11 The conservation process was filmed by the BBC and a copy of that film can be seen at (link now expired)
http://www.bbc.co.uk/mediaselector/check/england/realmedia/insideout/northeast/090114_io_north_east_swan?size=16x9&bgc=C0C0C0&nbram=1&bbram=1&nbwm=1&bbwm=1

12 Cox. J. (1773 and 1774?) A Descriptive Inventory of the Several Exquisite and Magnificent Pieces of Mechanism and Jewellery Compriz'd in the Schedule annexed to an Act of Parliament..for enabling Mr. James Cox, of the City of London, Jeweller, to dispose of his Museum by way of Lottery..MDCCLXXIII.

13 John Martin Robinson 'Silver Sensation' Country Life, May 13, 2009, pp.84-86

14 Eighteenth century audiences likely viewed Swan with the head facing the right whereas the Bowes Museum logo for instance depicts the Swan from the side it was wound and initiated, with its head facing the left.

15 A Catalogue of Valuable Property forming the late Mr. Weeks' Museum..Forster and Sons, 1834. 3rd Day (16th July) lot 273 £189.

history of restoration, maintenance and repair World War II – 2008, a catalogue entry is presently (2008) being updated by Howard Coutts, Curator at The Bowes Museum.

The Attribution of Life

Completed around 1774, Swan is a product of the period known as the European Age of Enlightenment, and is designed and executed in such a way that it not only entertains but according to Kirk, may have educated.

'*What the eighteenth century undeniably saw, even from the slightly educated, was a growing appetite for understanding and for improvement: these have proved necessary, if not sufficient, conditions for modernity.'* [16]

The enlightenment was to established a new understanding of the world; the application of biology, physics and chemistry - science - in determining what we now consider, fact. John Joseph Merlin was well connected with the literary, scientific and artistic communities of late eighteenth century London; a dynamic element during this period of re-evaluation of knowledge. Merlin's automaton including the Swan have informally been described as having lifelike qualities. Charles Babbage, as a child a visitor to Merlin's museum of automata describes one of the objects as, *'an admirable danseuse'*, who *'attitudinized in a most fascinating manner'*, and whos *'eyes were full of imagination, and irresistible'*[17]. Given this backdrop, was Merlin pushing the pre-Darwinian boundaries of what could be achieved in terms of 'creating life', just as his contemporary, James Watt had created steam engines that performed magnitudes beyond the feasibility of the effort of humans? As discussed by Leinhard[18], Merlin and Babbage may have attempted the same leap in terms of life-likeness and even intelligence.

The American novelist Mark Twain saw the Bowes Swan at the Paris exhibition in 1867[19], and described the experience in his book The Innocents Abroad*: 'I watched the Silver Swan, which had a living grace about his movement and a living intelligence in his eyes-watched him swimming about as comfortably and unconcernedly as if he had been born in a morass instead of a jeweller's shop - watched him seize a silver fish from under the water and hold up his head and go through the customary and elaborate motions of swallowing it...'*[20]*,* The mechanic - Merlin - at least from Twain's point of view as a professional observer, had created an object that transcends the space normally occupied by such things. It had been attributed a 'life' that challenges the viewer's previous experience.

If as expressed by Twain, the Swan is perceived to be 'alive', this creates an intangible, professional practice (ethical?) element to the process of making a physical alteration to the present incarnation of the machine. It is not known if the temple existed when Twain saw the Swan, but if not, the person winding and operating it would have been, as now, on public view, and the 'lifelike' nature of the show would have been changed and arguably diminished. This was considered in the re-design of the zig-zag track.

The recent overhaul of the Swan mechanism took place in a temporary workspace, on view to the general public. Although there was what appeared to be a high level of interest in the mechanics of the Swan when it was disassembled, will that interest subside once the mechanisms are again 'hidden'.

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16 Kirk, L. (2000). The Matter of Englightenment. The Historical Journal, **43** , pp 1129-1143

17 Leinhard, J.H. (1988-1997). The Engines of Our Ingenuity http://www.kuhf.org/

18 ibid

19 McKendry. John. J. (Frb. 1964) Come, Come to the Fair. The Metropolitan Museum of Art Bulletin, New Series. Vol 22. No.6. pp.185-200.

20 Twain, M. (1869). The Innocents Abroad. Oxford.

Is it important to understand the Swan as an entity? Without the outer casing of silver neck rings the Swan cannot successfully operate as it is so finely balanced, and its 'undressed' appearance is appropriately anatomical as to conclude that the Swan is only the Swan, and has life-like qualities when considered as a whole?

The Dilemma of Intervention

Since the mid-1970's, Swan has been operated typically on a twice-daily basis within one of the museum's public galleries (fig.6.). In-gallery supporting display material, on-line images and text detailing the recent disassembly and overhaul of the Swan are now available at www.bowesmuseum.org.uk.[21] However, the level of perception or interest or 'understanding' by the public, of the operation of the machine and its mechanisms, and the change caused by the operation of the mechanism has not been surveyed. It could be possible that some audiences pay little consideration to, or have little interest in, or have little awareness of the Swan mechanism. They may be only conscious of its external appearance and daily performance. It could therefore be argued that from this point-of-view, the mechanism is an irrelevance, and could, without little detriment to the typical visitor experience, be disregarded. Does the perception of the object diminish the significance of the decision-making process relating to further alterations to the mechanism? A view biased towards the importance of the outward appearance, over the mechanism, would liberate the decision-making process in relation to fitting new parts.

Fig. 6. How relevant is the mechanism of the Swan to the viewing public? Image The Bowes Museum.

Alterations or changes to historic dynamic mechanisms are commonplace because as they operate, they wear. Following the currently accepted conservation principle of minimal intervention[22], in conservative practice, later alterations to an object are not uniformly re-altered unless they have a major negative impact on the aesthetic, physical or metaphysical integrity of the object.
In the case of the Swan, the 20th century zig-zag cam profile and transverse water bar were designed and made using methods that likely appeared good practice at that time. They may now appear, by broadly accepted conservation standards to be old-fashioned, driven by the imperative to restore mechanical function rather than a broader sense of preservation. This work reflects a particular environment at a particular time. This creates an arguable basis for their validity, and raises the professional practice question of whether this later work should be preserved.

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21 Pages now removed (2023)

22 American Institute for Conservation of Historic and Artistic Works. (2003). AIC Definitions of Conservation Terminology in AIC Directory

As an interventional alternative, rather than replace this twentieth century work, a treatment option exists to modify 18^{th} century components to better accommodate later change. In the case of the zig-zag cam, treatment might consist of re-forming the eighteenth-century lower neck lever rather than extensive replacement of the cam sections.

The limitations of the twentieth century water bearing bar have already been accommodated by modification of the eighteenth-century fish operating lever[23], thus setting a precedent.

For about forty years the Swan has operated with these later components. Extrapolating the potential level of wear/damage/change with any degree of accuracy is difficult as on-going wear can unpredictably transfer to rapid failure. The justification for making new parts may nevertheless be difficult as existing ones appear to have worked for two generations and may therefore be perceived by some as fit for purpose. Computer modelling may step in here to more reliably predict future change.

The argument for 'originality' versus 'authenticity'[24] makes a case for both intervention and non-intervention. Further new parts might in no traditional physical way be original, but the result of fitting those parts would result in the interpretation of the operation of the Swan being more authentic i.e. returning Swan to a conjectured earlier performance. Whereas it could be argued that the 1960's components are entirely 'authentic', but are not 'original'.

Considering it is possible to re-establish a model of an eighteenth century cam profile and water bar, any remaking of parts may require clear understanding of the wider environment, and the robust management, understanding and support of controllers, decision makers and supporters of the object.

Wear versus operation

Mechanical automata form part of a group of objects referred to in this text as *Dymamic Historic Objects,* that is historic objects forming part of the larger cultural property, that are subjected to the same threat of damage, deterioration and decay as static objects (agents of deterioration), with the additional demand of possessing the ability to operate and be operated. The operation of dynamic historic objects provides a set of professional practice and contextual challenges in addition to those those associated with so-called static objects.

Podmaniczky states *'a boat isn't a boat if it is out of the water',*[25] This could be translated as unless the object is in context and performing its conjectured original function, part of the story of that object and its interpretation is missing, or maybe, a new story and new object is generated. Mechanical automata fall neatly into this contextual discussion and may require particular policy making decisions; namely to run or not to run, to operate or not.

The Swan is a typical and important example of such a case. In its static mode, the automaton is unarguably a 'fine' piece of craft. The chased repoussé silver body, neck and head were described as *'extremely well observed, down to tiny features such as the ridges on the sides of the lower bill'*[26] and the stream of 140 hollow twisted glass rods on which the Swan appears to swim is undeniably of some visual impact. When in operation however,

23 See section How the water mechanism works p.83? for a description of this mechanism.

24 Podmaniczky, M. (2009) Authentic, Original, Genuine, Implication of such notions for conservation. West Dean College.

25 Podmaniczky, M. (2009) Authentic, Original, Genuine, Implication of such notions for conservation. West Dean College.

26 From the Bowes Museum catalogue entry. Comment from Dr. Joanne H. Cooper. Natural History Museum.

and the Swan performs the preening and fishing actions, accompanied by twelve bells of music and the glass rods contra-rotate, the experience for the onlooker is different. This experience comes at a price; when the Swan operates wear takes place (fig.9.) and that wear is inevitable and irreversible, with the additional risk of more rapid wear or even catastrophic failure of one or more components. In essence, the decisions taken prior to the operation of historic objects could be seen in the form of a cost / benefit analysis. The cost is primarily in the form of change, often presented pejoratively as wear, damage and deterioration. The benefit is sold as presenting in many forms including audience enjoyment and entertainment, object interpretation and sometimes monetary or footfall related income.

A question; is Swan and its performance as a 'dynamic' object more important than any part of the mechanism?

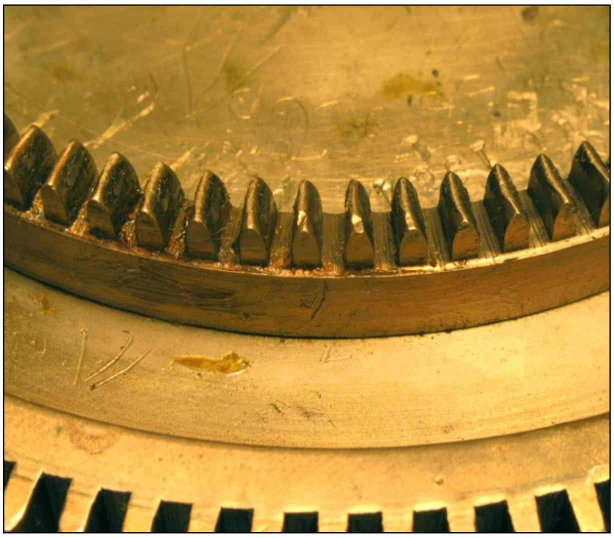

Fig. 7. Main cam driving wheel. Cat. Ref. X.4653.30.4. Showing wear on wheel teeth.

A catastrophised argument might be that there are a number of scenarios that could lead to an event resulting in a significant amount of damage to eighteenth century and later parts. e.g. one of the four mainsprings that drive the Swan may fracture: the energy recoil could start a series of events, damaging any one or more of the wheels in the driving train. Like almost every other dynamic mechanism, the Swan is being worn away by performing the very act it was almost certainly designed and built for; in this case entertaining and possibly 'enlightening' an audience[27]; a common argument for its routine operation.

If we disregard any thought of how the object may have been interpreted in past contexts, and attempt to assess the object in isolation, the operation of the mechanism, and the preservation of the mechanism in the sense of preserving individual original components are apparently mutually exclusive; when the object operates, it wears. Wear in this sense is usually considered a negative. In many respects, historic damage, decay, signs of use and miss-use may be considered valid and worthy parts of the history of an object. Patina through age and wear for example may be seen as the reinterpretation of dirt and dust, a positive spin on an ostensibly negative process. The Swan is 240 years old and wear is consistent with use during that period. We cannot by definition undo historic wear, what is important, is the effective and accountable management of future damage (change).

27 It is not known if the Swan was originally intended for a public or private audience.

If a piece of military clothing or equipment such as Nelson's blood-stained and musket-ball-pierced uniform (now a conservation cliché in it own right due to its frequent use in the argument for the preservation of historic dirt and damage) www.nmm.ac.uk/collections/nelson, shows signs of wear or damage (change) that are generally accepted as legitimate, are these to be preserved with the same vigour as the primary object? Could this concept extend to cover wear that takes place due to the 'every-day' operation of an historic object like the Swan? After all, the Swan *was* undeniably made to be operated. This embraces the application of the concept that what can be created, can be destroyed, as explored by Strahilevitz,[28] even if it is arguably to the detriment, or at least evolution of what future generations will inherit. Every time the Swan is operated it is fractionally more worn out/changed/different.

Who has or controls the right to change/use/wear-out/destroy a thing, and how is that ownership and control attributed, monitored, justified and accounted for?

The question of ownership and control

The aim of this section of the thesis is not to provide answers to this issue, but to begin to assess the types of thought processes, policies or guidelines curators, conservators, owners and audiences employ when making decisions about the operation of objects in their care, area of responsibility or influence.

This element of the research question is generated by the present-day (2009) operation, future operational management and conservation treatment of the Bowes Swan Automaton. The result of raising the question in relation to this object is, however, not specific in its aim, but deals with issues common to many dynamic historic objects.

If given that the observation of the performance of an object like the Swan links that object to a place and an experience in the memory of the witness; the Swan could be described as the informal property of all viewers, past, present and future. Locally[29] the Swan is sometimes referred to as *'our Swan'*. The Swan is also designated as internationally important in the sense that it is arguably the 'finest' (most life-like) operational eighteenth-century automaton. If it is implied that the International community have a shared responsibility of ownership, how is the burden of ownership weighted? At different levels, there are many possible permutations of ownership of cultural property as explored by the International Journal of Cultural Property.[30] According to that publication, the owner, legal or otherwise may not necessarily have influence over the treatment of that property; and that any treatment is influenced in part by the controller[31], and the controller may be influenced by many factors, including the view of conservators and conservation organisations. As any new cam track profile, or re-design of the water bar, may change the outward appearance of the performance of the Swan, who is, or should be the decision maker(s)?

Curators, conservators and keepers of so-called significant museum objects on public display may all play a part in managing an object, therefore the issue of ownership is complex. For example; the Swan was almost certainly built as a business proposition,[32] possibly for export to the Far East via the East India Company, along with thousands of smaller automata, toys and clocks. It may be that due to difficulties in that branch of the export trade, the Swan

28 Strahilevitz, L. J. (Jan., 2005) The Right to Destroy. The Yale Law Journal, Vol. 114, No. 4. pp. 781-854.

29 Informally by Bowes Museum staff and visitors to the museum during the 2008 conservation process.

30 International Journal of Cultural Property. Cambridge University Press.

31 Controller defined as the primary or overriding decision making entity.

32 Smith, R. (2008) The Sing-Song Trade: Exporting Clocks to China in the Eighteenth Century. Antiquarian Horology (March 2008) pp. 629-658.

stayed in London and remained there until the middle of the nineteenth century. Does the will or wish, written or conjectural of any of the multitude of influences, past, present or future, constitute a form of ownership or control? The answer to this question may be important to the future of the Swan and allied cultural property. It appears that presently (2009) many decisions are made locally[33] and therefore inevitably rely on or are influenced by localised perceptions. In the case of Swan, the people of County Durham are understandably consulted on issues, but what about the people of, say, Arkansas or non-visitors? Who gets to decide who decides?

Conservation 'ethics' and related professional codes of practice are under a constant state of critique, evaluation and review, '*Continually reassessing the applicability of new approaches to changed circumstances'*[34] Part of the 'duty' of the conservator is to keep abreast of those changes and apply evolved ways of thinking to the management and treatment of historic objects. Part of that process is to consider the widest practicable view of cultural property, encompassing the tangible, intangible, physical and metaphysical. The Swan is considered by many to be important in its own right, and is highly representative and illustrative of the challenges we face in decision making.

Conservators and attendant professionals face common questions concerning the process of determining courses of action in relation to dynamic historic objects. This professional body is informed and influenced by stated codes of practice, although few, if any codes relate specifically to this group of objects. It appears that many decisions relating to the care and operation of such objects are made on a local basis, with an element of subjectivity as individual decision makers are motivated by their values and beliefs.
In the case of the Bowes Swan, in common with many institutions, the controller or controlling organisation[35] has as one of their influences, the need to engender capital, fund-raise, and maintain the contextual financial viability of the framework surrounding the object. Given a level of ownership, the decision maker is faced with creating a balance between ethical responsibilities with financial demands. These demands are typically seen as mutually exclusive but that is not always the case. New digital opportunities may present ways of 'using' the object without the historic associations of 'wear'.

It may be that allied conservation organisations will support further investigation of this element of the question; the wider issues relating to the operation of dynamic historic objects.

In addressing this issue an informal questionnaire[36] was circulated requesting the views of a small group of professionals in relation to policy. The collective view amongst respondents appears to be that further investigation is needed to further compile the views of related professionals, in order to determine the most efficient and effective way of creating a set of professional guidelines relating to this subject area.
It lies outside the remit of this paper to pursue this issue in depth, but it is noteworthy that the demand and interest appears to exist to develop a collective body of thought.

33 . Fraser, I. Conservator, Leeds Museums and Galleries. (2009) In answer to the question 'Does your organisation employ a specific written policy in relation to the operation of dynamic historic objects in a public environment? e.g. a museum gallery. No, it does not. Other comments: There are not a right lot of LMG policies regarding collection care. Policies at an organisational level on something that does not have a specific regional, subjective or legal context often just re-invent the wheel. There are usually exceptions to policies as well, and items and issues that need to be considered on their own merits. For that reason I have tended to be anti-policy.
34 Jones, S. Holden, J. (2008). It's a material world, caring for the public Realm. Demos. Recommendations for the conservation sector. p.99.
35 Director, Trustees, curatorial staff etc.
36 Appendix 6.

This particular automaton has been subjected to wear, losses, damage, repairs, remaking and re-finishing. These processes, some of which are on-going, combined with environmental degradation[37] have, and continue to change the physical nature of the object. In step with these physical changes, less tangible alterations occur such as context, interpretation, and understanding of the object. The discipline of conservation is broadly based around the preservation of such objects and their contexts[38], collectively referred to as cultural property.[39]

It is the duty of the body of professional curators, conservators and interested parties to raise, investigate and where possible answer such questions related to tangible and intangible aspects of cultural property.

Background to the 2008 Swan Conservation Project

'Conservators should regularly be involved in public engagement activities'.[40]

Fig. 8. The temporary gallery workspace is unveiled at the start of the 2008 conservation project.
Image the Bowes Museum.

At the turn of the millennium, The Bowes Museum began a series of capital projects as part of a large programme of refurbishment[41], not only to the fabric of the Museum building, but to many of its public galleries, including a proposal to refurbish and redisplay the gallery of silverware and fine metal objects.

One of the most important and frequently visited of this group of objects is the Silver Swan. The redisplay of the Swan would naturally form a significant part of such a project. With this intention in place, the opportunity then existed to begin the process of investigating the history and mechanism of the Swan in more depth.

Following a meeting of key museum management, curatorial and conservation staff, together with external advisors,[42] the idea of a comprehensive mechanical overhaul of the Swan mechanism was proposed.[43]

37 Kerschner, R.L. (2007) Providing safe and Practical Environments for Cultural Property in Historic Buildings-and Beyond. The Getty Conservation Institute.
38 American Institute for Conservation of Historic and Artistic Works. (2003). AIC Definitions of Conservation Terminology in AIC Directory
39 Ibid.
40 Jones, S. Holden, J. (2008). It's a material world, caring for the public Realm. Demos. Recommendations for the conservation sector. p.99.
41 http://www.thebowesmuseum.org.uk/blueprint/Introduction/
42 Adrian Jenkins (Museum Director) Jane Whittaker (principal Keeper), Howard Coutts (Curator), John Old (Head of Conservation), Jonathan Betts (Senior Curator of Horology, National Maritime Museum), Martin Rodda (Freelance Metals Conservator), Matthew Read, Ray Mand (Engineer – Retired), Roger Smith (historian), John Martin-Robinson (Architect historian).
43 Other concepts such as three dimensional virtual modelling and the manufacture of a facsimile were considered at this stage.

Prior to the 2008 project, the Bowes Swan had not been completely overhauled since the early 1970's, a period of almost forty years.[44]
Between 1980 and 2008, the maintenance of the mechanism of the Swan was carried out by Ray Mand of the University of Durham department of engineering [45]. Mr Mand had, on a regular basis, partly disassembled and inspected the Swan and its mechanism, carrying out repairs, remedial work and maintenance as required. Much of this work consisted of removing the silver elements, allowing access to lubricate many of the mechanism's bearings. It was however acknowledged that some bearings[46] in the mechanism were not accessible without complete disassembly of the three movement frames. The conclusion being that those inaccessible bearings may be relying on forty-year-old lubrication, with the possibility of micro cold-welding and galling taking place.[47] (fig.9.).

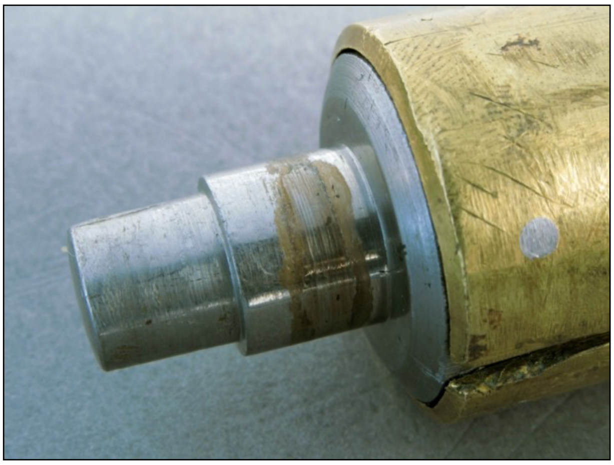

Fig.9. Cat.Ref. x.4653.k.44. Barrel arbor. Wear/damage to bearing surface.

In addition, many of those bearings were well lubricated, but that lubrication may inevitably be contaminated with degraded oil and dust[48]. These components would therefore benefit from disassembly and the application of fresh lubrication.
It was decided as a consequence of these assumptions, that the Swan should be subjected to complete disassembly, documentation and cleaning.

The major overhaul of the Swan (1968-72)[49] was in-part recorded[50]. The surviving records link to other post-war restoration work and when summarised, outline the general difficulties encountered in running and maintaining a complex historic object. Many of the issues discovered during 2008 project were however 'new' and unforeseen, as they were in part due to the work carried out in the 1960's and early 1970's, a period when a succession of restorers and repairers attempted work on the machine with varying outcomes.

Since 1972, the Swan had been operated for view by the public, typically on a twice-daily basis plus other ad-hoc performances. Some of the issues discovered during the 2008 project were not anticipated, as they were not outwardly visible in the every-day operation

44 Regular maintenance had been carried out without complete disassembly by Ray Mand, formerly of the University of Durham Engineering department.
45 Ray Mand. Technician and Engineer, Durham University (Retired).
46 Barrel arbor bearings.
47 On disassembly this was found to be the case. Cold welding is the mechanical bonding of metallic surfaces through relatively high pressure, high friction contact (slow moving heavily loaded bearings).
48 Clock mechanisms are not generally sealed from atmospheric pollutants and contaminants.
49 Carried out by Tom Bryson-Smith on behalf of the Bowes Museum.
50 Bowes Museum Catalogue entry presently being compiled by Howard Coutts, Senior Curator, Bowes Museum.

of the machine. One of these issues being the damage (change) and potential damage (change) caused by the later (1972) ziz-zag track.

The 2008 Conservation Project.

Following the management decision to overhaul the Swan, project fund raising began and by summer 2008 project conservators Matthew Read, Karen Barker and Emma Cooper had been appointed on a contract basis under the supervision of Head Conservator John Old and other senior museum staff.

Work on the object began on 1st of September 2008 (fig.10.), in an on-public-display workspace, the main phase lasting approximately 15 weeks.[51] During that period the Swan was disassembled, each component labelled and allocated a unique reference number[52]. Documentation consisted of a general overall written description of the component or group of components, followed by photography with height, width, depth measurement, with a more detailed description of individual components including condition, wear, damage etc.

Cleaning

The majority of the brass and steel components were hand brush washed (cleaned) and rinsed in baths of white spirits[53], dried in maize husk granules[54]and re-assembled using one of three grades of mineral clock oil[55]. Other repairs and alterations were carried out including cleaning of the twisted glass rods, and replacement of and refinishing of reflective backing plates[56]. All processes were recorded in the manuscript conservation report document.

How it works; The main driving movement, neck operating mechanism (including the multi-function cam with zig-zag track) and the neck structure.

The main driving movement (fig.10.) is the largest of the three movements that drive elements of the Swan. Like the water and music driving movements, the main movement is driven by springs. There are four flat spiral springs in two pairs contained within two brass barrels. The two barrels are in tandem, linked by a cord, with a second cord connected to the upper barrel winding onto a single fusee.[57] The fusee is manually wound via a reduction gear.
The fusee great wheel drives through an intermediate wheel and pinion onto a brass wheel screwed to the arbor of a multi-function cam. (fig.11.) The multi-function cam driving wheel has a contrate (right-angle) gear screwed to its face which leads off to a subsidiary train terminating in the control mechanism, an adjustable fly (air-brake) with two vanes driven through a worm wheel and worm.

A more detailed description of the main driving movement will be contained in the document 'Report of the Swan and Catalogue entry, Bowes Museum'[58]

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51 For an overview of the Swan conservation project see: http://www.thebowesmuseum.org.uk/the-silver-swan/history/
52 Now forms part of the Bowes Museum object catalogue number x.4653.
53 White Spirits
54 Grit -0-Kobs TM. Supplier H.S. Walsh.
55 Moebius ® D3, D4 and D5. Supplier H. S.Walsh. Moebius® is a registered trade mark
56 The reflective backing plates consist of sheet metal with a reflective coating lying just under the layer of twisted glass rods. The purpose of these plates is to throw or reflect light back into and through the rods to enhance the simulated water effect. During the 2008 conservation project these sheets were identified as modern (1960's / 1970's) and of aluminium and steel with glued aluminium paper reflecting layer. It was decided that due to the poor appearance of the sheets that they would be replaced with new sheet brass (3mm CZ120) and the whole leafed with palladium. Original fixing holes used throughout.
57 See glossary (Deleted in this version)
58 Catalogue entry presently (Octr. 2009) being compiled by Howard Coutts, Senior Curator, The Bowes Museum.

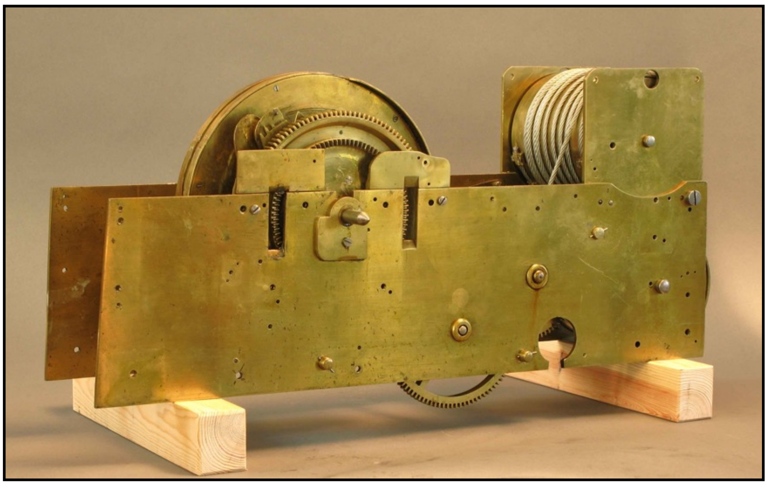

Fig. 10. Cat. Ref. x.4653.k. Main driving movement including the multi-function cam.

A description of the Multi-Function Cam. (fig.11.)

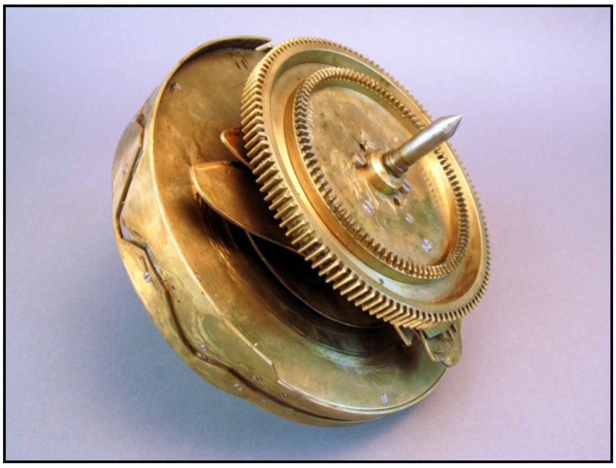

Fig.11. Cat.Ref. x.4653.k.30. The multi-function cam with zig-zag track on the periphery.

The Eight Functions of the Multi-Function Cam are as Follows (as seen in Fig. 11 from front t0 back):

1. Lobed cam operating the lower neck lever. (part No. X.4653.k.30.12)
2. Lobed cam operating the Upper neck lever. (part No. X.4653.k.30.10)
3. Zig-Zag Slotted cam operating the rotation of the neck via a toothed sector and pinion. (part No X.4653.k.30.14)
4. 'High-Frequency. Multi-part cam screwed to the rear face of the drum operating the 'preening' action of the Swan's beak.(part No X.4653.k.30.15)
5. Lobed Cam operating the head nodding action (part No X.4653.k.30.5,.6 & .8)
6. Lobed two-part cam operating the 'fish-ejecting' and 'fish fighting' action (part No X.4653.k.30.18 &.19)
7. Lobed cam operating the seven fish on track swimming action (part No X.4653.j.1)

The multi-function cam lies in the middle of the chassis frame, below the 'water line', below the Swan's hollow body.

In conceptual terms, if the four mainsprings are considered the pumping heart of the machine, the multi-function cam could be thought of as the 'brain' of the mechanism, controlling all the actions of the Swan's neck, the fish that appears to be eaten by the Swan, and the sub-automaton consisting of seven articulated silver fish that appear to swim in the river of twisted glass rods below.

The multi-function cam rotates once per operation of the Swan.
The programming of the Swan's movements is facilitated by the lobed, and zig-zag profile cams, screwed to the drum shaped cam body.

The cam body (fig.12.) comprises a sheet brass disc shaped drum, approximately 239mm diameter and 23mm deep, fabricated from two discs of brass screwed to a central brass core, with an outer rim with brass lugs, the whole screwed together and orientated vertically. The drum rotates on a steel arbor turned between centres, pivoted in removable brass bearing pieces screwed into the plates of the main movement frame.

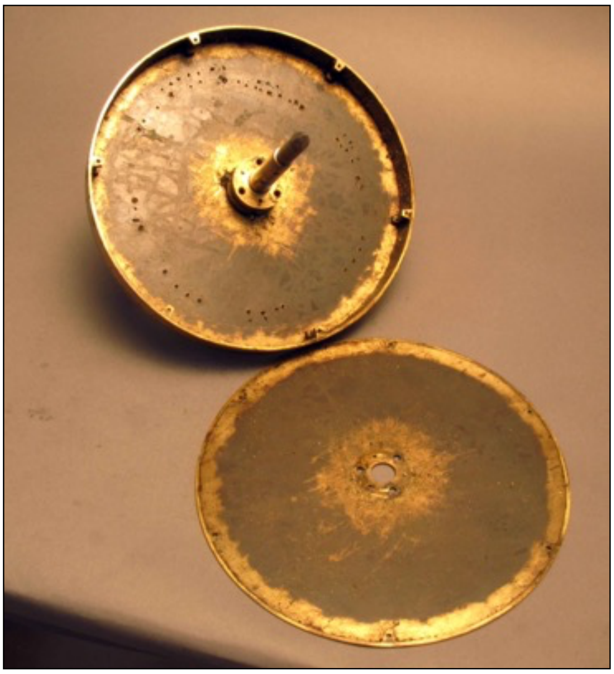

Fig. 12. Cat.Ref. x.4653.k.30.20,21,22&23.

The first three lobed cams (fig.13.) are screwed to bosses mounted on the front of the main cam arbor. The multi-piece, high-frequency preening cam is screwed directly onto the rear face of the cam body. The fish operating cams are screwed to a boss on the back of the main cam arbor, and the swimming fish sub-automata cam is screwed to a separate boss on the back of the main cam arbor, but fixed outside the main movement frame plate.

Fig.13. Cat.Ref. x.4653.k.30. Lobed neck operating cams. The cam nearest the cam body operates the lower neck lever.

In operation, the lobed cams are followed by pivoted iron levers. It is the innermost of the three main neck operating levers, and its proximity to the current zig-zag cam that forms the basis of this Masters question. These levers are attached to sliding followers directly below the Swan's neck, with fine steel chains passing through the base of the Swan's neck and up through the neck structure. The chains pass over numerous friction reducing guide rollers, and are attached at their upper ends to various parts of the neck, beak, head and fish.

The multi-piece zig-zag cam is screwed onto the outer curved face of the drum. It is formed with a single profiled slot running along its length.
Depending on which rotational phase the cam is in, one of a pair of pins screwed to a toothed sector is engaged in the slot (fig.14.). As the cam rotates the reciprocating action of the pins and sector, caused by the zig-zag cam, operates a gear at the base of the Swan's neck, causing the neck assembly to rotate about a vertical axis.

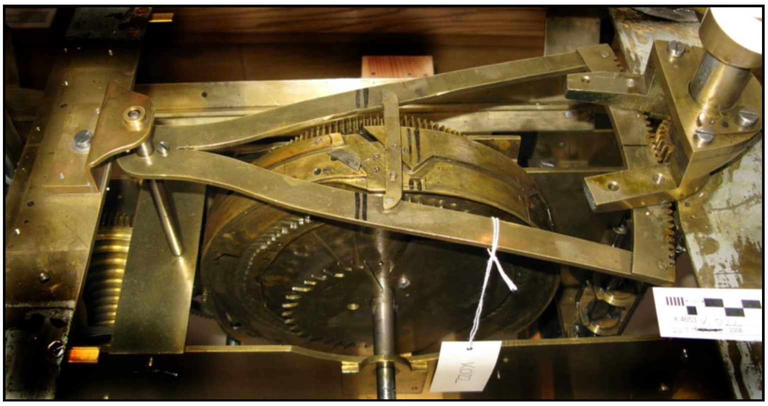

Fig.14. Cat.Ref. x.4653.k. Zig-zag cam, sector and neck pinion.

The neck assembly pivots on a hardened steel bearing piece, and is retained by a split brass bearing and retaining piece, normally hidden by the silver body shell.

The relationship between the modern zig-zag cam profile and the eighteenth-century lower neck operating lever.

The Swan completes three phases during its operation; looking around, preening and fish catching. As the present (1968-72) zig-zag cam track profile does operate the rotation of the Swan's neck, and satisfy these three phases, why is it under investigation?

When disassembled in 2008 it was clear that the edge of the zig-zag track had been rubbing against the edge of the eighteenth-century lower neck operating lever (fig.15.), to the degree that the zig-zag cam deflects the iron lever to the point where its iron cam following roller (fig.17.) is forced off its lobed cam. This action not only appears to increase load, friction and wear at the bearings, but also appears to increase wear by additional load on the eighteenth-century driving train gear teeth. New - and possibly unnecessary - wear also takes place on the edge of the iron lever. Possibly of greatest significance, when the lever roller if forced off the track, the entire mechanism experiences a jolt. Occasionally the lever and track elements jam.

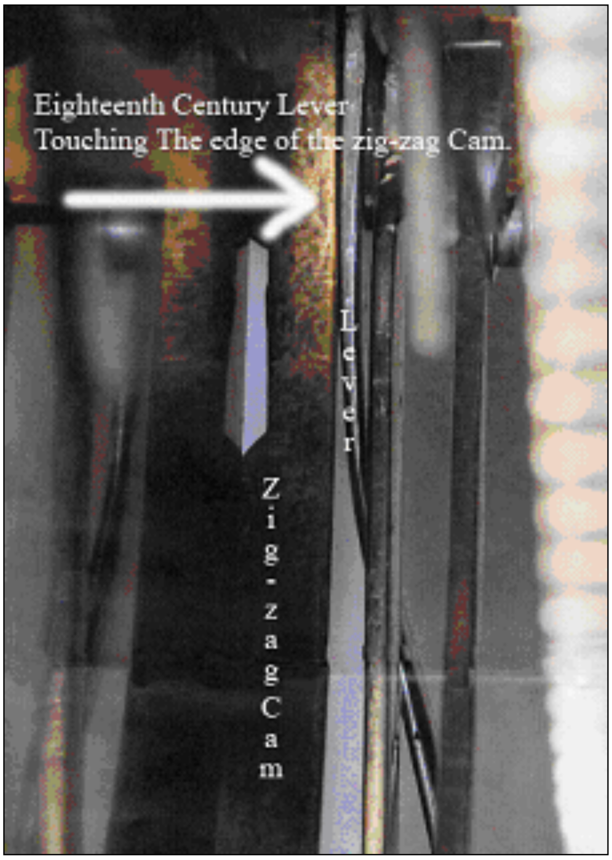

Fig. 15. The zig-zag cam rubbing against the lower neck lever.

As described earlier, the Swan is driven by four large mainsprings (two more than the initial design intended)[59]. The operation of the Swan once initiated is not limited by any control mechanism, emergency stop or clutch. Any additional friction or resistance not intended as part of the original design is at the least unwanted, and undesirable, and at the worst could lead to, precipitate, or hasten a catastrophic failure of one or multiple components.
The iron lever that is being deflected by the 1968-72 zig-zag profile might be described as a relatively substantial piece of material, measuring some 18" long x ¾" high by 1/8th" thick. It is attached, via a follower, to a hardened and tempered steel chain measuring 2mm x 1mm

59 A second mainspring barrel was almost certainly added for extra power during the development/making or early trials of the Swan. This was outlined by Camerer Cuss. T.P. Camerer Cuss. 'The Silver Swan'. Antiquarian Horology. No.11.vol.4. (June 1965). Pp.330-334.

section (fig.16.). This chain is one example of a component that may be particularly vulnerable.

Fig 16. Detail of the neck operating fusee chain (centimetre scale).

Fig. 17. 18th Century Lower neck operating lever. Detail of cam roller.

Modification of the overhanging section of the zig-zag profile, could entirely eliminate these risks and any associated 'unnecessary' wear, whilst increasing the smoothness of the overall operation of the machine.

In addition to the above, the later zig-zag cam profile is of an angular design (fig.18), and may be exacerbating wear through relatively rapid acceleration and deceleration of the Swan's neck during operation. This compared with a conjectural, 18th Century serpentine profile may not cause the same level of wear, due to more gradual dissipation and increase in inertia. Therefore the design and prototyping of such a profile may inform future care of the object as a whole, while more accurately reflecting the overall intention of the maker.

Analysis of the Zig-Zag Track.

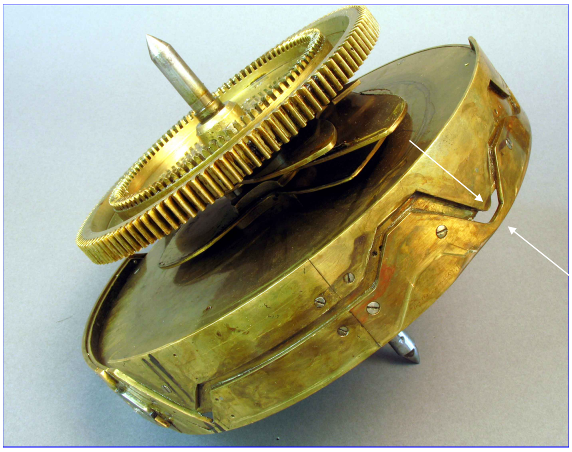

Fig. 18. The overhanging zig-zag track mounted on the multi-function cam body with toothed driving wheel.

The rotation of the Swan's neck about a vertical axis is described in the Catalogue of James Cox's Museum (London 1773 and 1774)[60] '…it turns its neck in all directions…' and again in a catalogue of the Valuable Property…Weeks' Museum[61]'…its graceful neck in a variety of forms, feathers itself and looks around for food in the water,…the Swan seizes one, which, after playing with…'.

From these eighteenth and early nineteenth descriptions, we know as today the swan originally performed at least three functions or phases that involved rotation of the neck. These three phases should be present in any revised track profile if historic accuracy is to be respected.

These phases are:
1. the 'feathering' or preening phase.
2. the fish catching phase.
3. the 'looks around for food' phase.

A Description of the Three Phases of the Zig-Zag cam.

1. The 'preening' phase.

As the only feathers the Bowes Swan can reach are those at the top of its folded wings, for the Swan to preen itself, it must rotate its neck either to the left or to the right or both by approximately 140 degrees from the looking straight ahead position (position 0 or stop/start position). Therefore,140 degrees is a likely maximum value for this phase.
Given this value, and that those other components within the mechanism involved in causing the reciprocating rotating action are in the most part original, and almost certainly in their original positions, the overall width of the cam and the extent of deviation of the zig-zag track are therefore defined. This is due to the neck gear pinion and the driving sector ratio also being of known values.
These known values are therefore taken as given, and introduce the concept of, and the question surrounding a one, two or three, sector pin system.

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60 T.P. Camerer Cuss, 'The Silver Swan' (Antiquarian Horology) No11. Vol.4.June 1965. pp.330-334.
61 Christies. Sale catalogue entry, May 26th 1864, lot 184.

As investigated later in this paper, a change in the number of sector pins is the only way to significantly increase the rotation of the neck for any given width of track. Presently the sector has two pins. Issues included whether it would be possible achieve the required rotation with only one pin; are two pins necessary or is it possible that at some earlier period, more than two pins existed?

2. The 'looking for food' phase

This is the least easy to define phase in terms of angular deviation of the neck, as the swan is surrounded by 'water', and therefore could rotate up to 180 degrees either direction, to look for food. Again, if we take a maximum value of 180 degrees at the neck, this relates to a known value of deviation of the sector pin in the zig-zag cam slot.
By definition, 'looking around' describes a reciprocating or searching action rather than a linear one, which again will be represented in the prototyped zig-zag cam profile.

3. The fish catching phase.

There are seven silver and silver-gilt fish that swim in front of the Swan. Each occupies an individual track, each track being approx. 1" apart. Therefore, the entire track is approximately 6" wide. It is presumed, as presently, that the Swan appeared to catch a fish from this area of the mechanism, which is essentially looking straight ahead. This area represents a relatively narrow band or angular deviation, compared with phases 1 and 2. It is therefore likely to be relatively linear, or in the case of the present zig-zag cam profile; a straight line.

The zig-zag Cam Today

As described above, the present zig-zag cam does contain the three phases that are regarded as essential ingredients, interspaced by necessary transitional sections.

The multi-piece zig-zag cam track profile as presently fitted to the Swan is in the main believed to originate from the early 1970's, due to being signed (scratched) and dated by the maker (fig.19.). It is attached to the 18th century cam body by modern screws. This evidence is further reinforced by the zig-zag cam track sections being manufactured from what appears to be a relatively modern mix or alloy of brass.[62]
Free cutting leaded brass shows a pink-tinged, rather than deeper yellow hue associated with lower zinc content eighteenth century brasses.[63]

62 Day, J Bristol Brass.
63 The recently purchased hand-held X-Ray Fluorescence Spectrometer (West Dean College) could be used to confirm this.

Fig. 19. Signed section of zig-zag track (1968-1972). X.4656 k.030.14

Fig.20. Lower neck operating lever showing signs of wear from rubbing on the edge of the zig-zag track.
Cat. Ref. X.4653.k.020

Fig.21. Later zig-zag cam section. Arrow indicating edge of the eighteenth-century cam body and overhang.

Fig.22. Angular design of the later zig-zag cam elements.

Fig.23. Multiple screw and steady-pin holes; many are now unused.

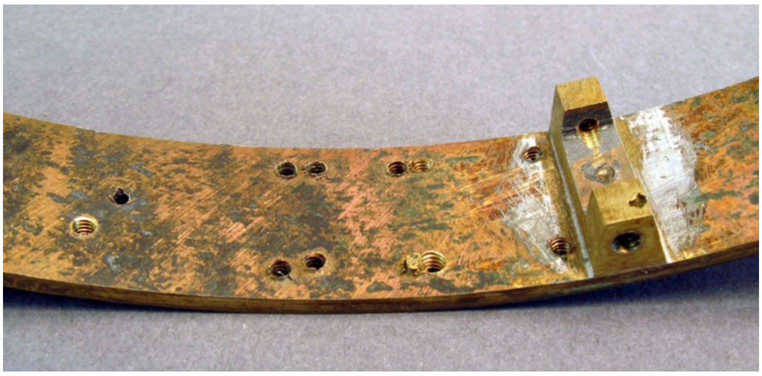

Fig.24. Early smaller diameter holes appear dark and later larger diameter (B.A.)[64] tapped holes appear bright.

What influenced the design of the present zig-zag track?

It is possible that the present zig-zag cam profile may have been influenced, or in part copied from a version that existed pre-1968. Or may have been derived from first principles. Or thirdly, it may reflect a new and relatively uninformed, means-to-an-end design.

In order to gather further data and evidence to answer this question, it would be necessary to return to the original cam body, and study the positions of the multitude of earlier drilled and tapped mounting holes (figs. 23 & 24.). On the basis that the site of a screw could not be in the same position as the cam track slot, a new design could be formed. Evidence from screw hole sites would be reinforced by closer examination of wear marks and corrosion shadows on the cam body. Further investigation of the reserve collection at the Bowes Museum, which is known to contain parts removed from the Swan during previous restorations, could reveal pieces of an earlier cam that may have been removed and retained. Although, during the 2008 conservation project, the reserve collection of known parts associated with the Swan was thoroughly catalogued. Insufficient time precluded an even wider search. On the basis that many of the parts removed during the 1968-72 restorations have been retained, it is possible, if unlikely that some earlier zig-zag track sections survive.

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64 B.A. Thread. British Association, developed during the late nineteenth century.

How the Water Mechanism Works

The Swan appears to swim on a lake or stream of 141[65] contra-rotating hollow twisted glass rods ranging from 165mm to approximately 1200mm long, and from approximately 6 to 8mm across flats (the rods are 'square' section). The majority of the rods have at one end a cemented brass cap with steel pivot (Fig.25.) and at the other a cemented brass pinion cap with steel pivot (Fig.26.).

Fig. 25. Glass rod cap end.

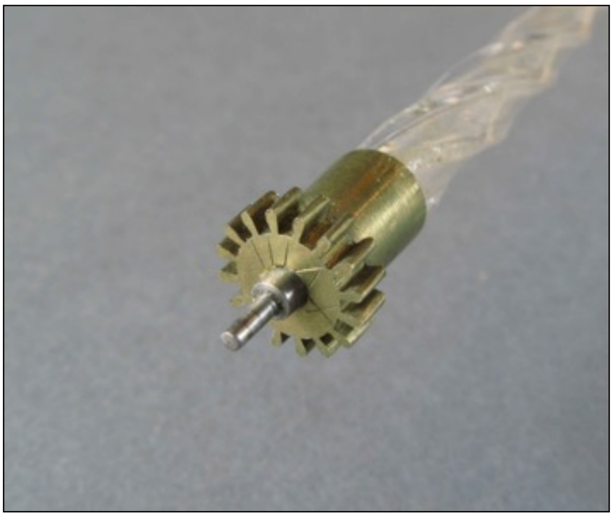

Fig. 26. Glass rod pinion end.

Only four rods are driven and as the pinion caps inter-connect, when one rod is driven by the clockwork mechanism, its neighbour contra-rotates and so on. The rods are driven by a single train, fusee driven movement regulated by a two-vane adjustable fly through a worm gear and worm. The movement is secured within the chassis frame near the front left-hand side. Torque is transmitted to the glass rods by a series of lead-off rods and bevel gears akin to that used in turret clock work. At their outer ends the rods are pivoted in modern (1960/70's) L shaped brackets (fig.29.) screwed to modern backing plates. At their inner or pinion ends, the rods are pivoted in a sectional bearing bar (figs.27 & 28.). The majority of

65 141, two of which are split into two shorter lengths.

the components are scratched 'T.B.S.'[66] and the date of manufacture; typically, the early 1970's.

In its own right the water bearing bar functions reasonably well, the individual sections of bearing adjustable for spacing via elongated screw holes, and for relative height via various metal shims. The bearing holes relating to those front rods (left hand side) are equidistant and horizontal. That spacing does not conform with the spacing of the fish track below. It appears that due to time constraints, when this incarnation of the bar was constructed, that a compromise has been made. The spacing of the relevant glass rods has been manipulated to allow the seven fish to move along some of the track, rather than the entire length, as almost certainly originally intended and substantiated by wear marks. A more satisfactory solution would have been to again redesign the water bearing bar.[67] This appears not to have been possible (and therefore a quicker solution was sought); to limit the movement of the fish to about half the length of track.

The secondary focus of this research project was to investigate a solution to this issue.

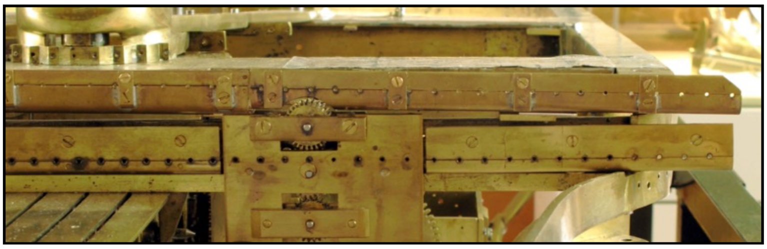

Fig. 27. Cat. Ref. x.4653.d. Main transverse water bearing bar.
Horizontal rows of drilled holes are bearing holes for the twisted glass rod pivots.

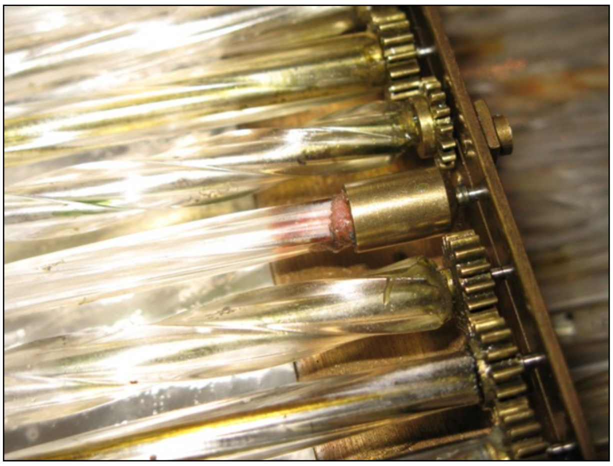

Fig. 28. Glass rods with pinions Transverse Water Bar end.

[66] Tom Bryson-Smith.
[67] Bowes Museum Archive contains correspondence that refers to this process.

Fig.29. Glass rods (bracket ends).

End of Part I

Part II

Masters practical work

Introduction

The primary Masters question relates to the design and prototyping of a revised zigzag cam profile. A test rig was built in order to replicate the rotating action of the Swan's neck, and modify that action with different cam track profiles designed not to impinge on the eighteenth-century lower neck operating lever as outlined in the introduction to this thesis. This section describes that process.

The Swan is a technically complex and well-made machine. It was neither necessary nor practicable to reproduce the required parts in the same materials or manner as the original. A significant simplification and rationalisation of materials was required when designing and building the prototyping mechanism; a typical methodology in prototyping.

The Swan mechanism is primarily made of cast brass, work hardened by hammering at high stress or wear points e.g. wheel teeth and bearing holes; and iron or steel, hardened and tempered at bearing points. These materials (brass and steel or iron) work well together as bearings, having a lower co-efficient of friction than either brass on brass or iron/steel on iron/steel, together with ability to be worked with carbon steel tools. For the purpose of this research however, long-term wear and durability were not to be assessed. Greater emphasis was to be placed on qualities such as ease of availability and cost of materials, and ease of machining and manipulating materials to perform their key functions. For example; rather than use metal as the material for constructing the frame and neck, it was possible to use plywood, and weight the neck with lead to provide satisfactory and worthwhile results. The Swan is spring driven; a difficult mechanism to manufacture, so alternative power sources such as an electric motor were investigated.

In order to construct a mechanism to replicate rotating action of the neck certain key components had to be constructed neatly and dimensionally very similar to the Swan. As a result of the 2008 conservation process, dimensions of all Swan components were available (+/-1mm).

As the ziz-zag track was at the centre of the project it would be reproduced and remodelled in brass strip as per that extant. Thin brass strip was relatively easy to fashion with traditional hand tools. Simplification of the manufacturing methodology was therefore not required. Of all components in the test-rig, it was important the track was reproduced in the most faithful and realistic manner.
The neck of the Swan would also be reproduced, but without the highly complex articulated design; therefore some allowances would be required in its interpretation.
With these two key components considered, other essential ingredients would include the toothed sector and neck pinion, gearing the zig-zag cam to the neck.
Working components were reproduced life sized (1:1 scale).

Summary

There were three aims within this part of the Masters question.

1. To redesign the track to prevent the overhang that causes cam sections to impinge on the lower neck operating lever.

2. To confirm through analysis that the two-pin system as presently used on the Swan is the most effective and necessary system.

3. To redesign the track to decrease the rate of directional change of the neck rotation in order to build and dissipate inertia more slowly, therefore reducing wear and introducing a more fluid appearance to the neck movement.

Given the need for relative simplicity in design and manufacturing of the testing platform, those components therefore essential to this element of the machine are identified in the list below:

1. A representation of the neck
2. The neck pinion.
3. The sector with toothed rack.
4. The multi-function cam drum
5. The zig-zag cam track.

Although secondary to the design of the zig-zag track, it was possible to build a lobed cam to raise and lower the swan's head and neck as it operates in order to illustrate the physical relationship between the two.

Method of Analysing the Swanulator

Once completed, it was be possible to operate the prototyping test-bed with different ziz-zag cam profiles to assess their success.

It is known and irrefutable that the existing cam profile impinges on the eighteenth-century lower neck operating lever. Elimination of this fault was the main criteria by which the profiles would be assessed.

The new profiles should also enable the three phases of the operation of the Swan (Preening, looking about and fishing) to take place. The number of pins in the sector has a direct bearing on the maximum rotation of the neck. An investigation and analysis of the number of sector pins is to be found in the chapter, '*a one, two or three pin system?*'

The outcomes of testing revised cam profiles, specifically the change in interpretation of the movement of the neck as dictated by the angular track design and revised 'fluid' track design are, due to the subjective nature of the aesthetic, difficult to quantify. From the perspective of the observer, photographic evidence and images of the cam and revised profiles will present some information requiring interpretation, yet witnessing first-hand the test bed running with contrasting profiles provide sufficient data to enable a subjective, but indicative view to be formed. A video of the test-bed in operation is included with this thesis submission.

Methodology (Swanulator)

Design

The over-all design for the test-bed was drawn-up using preliminary sketches (fig. 32, 33.) followed by an AutoDesk QuickCad drawing (fig.34.),[68] with key components shown colour coded in front elevation and plan view.

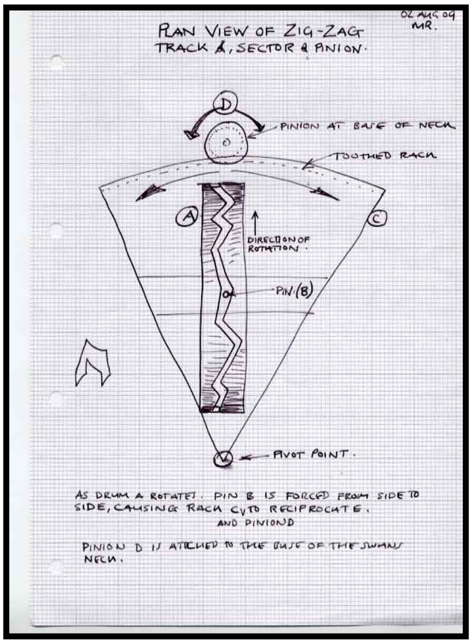

fig.30. Test Bed Preliminary Sketch 1.

[68] Autodesk www.autodesk.com.

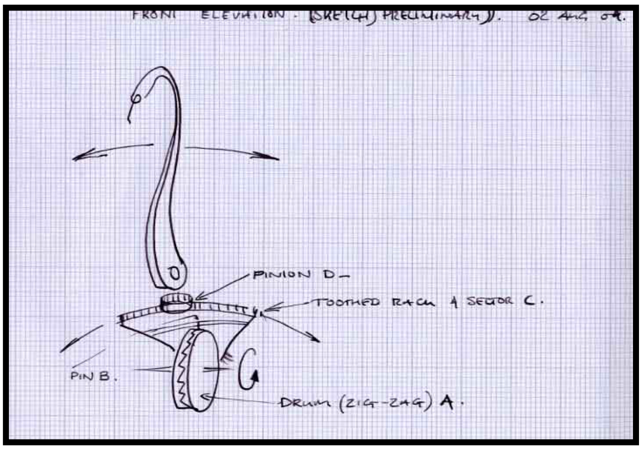

fig.31. Test Bed Preliminary Sketch 2.

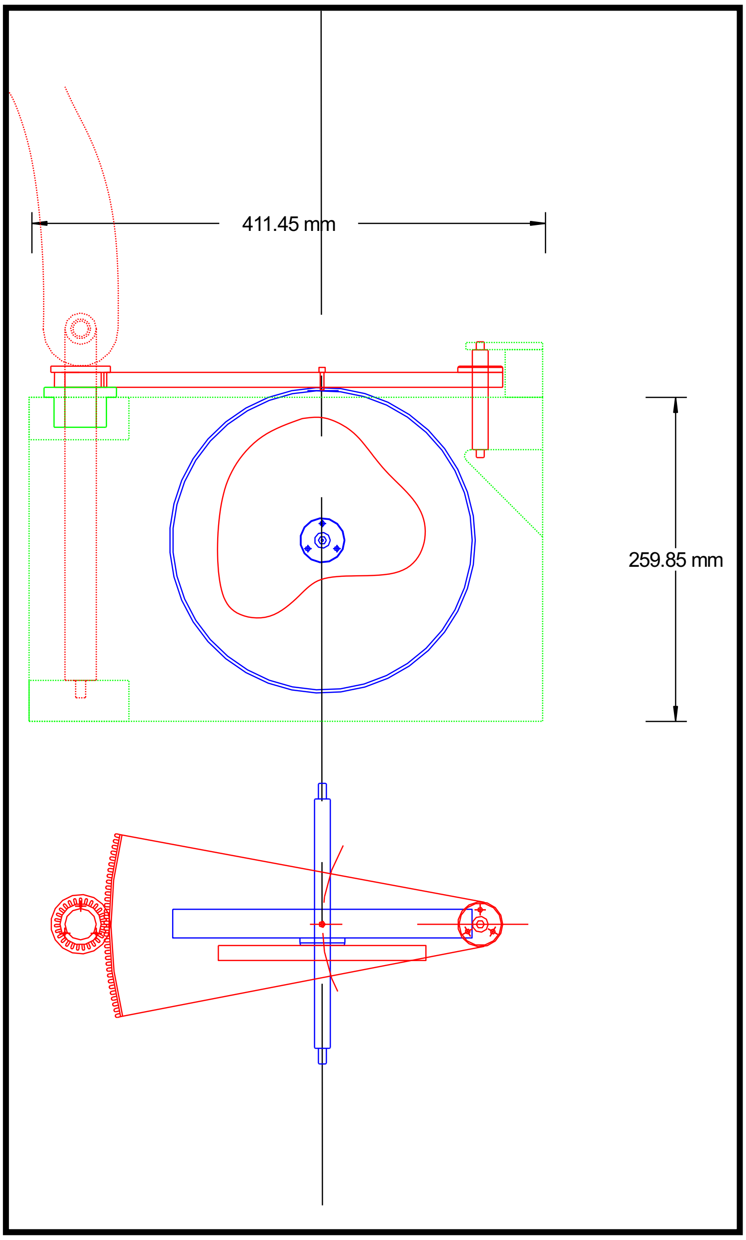

Fig. 32. Swan Test Bed CAD , Front elevation and plan view. Drawn to scale but not reproduced here to scale.

The Frame

The eighteenth-century main driving movement of the Bowes Swan has a frame consisting of two brass plates, separated by triangular, drilled and cross-pinned brass pillars. The design being consistent with 18th century clockmaking practice.

This frame in modern terminology would be called a chassis design, ie if used independently of the surrounding chassis, the frame alone does not have enough structural integrity or strength to withstand operational forces of the four driving springs. For the purpose of the prototyping test bed, the stand-alone movement frame would have to be stronger and more rigid in its own right, than the original.

Subsequently, in the test-bed, the plates were constructed from 18mm birch plywood in the form of a glued-and-screwed construction, open box (fig.33.), of approximately the same height and width as the original brass frame.

An isometric scale pencil sketch was produced by the author and the box frame made accordingly.

This frame was relatively inexpensive, rigid, and quickly produced by in house workshop technicians. The material lent itself to easy modification, as proved necessary when fitting the lower neck lever.

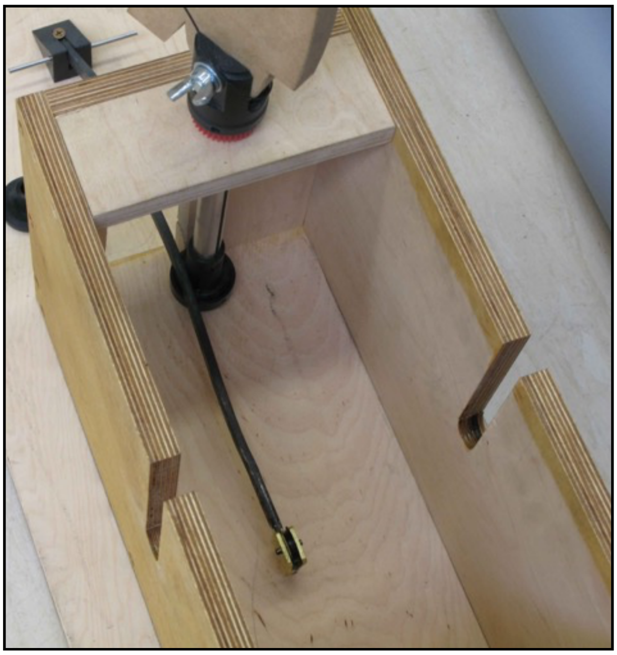

Fig. 33. Test Bed. Plywood box frame detail.

The box-frame was slotted vertically, halfway down its height in order to accommodate the cam arbor, and then fitted with removable bosses acting as bearing pieces for the arbor, fixed bosses acting as bearing pieces for the neck and a fixed lower bearing block for the sector pivot, and a removable upper bearing plate for the sector arbor pivot.

The Cam Body

With the box-frame in place with its vertical slot formed for the cam arbor bearings, the cam arbor was end-centre-drilled to be turned and trued between male centres.[69] Turning between centres is a manufacturing technique that allows the work to be returned to the lathe at any point with guaranteed concentricity. As the brass strip zig-zag track is only approximately 1.6mm thick, concentricity of the drum body is important to prevent disengagement or jamming of the sector pins.

The main arbor bearings were turned from the engineering plastic Delrin®[70]. Delrin is an excellent material for this type of relatively lightly loaded, plain bearings, having a naturally low co-efficient of friction, and being naturally self-lubricating.

Machined plain bearings were turned and bored to a sliding fit +/- 0.1mm on the main steel cam arbor. With the arbor in place, the flanges were screwed onto the vertical faces of the box frame.

The cam body (fig.34.) followed the dimensions of the original; approximately 25mm thick and 240mm diameter. Delrin® was also chosen for the material of the cam body, due it its ease of machining. It was fabricated by flame welding to obtain the overall dimension, then roughed out to a glued-on paper template using a bandsaw.
It was then centre–drilled and mounted on a face plate in the gap bed of a centre lathe. The outside diameter turned slightly oversized. A flanged brass mounting boss was then turned and bored undersized for the steel arbor, then flame heated and cooled to a shrunk-on fit, with a M6[71] grub screw for additional security. Once in place the arbor was put back between centres and the face of the mounting boss skimmed to bring it true and perpendicular to the arbor. The Delrin® cam body was then fitted against the flanged brass boss and secured with three M6 machine screws. The assembly then once again turned between centres and the outside of the cam body skimmed in the lathe to final diameter and concentricity.

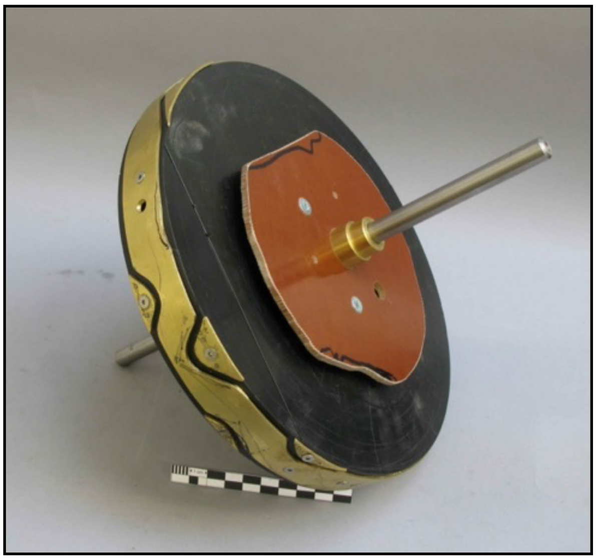

Fig.34. Delrin® cam body with Zig-Zag cam and lower neck lever cam in place.

[69] Turning between centres is the earliest and simplest methods of turning in a lathe which guarantees a high level of concentricity.
[70] Polyoxymethylene (commonly referred to as POM and also known as polyacetal or polyformaldehyde) is an engineering thermoplastic used in precision parts that require high stiffness, low friction and excellent dimensional stability. It is commonly known under DuPont's trade name Delrin.
[71] M6 is part of the ISO standard thread range (6mm outside diameter).

Sector and neck pinion

As described in the chapter *How the Bowes Swan works*, the neck of the swan is caused to rotate via the zigzag track operating a toothed sector and geared pinion at the base of the Swan's neck. In the Swan, the geared sector and neck pinion are of brass. The pinion being machined from solid material and then split to facilitate assembly, and the sector being fabricated from strip material. As above, strength and longevity were important criteria when the Swan was made. In the test-ring, off-the shelf plastic gears of involute form - an engineering standard - were purchased from a robotics supplier.[72] The most important factor with the gearing being the ratio between the radius or pitch circle[73] of the sector rack, the pitch circle of the driven neck pinion and the radius of the zig-zag track pin in relation to the sector pivot.

In the Swan the sector radius is approximately 300mm, and the neck pinion has a pitch circle diameter (effective diameter) of 38mm. The relative number and shape of the teeth on the gears is almost irrelevant as long as the overall ratio is maintained. The Swan, like almost all historic clockwork has gear teeth of cycloidal profile.
In clockwork, cycloidal gearing is used to preserve the constant angular velocity of one gear being driven by another gear. In engineering, as in the test rig, involute profile gears were used. Typically, involute gears are stronger than cycloidal for any given tooth size, but exert greater pressure on the bearings and do not develop such even angular velocities. In the test rig these issues were not significant because unlike a clock, the Swan has no timekeeping function, and as stated, longevity within the tests was not crucial.

Rather than cut the toothed sector rack, a length of glass reinforced plastic rack was purchased. This had to bent around the radius of 300mm. It was supplied as a rigid, straight section. In order to increase its flexibility, the backing was milled from approximately 10mm, to approximately 2mm thick.
To form the body of the sector, a 6mm thick Perspex® sheet was sawn to radius on a bandsaw, using a plate of MDF and dowel pivot as a jig. The use of Perspex rather than metal for the sector has the advantage of being transparent; the ziz-zag track and sector pins can easily be seen. In addition Perspex® is relatively easy to machine, drill, tap etc.[74]
The sector body and toothed rack were then screwed together.[75] (fig.36.)

A transverse piece of Perspex® screwed to the top of the box frame provided a bearing surface for the sector pivot, with a turned, oil-filled, green Nylon shouldered plain bearing and machine screw providing the pivot point.

Once assembled, the sector was drilled and tapped to take the two cam follower pins (fig.35.), which were turned from B.A.[76] screws and fitted with locking nuts as to be height adjustable.

[72] www.technobots.co.uk/acatalog/Online_Catalogue_Mini_Plastic_Gears_51.html#a4600_2d102
[73] The Pitch Circle is the effective diameter of a gear.
[74] The process of manufacture involves many additional operations such as countersinking, de-burring, filing, spot marking etc. This applies to most of the components made for the Swanulator.
[75] Ibid.
[76] British Association.

fig. 35. Test Bed Sector pins.

The metal neck pinion of the Swan was substituted for one off-the-shelf of a very similar diameter to the original, made from engineering plastic (fig.36.). Outside diameter was correct as bought, with only the inside diameter of the gear needing to be machined to undersized to a push-fit onto the Delrin® neck boss.

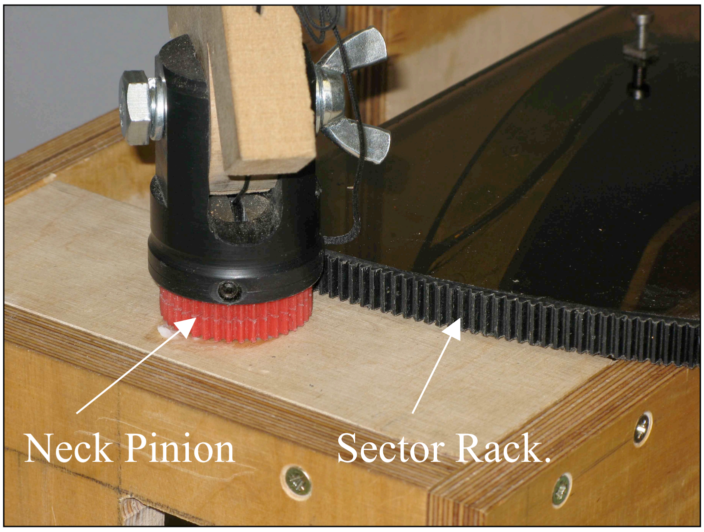

fig.36. Sector rack and neck pinion detail.

The sector arbor was turned from a length of 8mm steel rod with a hard soldered brass flange, drilled and tapped to accept fixing screws for the sector.

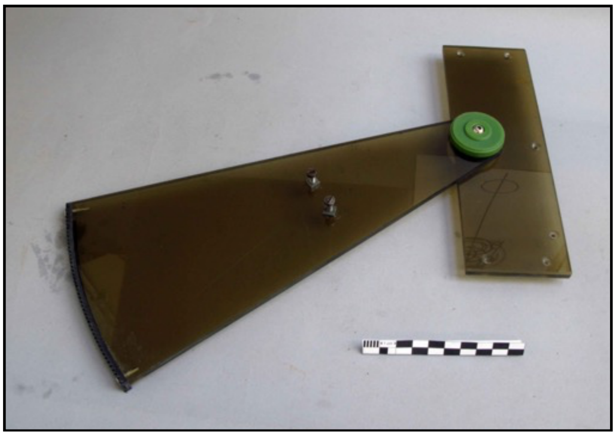

Fig.37. Completed Sector with Nylon bearing.

The Neck

fig.38. The completed test rig (excluding motor).

The approximate form of the Swan’s neck (480mm tall) was sketched onto a sheet of ½” thick medium density fiberboard, and band-sawed to shape, with a 12mm hole mill-drilled to provide a pivot point. The Neck Arbor was turned from brass rod, slotted at the upper end to accept the wooden neck, which pivoted on a Delrin® pin. Delrin® rod was slotted by milling to embrace the neck profile, and turned and bored to provide a top bearing, allowing the Swan’s neck to rotate, and a socket for the neck arbor. The Arbor turned from a length of aluminium rod, drilled at the lower end and fitted with a steel plug to act as bearing thrust piece.

The whole neck assembly was height adjustable, by means of an M6 grub screw in the base of the box frame, the other component of the thrust bearing.

For the upper bearing seating, a piece of 18mm birch plywood was sawn to shape and the bearing bored in the lathe using a four-jaw-chuck.

The Motive Power

With the box-frame, cam body, sector, neck pinion and neck in place (fig.40.), the issue of motive power was further investigated. The Swan is spring driven through a series of gears; in all, a significant set of mechanics that were not relevant to this part of the project.
The test rig required a reliable and repeatable method of turning the cam.

The cam rotates once per operation of the Swan. One cycle takes approximately forty seconds, with the duration being adjustable via altering the geometry of the air-brake. The simplest, least expensive and easiest to implement form of motive power would be to hand-crank the machine directly from the cam arbor or through a single reduction gear. This method was dismissed as it would be difficult to crank at a given and uniform rate, and it would not be viable to constantly cycle the machine for any significant period. A spring-driven mechanical method was also excluded due to the complex and time-consuming nature of manufacturing such a system, therefore power from an electric motor became the remaining viable option (fig.39.).

Electric motors with or without gearboxes are manufactured in a multitude of forms to suit a large number of applications. A web-based search revealed several options that would fit the requirement of the test rig; one output revolution per forty seconds with approximately 1Newton metre of torque[77] The torque requirement being an estimate plus a margin, based on the estimated manual winding input requirement for the Swan.
New purchase options were typically a few hundred pounds, and therefore undesirable on a cost basis alone, especially given the relatively short period the test-rig would have to operate.
The majority of small geared motor applications use a 12 or 24 volt DC motor driving into a worm and worm wheel gearbox. The low voltage option has the advantage of being relatively safe to operate without the risk associated with mains voltages, and the worm gearbox has the advantage of being compact and efficient in terms of frictional losses associated with the alternative epicyclical gearing.
An internet-based auction site offered motor gearbox options but with outputs typically in the dozens of revolutions per minute; too fast for the test rig. The output from one of these motors could be geared down with a further gearbox. A supplier was found[78] offering second-hand worm gearboxes with input to output ratios typically 20:1, 40:1 60:1 and 80:1. Not knowing the exact output R.P.M. [Revolutions Per Minute] of the primary motor gearbox combination, a 40:1 worm gearbox was purchased on the basis that given a variable power supply, the motor could be under or over driven accordingly. The gearbox is the type normally fitted to a clay pigeon trap, therefore presumed to be durable enough for the purpose of the tests.

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[77] 1 Nm (Newton Metre) is a measure of torque (turning moment). 1Nm = approximately 0.1 kilogram/metre.
[78] Brown Europe www.browngroupltd.com

As supplied, the motor gearbox combination output shaft, and the worm gearbox input shaft were of incompatible diameters. Pitch circle diameters of the unit mounting holes were also different.

Overcoming the motor/gearbox incompatibility consisted of turning a flanged Delrin® bush to a tight push-fit on the splined motor output shaft.   The two units were then forced together with a sandwiching disc of Tufnol®[79], pre-drilled at the relevant pitch circle diameters.
Once assembled the combined units were tested at the motor's recommended rating of 24volts.   This resulted in a final output of approximately 0.5 R.P.M., rather than the approximately 0.75 R.P.M. required. This problem was overcome using the variable power supply and driving the motor at 40 volts. Given the industrial nature of the motor, this did not cause an issue for the relatively short-term requirement.

To connect the gearbox output to the cam arbor, a Delrin® coupling was made with a slightly barrelled inner element which allowed for any slight misalignment of the two components. A grub-screw keyway arrangement allowed the gearbox and motor to be quickly fitted and withdrawn from the driven arbor.

fig.39. Assembled motor/gearbox and auxiliary gearbox unit.

The ZigZag Track

With the main part of the test bed and motive power complete, the zig-zag track and profiles remained to be designed, made and fitted.

From the 2008 conservation project, the existing (1968-72) zig-zag track was recorded by digital photography, by measuring, and importantly, by a pencil rubbing (fig.40.). The pencil

[79] Tufnol® is a registed trademark of Tufnol Composites Ltd and is a type of phenolic board reinforced with laminated woven cotton cloth. Tufnol® Whale Whale Brand® is a most useful general-purpose material and is the most popular grade for a wide range of mechanical applications and general uses, such as gears, spacers, jigs and fixtures, wear resistant components, low voltage insulation and many others.

rubbing gives a near 1:1 reproduction of the track. This rubbing was translated into digital AutoCad® format (fig.44.) Once digitised the AutoCad® tool 'Join Splined Curve'[80] was used to smooth out the track profile, but retaining the overall nature of the existing track with the three essential phases as described earlier. This modified profile was then translated into a new two-pin track on sheet metal.

fig.40. Pencil rubbing of the zig-zag track made by Miles Campbell (student assistant) during the 2008 conservation project.

[80] This tool joins a series of reference points with one smooth curved line.

A one, two or three pin system?

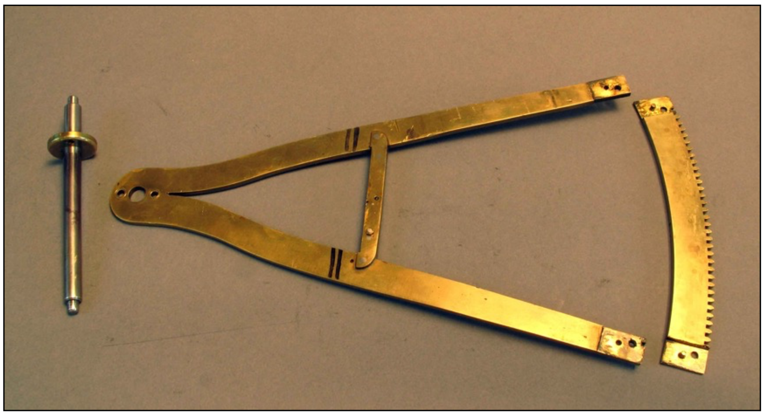

Fig 41. Bowes Swan neck operating sector (disassembled).

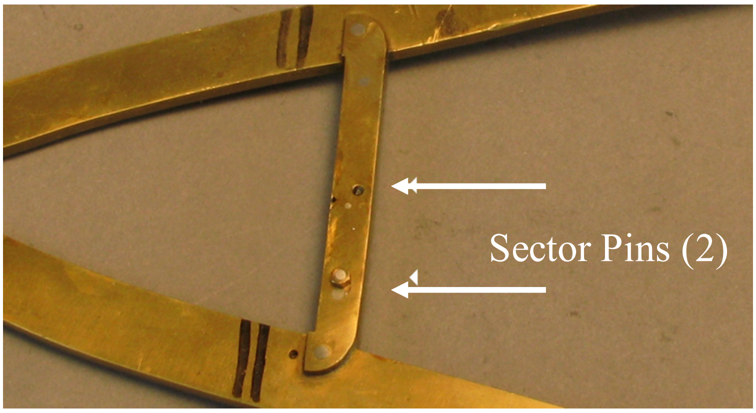

fig. 42. Sector detail showing the two pins. One central, and one that due to asymmetric position and idiosyncratic construction appeared to be later.

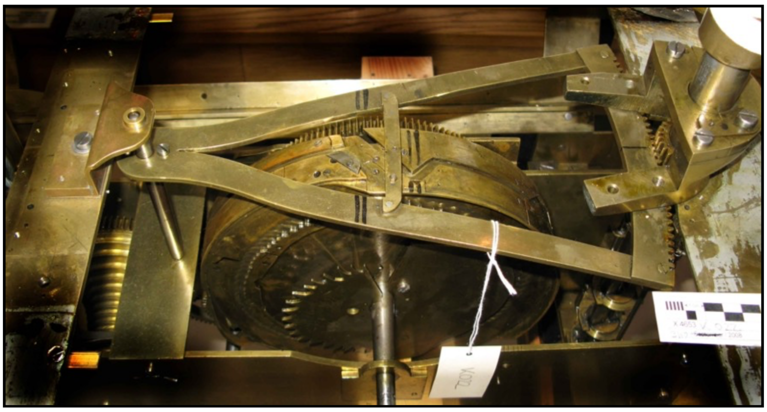

fig.43. Sector in position within the Swan mechanism.

In this section of the thesis, questions are investigated including how many pins were originally in the sector, what would the advantages or disadvantages be on altering the number of pins, and can a track be designed to work with only one pin?

The sector pins engage in the slot in the zig-zag track (fig.45.). As the track rotates, the pin or pins are deflected by the track and cause the sector to reciprocate. Due to the sector rack and neck pinion arrangement, in turn causes the neck to rotate.
There is a direct relation between the maximum angle the neck can rotate, the width of the track and the number of sector pins. The greater the number of pins for any given width of track, the greater the maximum angle of rotation.

At present, the two pins in the Bowes Swan sector are arranged with one centrally, and one offset by approximately 20mm (fig.42.). This suggests that the second offset pin was a later addition. There is a precedent in the arrangement of the mainspring barrels for a certain amount of alteration to the machine in the early period. The asymmetric positioning of the two sector pins suggests the off-set pin was added to increase the overall rotation of the Swan's neck.

The prototype mark 1 zig-zag track was designed to operate with two pins at approximately the same centre distances as in the Swan, but mounted equidistant from the track centre. The transposition of the pins has no overall effect on the maximum angle of rotation, but shifts or biases the range left or right of the straight ahead position. With any zig-zag track profile, and any number of sector pins, the left right bias can be altered by the initial set-up of the sector rack and neck pinion. It is however taken for this exercise that the stop/start position is looking straight ahead and will thereafter be referred to as the zero position.

If a single pin system is calculated with a zero position in the track centre. It can be seen that for any given width of track and in combination with a given diameter of sector pin, there is a maximum possible deviation from the zero position. This relationship can be expressed as a mathematical formula.

If **W** = the overall track width, **w** = the minimum track wall thickness required in order to retain the pin and **r** = radius of the sector pin, the following formula can be applied in order to calculate maximum deviation (**d**) left and right combined from position zero.

$$d = W - (2w + 2r)$$

The Bowes Swan has a cam drum width of approximately 23mm. It is taken, as no evidence exists to the contrary, that the overall cam width (**W**) is about the same value. We know a wider track results in excessive overhang and the present lower neck lever issue. For this exercise W is give the value 25mm (approximately 1"). The sector pins are given a diameter of 3mm, equating to those fitted to the Swan. Therefore **r** = 1.5. **w** is more difficult to attribute a value to as the minimum wall thickness depends on two factors; the limitations of the manufacturing process, and the required strength of the wall, having to bear the transmitted inertial from the Swan's neck. An arguable value of 2mm is given for the minimum wall thickness.

Therefore for a single pin system:

$$d = 25 – (4+3)$$
$$d = 18\text{mm}$$

For a two pin system using the same values for W, w and r, the following formula can be applied:

$d = 2W - (2w + 2r)$

Therefore: $d = 50 – (4+3)$

$d = 43$

Likewise, for a three pin system and every further pin added, W is multiplied by the number of pins.

It can therefore be seen that the addition of extra sector pins greatly increases the value of d, displacement from the zero position and therefore greater angular rotation of the neck.

In the Swan, the value of effective sector radius, effective neck pinion diameter and sector pivot point to sector pin distance are all known. Given that these values are the same as, or similar to the values when the Swan was made, a unit of **d** can be translated to a value of angular rotation of the neck using the following formula:

C = effective sector circumference (The pitch circle diameter [PCD]of the sector x pi).
Sector radius = 300mm, therefore the circumference = pi (2r) = 1884mm.

c = effective neck pinion diameter (PCD) of the neck pinion x pi).
Pinion pitch circle diameter = 38mm therefore the circumference = pi PCD = 119mm.

P = the sector pin distance from the sector pivot point to the sector pin as a proportion of the effective sector radius. The effective sector radius = 300mm. The sector pivot point to sector pin distance = 124mm, therefore the ratio 1:2.4

The ratio between the effective circumference of the sector and the PCD of the neck pinion equals approximately 15:1 One degree of angular rotation of the sector = 15 degrees rotation of the neck pinion.
In order to reach the preening phase, the neck must rotate approximately 140 degrees from the zero position. The sector must rotate approximately 9.3 degrees, or approximately 48mm at the circumference which relates to a displacement of approximately 20mm from the zero point at the sector pin.

From the above we can see that if a 20mm pin displacement from the zero point is required, a single pin system does not have enough range, and it is concluded that given the present arrangement of components, the swan must have a minimum of two sector pins. With a two pin system and a track approximately 25mm wide, a pin displacement of 20mm is possible. This reduces the likelihood of an earlier three pin system that would enable a neck rotation of in excess of 140 degrees from the zero point, which is physiologically unrealistic, and therefore unlikely to have ever existed.

Design for The Zig-Zag Track (Mark 1)

At this stage it is necessary to re-visit the early presentation and interpretation of the object, with specific relevance to the neck-operating mechanism. *; it turns its neck in all directions,* *extending it backwards and forwards, and moving round on each side to the very tail*[81]. If this description is taken as accurate, 140 - 160 degree rotation of the neck is required on at least one side which dictates a minimum effective width of the zig-zag track and a two pin system.

Viewing the Swan from what was in the eighteenth century the back, also has an impact on the design of the neck rotating element of the multi-function cam. The Swan begins and ends its display with the head and neck in line with the body. The first movement is towards what is now called the back of the machine. This is somewhat counter-intuitive and substantiates the case for the earlier display format.

What has yet to be established with any certainty is the balance, or bias between rotation to the left, and rotation to the right of the zero point. Unless further evidence comes to light, or closer investigation of the vacant screw holes in the cam body takes place, only an informed guess can be made. The overall balance or bias is however not a critical element at this stage in the process of designing a new zig-zag cam, as it is the overall width of the track in relation to the lower neck lever that is important, i.e. it is not necessarily whether the Swan neck is biased left or right as the entire track can be transposed.

Any further alteration to the neck rotating cam may take into consideration an outward change in the performance from an audience-led view. There is value in reinterpreting the 1970's layout when designing the new cam prototypes, as it is likely that this profile is based on an earlier, possibly eighteenth-century design. It is known the Swan was operational prior to the 1968-72 project, and therefore, likely that the maker of the present cam based his design on it.
Alternatively, there would be value in returning to first principles. ie the study of the sites of eighteenth-century screw and steady pin holes. However, during this research project this was not possible due to the complexity of, and risk involved in the process of accessing the cam body, which involves removal of the glass rods.
Given the opportunity to once again disassemble the Swan, this would be a priority.

The cam body measures approximately 240mm diameter, the cam track should therefore be approximately 753mm long; 240 x pi. (actual measurement on the rubbing approximately 780mm), the additional 27mm being accounted for due to the thickness of the track material (approximately 3mm, and in places a double layer).

In order to identify elements along the track linear measurement was used. e.g. the 'preening'. Section begins at approximately 50mm and ends at approximately 230mm, the start/stop position being 0 or 780mm.

[81] Cox. J. (1773 and 1774?) A Descriptive Inventory of the Several Exquisite and Magnificent Pieces of Mechanism and Jewellery Compriz'd in the Schedule annexed to an Act of Parliament..for enabling Mr. James Cox, of the City of London, Jeweller, to dispose of his Museum by way of Lottery..MDCCLXXIII.

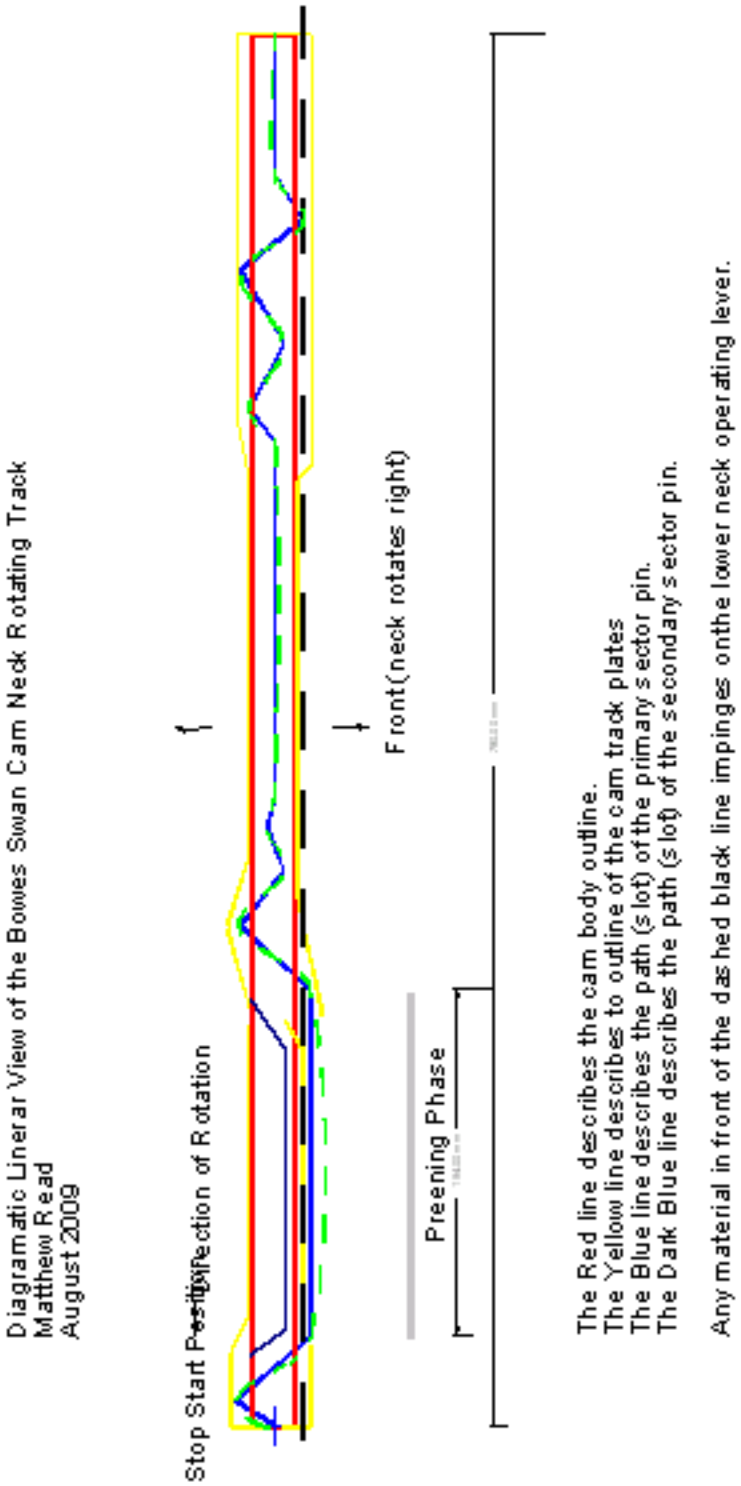

fig.44. Autocad® Drawing of the zig-zag track plus 'splined curve' variation.

For the majority of its length the track consists of a single slot (blue) formed by two pieces of brass sheet screwed to the cam (yellow). It is into this slot that the sector pin locates.
At the preening section (50 – 230mm) the Swan turns its neck through approximately 160 degrees, the greatest rotation from the stop/start point, necessitating the use of a second sector pin and double layer track section (dark blue). Given that the relationship between the sector pin, sector pivot and rack and pinion approximate to their original positions and relative dimensions, and that the preening action of the Swan was an original design intention, it is not possible to contain the Zig-Zag track within the width of the cam body (approximately 25mm). The maximum sector pin deviation from the centre line (stop-start position) of the modern cam design is approximately 19mm to the back and approximately 25mm to the front. It is the protruding finger that catches and draws the sector pin back in at the end of the 'preening' phase, and the overhanging wide plates at the phase following the fish catching action that impinge on the 18th century lower neck operating lever; the basis of this thesis.

As fixing screw holes remain that once held earlier (original?) track profiles (image), determining an earlier profile form may be possible, and new parts could be manufactured to comply with exiting fixing positions, broadly meeting the generally accepted criteria of reversibility. Removing existing parts, although not original, and fitting new does however raises ethical questions.

It is apparent from images of the cam and track that the present track design does not follow, at least in part, its earlier path, the evidence being visible screw holes at the root of the slot. These screws would block the path of the sector pin.
It is also likely that the angular sections of the track e.g. 0 – 60mm and 550 – 700mm may have being more serpentine in form, possibly similar to section 250 – 350mm.
This would translate into more fluid movement of the neck and possible, less wear due to relatively sudden changes in direction.

The overall conclusion from analysis of the track and cam body was:

> The original cam may only be in part similar to that extant.
> The original cam slot is likely to have been more serpentine in design.
> There are multiple unused screw holes and steady-pin holes; the original track may have been constructed from multiple, smaller sections
> It is quite possible to design a new two-pin track using only existing screw and steady-pin holes that would modify the outward appearance of the movement of the swan's neck, without impinging on the lower neck operating lever.

The multiple, prototype zig-zag track sections were manufactured by using a hand-held piercing saw, as they may have been originally. This remains the most expedient method of manufacture for this type of material on this scale. They were then drilled and countersunk to take M3 countersunk Allen head machine screws and raised to the approximate radius of the cam body by hammering into a wooden former.
The cam body was drilled and tapped and the whole assembled.

Fig. 45. Prototype zig-zag cam Mark 1.

Testing the Swanulator (phase 1)

In testing the Swanulator operated successfully. The motor had adequate torque and the zig-zag cam, sector and neck pinion all performed their functions.

Once operating, certain preliminary observations were made.

1. The smoothing out of the 1968-1972 cam profile had not been as effective as hoped. Whilst the action of the Swan's neck was certainly comparable with that of the Bowes Swan at present, the aim of the test bed was to develop a profile that would provide a more realistic 'swan like', serpentine action, and as a result reduce wear and tear.

2. The re-modelling of the cam profile to transpose the relative positions of the two sector pins, had been successful and effective in the elimination or significant reduction of the excessive track overhang. The required angular rotation had been retained.

3. Without the lower neck lever in place, explanation to a third party of the importance of eliminating the track overhang and its impact on the lever was difficult; the Swanulator did not fully illustrate the problem.

A conclusion from the above three observations was that the test bed could be refined and improved in order to satisfy the demands of the hypothesis that an improved cam profile was possible.

Those improvements or alterations in Mark 2 would include:

1. A new design of track profile to include the three necessary phases but not based on the 1968-1972 profile, but based on first principles embracing the three phases as described earlier.

2. The introduction of an interpretation of the lower neck lever and associated lobed cam, lever follower and neck raising /lowering mechanism.

Design for the Zig-Zag track (Mark 2)

In the design stage of the mark 2 zig-zag cam profile, it was already established that the action should be as serpentine and flowing as possible, given the constraint of complying with the three phases; preening, fishing and 'looking about'.

The prototype track mark 1 was made by following a smoothed-out version of the existing track. In order to keep the inter-pin distance constant, a plastic pen-holding jig was made, with two holes drilled at the appropriate centre distance. The tracks made by the two pens were used as guide lines for sawing. Only single cuts were made for each pin track, and the sections liberated by sawing were moved approximately 3mm away from the main track in order to form the groove for the pins. It became obvious that this was not an entirely satisfactory method of manufacture for curved sections. Due to the tangent of the curve in relation to the main track, the desired 3mm slot could be significantly narrower and require subsequent modification by filing. This filing process introduced error and 'play' into the system.
When making the prototype mark 2 zig-zag track, it was necessary to make a more sophisticated marking out jig.

The new marking out jig consisted of a length of rectangular section brass, with four scribed and drilled holes, each fitted with a hardened and tempered, pointed steel pin. The steel pins being planted in two, 3mm spaced pairs, each pair being 20mm apart. The sharp points on the steel pins and their relatively accurate placement gave a clear path for the piercing saw, and significantly reduced play between the pins and the track groove walls.

The first zig-zag track prototype was produced from a strip of brass 25mm wide with sections cut out to form the neck rotating elements. The method had the advantage of being relatively quick to manufacture as only the elements where the neck is rotating had to be sawn. The elements where the Swan was looking straight ahead or fishing were un-sawn strip. The drawback of this method was that during playing the straight sections, the swan test rig appeared lifeless. In the Mark 2 prototype zig-zag track, the marking-out or scribing using the new jig was done on sheet material, with only ink guidelines delineating the final track edges. The result of this modified marking-out was that the entire length of the track had to be sawn by hand, thus taking significantly longer to make than the first example, but the positive result was that no section of track is absolutely straight and the action of the neck was subsequently more lively.

Once sawn, the new track profiles were shaped in the same way as the first, and secured to the Delrin® cam body with countersunk 8BA screws, those being slightly smaller diameter, with shallower heads than the countersunk M3 screws used previously. The 3mm diameter sector pins remained as before.

Following the testing of the mark 1 zig-zag cam, and anticipating Mark 2 cam, it was apparent from the action of the test rig, that the cam alone could not convey the relevance of the relationship between the cam overhang, and the lower neck operating lever to a third party. It was therefore considered useful, in order to interpret and comment on the action of the proposed Mark 2 zig-zag track for the lower neck operating lever to be in place. Its proximity to the track could then be seen and recorded.

Designing the lower neck lever an associated work

At the outset of the practical work, it was not felt necessary for the lever to be in place, nor was it intended for the neck to move up and down automatically. However, as the design of the cam body and arbor followed the original, there was as a result, adequate space and facility to fit the lever and lobed neck cam.

In the Swan mechanism, the raising and lowering of the neck is controlled by three lobed cams sharing a common arbor. These three levers operate three chains within the Swans neck; one each for the lower, middle and upper sections. It is the arrangement of these three points of attachment, and their respective cams having individual profiles that give the Swan its lifelike appearance.
Making the three cams, levers and control mechanism was outside the remit of this project; the resultant benefit would not be proportional to the time invested. It was therefore decided to control the entire raising and lowering of the neck from one lobed cam and one lever. The lobed cam, like in the Swan, would share a common arbor with the main cam body. The two would rotate together, and the two lowering phases of the neck would coincide with the zig-zag profile.

Following the design of the Swan, the lobed cam would have two cut out sections, one each corresponding with the preening and fishing phases. The latter being more relieved, allowing the neck to drop further than the former.

The lever following the lobed cam is pivoted in front of the swan's neck, below the water line, with the point of attachment for the control line approximately half way between the two. This means that any movement at the cam is translated into half that value at the point of attachment. This does not constitute a problem, other than for the lever to follow the dimensions of the original, it had to extend through a slot cut in the front of the plywood box-frame. The base of the box being extended to provide a pivot point.

Part of the original design of the Swan, was the mechanism that allows the neck to rotate and the levers to operate the raising and lowering (and other functions) independently. This action is facilitated by a series of five sliding steel discs with forked followers attached to the levers; a mechanism well beyond the scope of this project. A simplified version was needed.

As described above, the three cams, levers and control chains would be simplified into one. A steel wire rope was substituted for the steel chains that run up through the core of the neck. The sliding discs and forked followers would be replaced with a single sliding Delrin® bobbin, embracing the lever whilst allowing the neck to rotate.

Making the lower neck lever and associated work. (fig.46)

A disc of 3mm thick Tufnol® sheet was roughly sawn to diameter and mounted on a flanged brass boss, screwed to the main cam arbor.

A slot was made in the front of the plywood box frame. The box frame was mounted on an extended plywood base-board, fitted with up-stands that would form the front pivot point for the lever. The up-stands were drilled through and a friction-fit steel pivot pin inserted.

The steel neck operating lever was fabricated with a forked end to form the frame for the lever following roller. A 15mm flanged roller was turned from Delrin, and through drilled to be embraced by the aluminium fork and a steel pivot pin fitted.

A Delrin® bobbin was turned, drilled and bored on the lathe to a sliding fit on the aluminium neck arbor, the bar having previously being removed and slotted along its length, and across the top end in the milling machine. This longitudinal slot would accommodate the control wire, and the top slot would take a guide roller.

The top guide roller was turned from Delrin®, cross drilled and a steel pivot fitted.

Fig. 46. Test rig lower neck operating lever and associated work in place.

Testing the Swanulator (Mark 2)

Once in place, the mark 2 zig-zag cam together with the neck operating lever was put on test driven by the electric motor as before.

Observations were as follows:

The revised zig-zag track profile combined with the refined manufacturing process related to a more Swan-like, graceful or serpentine action of neck rotation. The play in the pin track was reduced but not eliminated.

The lowering and raising action of the neck did work, albeit not with the efficiency or grace of the original yet helped to explain the phases of the action of the neck. It clearly illustrates the relationship and space between the zig-zag track overhang, and the lower neck operating lever.

The raising and lowering of the neck lacked a great deal of the sophistication of the Swan, due in part to combining of the action of three lobed cams into one. Also in part due to the test-rig neck being solid and the Swan neck being a highly complex structure.
Given these limitations the result is rather clumsy but conforms to the core MA question and could be described as fit for purpose.

The test-rig; next steps

In order for the discussion contained within this document to be further informed and directed, additional data from the Swan would have to be extracted. The source of this data is known; the rim of the body of the extant zig-zag cam. The data is in the form of numerous drilled and tapped (threaded) holes, with associated smaller plain drilled holes. These are the sites of fixing screws and steady-pin or locating pins for the various track sections. It would be necessary to separate out eighteenth century and later holes. This could be done by examination of the thread profile and burr thrown up on the inside of the rim as part of the threading process. Eighteenth century thread forming consisted of a part cutting and part displacing action. Modern thread forming is almost all cutting. We know the present track sections are retained by BA screws. These holes could be identified and eliminated. By plotting all the eighteenth-century holes in a linear fashion, similar to the rubbing taken of the zig-zag track, the possible earlier cam profiles could be plotted by following the gaps between the screws and steady pin holes, and by over-layering the modern and revised profiles.

This process would not be a particularly difficult or time-consuming process, however accessing the cam body is rather more difficult as it involves removing the swan's body and then removing and packing approximately half of the 141 twisted glass rods that simulate water. This is a time consuming and relatively risky process due to the presence of the glass rods. It would have to be demonstrated that the potentially significant benefit of replacing the zig-zag track outweighs or at least balances the risk, time and expense of the process. The test-rig would be part of the preliminary phase of this process, in demonstrating to museum staff, funding bodies and the general public the very nature of the problem and the risk and / or damage it creates.

The Water Bearing Bar

Introduction

The body of this thesis text investigates the Swan's central multi-function cam, and in particular the function or mal-function of the zig-zag track that controls the rotation of the Swan's neck. This part of the mechanism was replaced between 1968 and 1972 as part of a major overhaul of the machine. Other components were replaced during this period including a transverse multi-piece structural brass bar that provides bearing holes for the inner ends of the 140 twisted glass rods. The spacing of the bearing holes now restricts the linear movement of sub-automaton fish in front of the Swan.

Given the thought processes developed during the redesign of the zig-zag track and the challenges raised by the subsequent proposal to re-make some of those later parts, what would be the outcome and cost / benefit of redesigning the water bearing bar?

How the Sub-automaton 'Swimming Fish' Mechanism Works

The multi-function cam arbor carries a brass boss onto which is fitted a brass stepped cam. A brass and steel lever (fish operating lever) operates against the cam. As the cam rotates the lever is operated a reciprocating action. The lever is drilled at its end and fitted with a control cord. The cord operates a bank of seven double rollers, each corresponding with one of the seven silver fish. Each fish sits on a steel pin (fig.48.) mounted on a sliding brass carriage. Each carriage fits into one slot of a seven-slot wide track (fig.47.). As the lever moves, the fish are pulled back and forth by the bank of rollers. The profile of the cam dictates the speed and direction in which the fish swim.

Above the fish track is a layer of twisted glass rods. At one end the rods have a cemented brass pinion cap with a steel pivot or bearing.
Every pinion gear must engage with its neighbour in order for the rods to contra-rotate. The carriage pins on which the fish are mounted protrude through gaps between the rods so the fish appear to be swimming on top of the glass water.

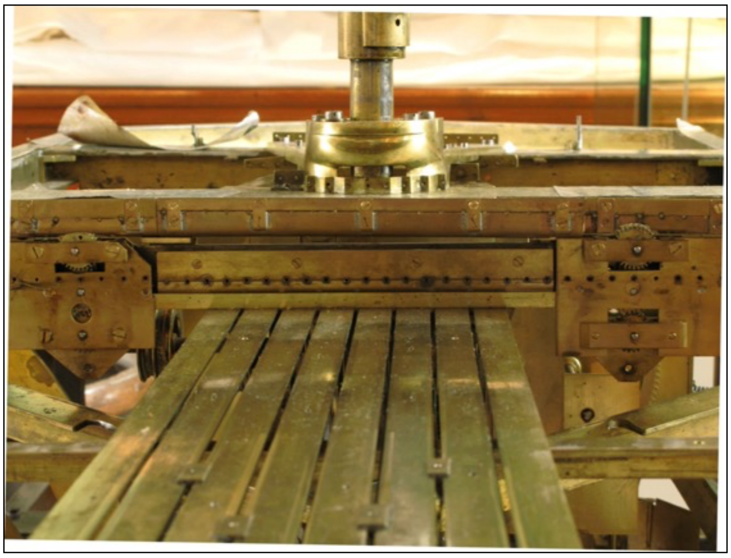

Fig.47. Transverse water bearing bar and fish tracks

fig. 48. One of seven fish mounted on its pin and sliding carriage

Findings of the 2008 conservation project relating to the water bearing bar

Wear marks on the fish track indicate that at one time the travel of the fish along the track was once approximately double of that at present. This reduced level of travel is facilitated by a reversible modification to the fish lever. Its effective leverage had been reduced by approximately 50%. During the 2008 project it was temporarily, and again reversibly, re-arranged to its earlier (original?) format. This resulted in greater travel of the seven fish consistent with wear marks on the track. The fish sub-automaton tested as satisfactory and more animated; in keeping with the eighteenth-century description of the fish *'sporting about'*.[82]

It was not until the twisted glass rods were replaced that it became apparent why the travel of the fish had been limited in such a way.
At their outer ends (front of the automata) the glass rod bearing brackets are coupled into pairs. The bearing holes are not equidistant. Between every other rod is a gap through which the fish mounting pin protrudes.
The transverse bearing bar has bearing holes for the glass rods that are equidistant, and not aligned with the track below. This results in the rods impinging on the track at the driven end. The point at which the rods prevent the fish from sliding along the track is about half way down the track length, hence the limited movement of the fish. This appears to be a result of the bearing bar being re-made (probably 1968-72). On discovering the fault, rather than again re-design and re-make the bearing bar, it appears a previous restorer has chosen the option of limiting the travel of the fish to the correctly spaced end of the rods.

A New Design for the Water Bearing Bar

As the sub-automaton operating cam, lever, bank of rollers and fish track all appear to be of eighteenth-century manufacture, and in their original positions, it is reasonable to conclude that the main fault lies in the relative positioning of the driven rod bearing holes.

Evidence of makers marks, dates of manufacture, together with the use of extruded brass of modern appearance and off-the-peg machine screws are all supporting factors. As it would be possible to infer that the design and earlier arrangement of bearing holes, there could be a justification for designing and making a new bar.

The bar consists of a supporting rail, with sections of bearings screwed to it. Each section is adjustable in height by packing with shim and washers, and has some level of adjustment in relation to its neighbour due to elongated, slotted and sloppy screw holes. The equi-distant nature of individual holes is not adjustable.

Another factor in this mechanism is the diameter of the twisted glass rods. It is not known how many of the 140 twisted glass rods that make up the stream of water in which the fish appear to swim are contemporary to the Swan. It is likely - partly due to the vulnerable nature of glass – that many are replacements.
Post-war documentary evidence states that some of the rods were replaced. The Bowes Museum has in its reserve collection, a stock of new glass for the purpose. The rods fitted presently to the automaton vary in width from approximately 5 to 8mm across flats (the section of most of the rods being square). It may be therefore that some of the issue with lack of space between the rods is not due to the bearing bar but that the rods are larger diameter than originally intended. This does not however explain the overall converging design.

Fig. 49. (line 1) shows diagrammatically the approximate present layout of the rod bearing holes.

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[82] A Catalogue of Valuable Property forming the late Mr. Weeks' Museum..Forster and Sons, 1834. 3rd Day (16th July) lot 273 £189.

A new design would have to effectively change the spacing of the rods but retain the distance between the bearing holes, otherwise the geared pinions would not intermesh and the rods would not rotate. There are two input points for driving power to this section of glass rods, meaning that a. only two rods are in fixed positions, and b. the two central rods do not have to meet.

Figure 49 (line 2) shows an alternative arrangement for the rods, with every second bearing hole placed at a diagonal position. This would result in the rods effectively being bunched into pairs but retaining the maximum gap between every second rod.

Figure 49 (line 3.) shows every bearing hole at a diagonal to its neighbour. This arrangement would effectively bunch all the rods together.

Working from first principles (the fish track), it would be possible to use a combination of horizontally, and diagonally drilled holes, in combination with the varying widths of rod sections, and small variations in pinion diameter, to design and make an entirely new set of bearings, retaining the 18th century bar chassis. Alternatively, only the central bearing piece could be removed and what remains of the earlier rail be rebuilt.

Replacing the Water Bearing Bar. What benefit, what Cost?

Any work carried out by a professional to historic material implies a monetary cost. For this work however as part of a Masters thesis, that cost is not considered, given the international importance of the object.

Other costs to be considered include the risk of damage to the object, and the duration the object would be off display. There is also a risk associated with the change in perception of the object, especially by those outside the museum and heritage staff structure; namely the general public, who have a clear picture of 'their Swan' as expressed during the 2008 conservation project.

Unlike the zig-zag track and multi-function cam, there is very little tangible physical damage caused to the machine by the later arrangement of glass rod bearings. Occasionally[83] one of the fish jams against a glass rod causing either the fish to stop working and/or the glass rods to stop rotating. This fault is relatively easily corrected and the damage caused is minor.

The interpretation of the object is however distorted by the later arrangement of the fish operating lever, as the fish only travel half their original distance along the track. As a consequence, the fish do not reach the position of the Swan's beak when it performs its fishing operation.

If the water bearing bar was re-designed and made, the operation of the automaton would unquestionably appear closer to that of an earlier period. The general public however, and in particular those who have lived with the Swan for decades are unlikely to be aware that a different arrangement ever existed, and rather than seeing a re-design as an improvement, may see further alterations as unnecessary and even negative. This raises again the question of ownership and responsibility. The conjectural, or even evidence- based restoration of an object, may be in the interest of individuals, or informed groups of individuals, but may not satisfy the needs or expectations of all influential groups.

[83] Bowes Museum now keep a written record of these events.

In conclusion the benefits of implementing the changes outlines in this research are relatively limited when compared with the zig-zag track. However, if the track were to be investigated from first principals, and the glass rods removed, it may be efficient to attend to the water bearing bar at the same time as the benefit would increase for little additional cost or risk.

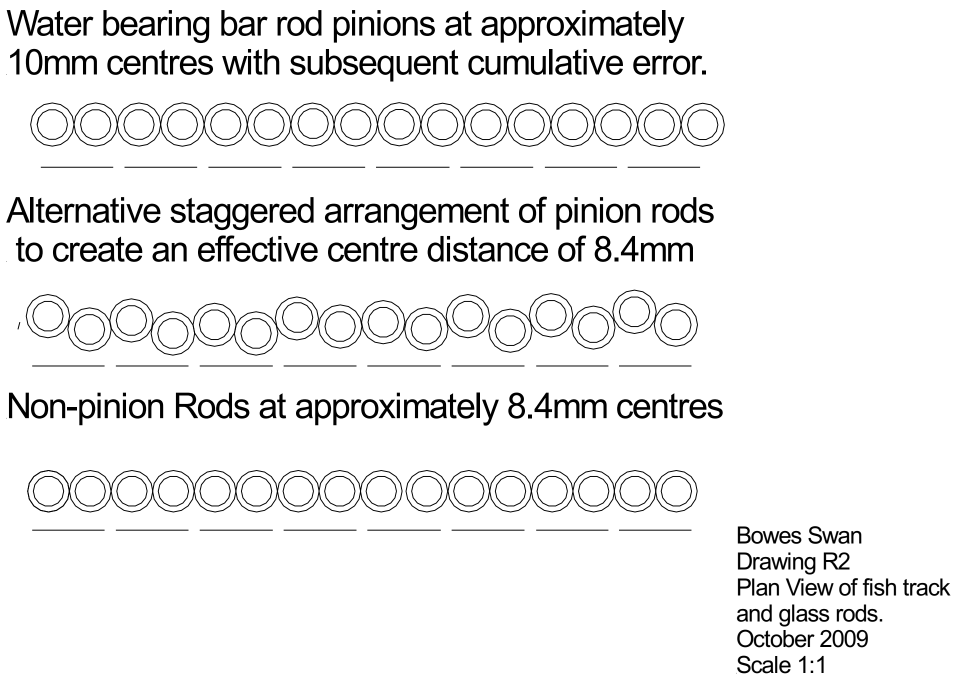

Fig 49. Diagrammatic view of the glass rods and transverse water bearing bar showing the rods in their present layout (straight line), and below in a suggested layout to bunch them together to allow passage of the swimming fish pins.

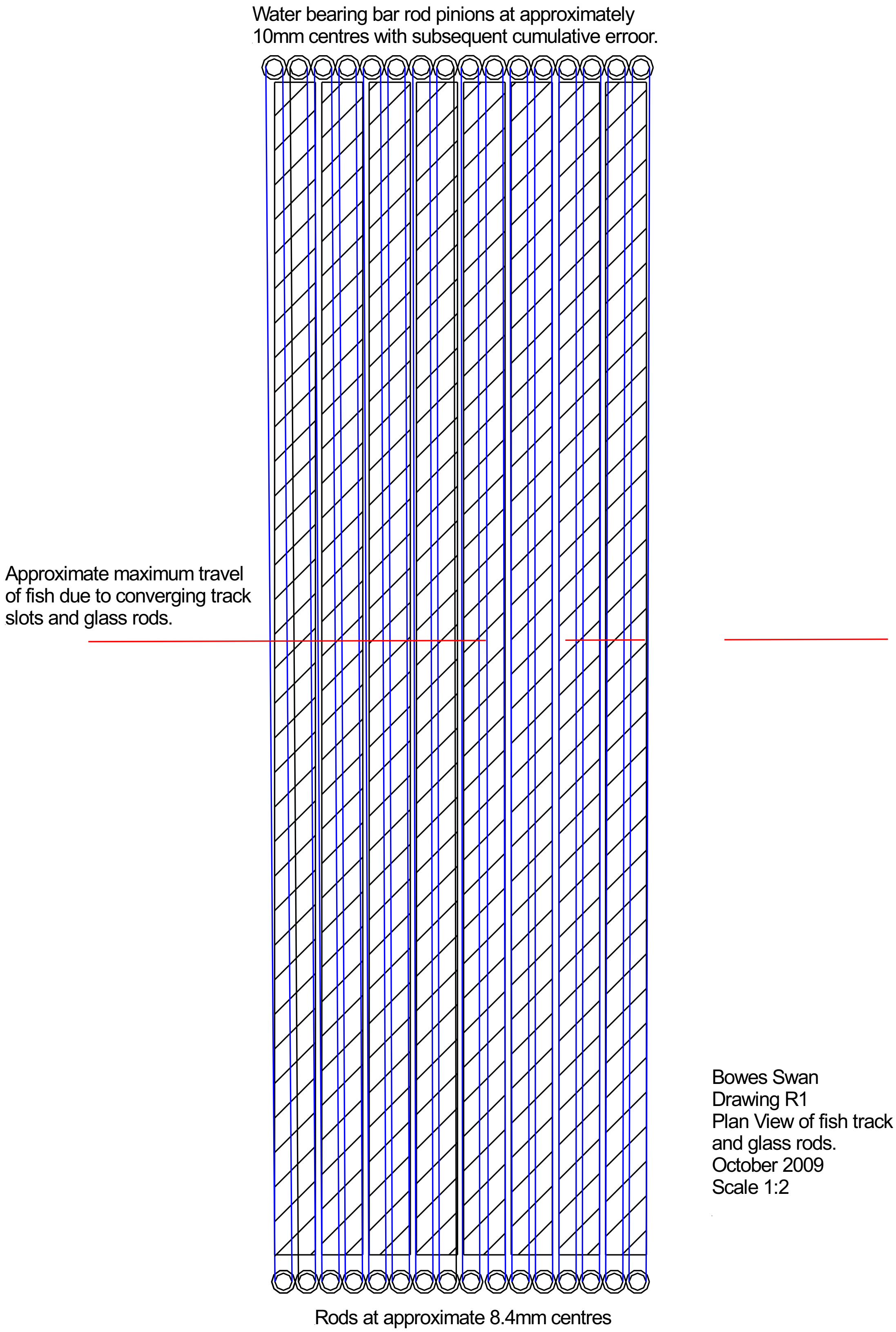

Fig. 50. Diagrammatic plan view of the glass rods (blue) showing the present layout with cumulative error in relation to the fish tracks (black).

Conclusions

Housed within the Bowes Museum, Barnard Castle, the Swan automaton is currently played every day the museum is open, once per day to a what appear to be a loyal and engaged public audience. Other than being separated from its original setting; an eighteen-foot-high 'temple', the late eighteenth century Silver Swan and its operating mechanism are in the main, intact and comprised of original parts. Consistent with the age of the machine, components within the mechanism and part of the silver casing show signs of wear, the level of wear depending on the type of material and level of stress experienced over the past 240 years.

As a result of a comprehensive disassembly and cleaning of the Bowes Swan in 2008, two significant parts of the mechanism were identified as having been re-made or re-configured in the period 1968–72. These were the zig-zag cam that operates the rotation of the Swan's neck, and the water bearing bar that holds a series of glass rods simulating water on which the Swan appears to Swim. These twentieth century alterations impact on the machine in several different ways. The zig-zag cam has a direct and arguably negative physical effect, causing tangible wear to eighteenth century components, with the conjectured potential of greater damage to the mechanism.

The water bearing bar has little if any physical ill-effect on the machine, yet has an impact on the outward appearance of its performance.

The zig-zag cam was the primary focus of this research, through the prototyping of two revised track profiles that eliminate the wear and resulting damage to other parts of the Swan. In order to evaluate these track profiles a test-rig was built, the *Swanulator* using dimensions extracted during the 2008 project. This was designed and built to simulate the mechanism that engaged this particular element of the Swan. The first track design followed that extant with minor alterations, and proved the principle of the overall new design, but in detail proved less satisfactory. A further revised track, with the addition of the lower neck operating lever was made that operated in a more 'swanlike' manner as hoped. The original designer/maker of the Swan went to considerable lengths to ensure the object looked as life-like as possible. It could be argued that the action of the Swan would follow that pattern. In order to create the optimum zig-zag cam, a study of the motions of a real swan might be appropriate. To qualify the success of that profile, the opinion of an expert in the field could in future be sought

The presence of the neck lever helped in the overall interpretation of the new cam. This suggested that without any further alterations to eighteenth century work, a new track could be designed, made and fitted, applying conservation principles that would offer significant reduction or elimination of unnecessary damage, while enhancing the outward appearance and interpretation of the object.

Investigating the re-design of the water bearing bar was a paper-based operation. The revised bar was a geometrical solution in the form of` a CAD drawing based on known eighteenth century dimensional values. Echoing preliminary results from the zig-zag track test rig, it appears feasible that a new water bearing bar could be designed and made without alteration to eighteenth century components, and applied in a reversible manner. This could legitimately enhance the viewer experience by more effectively enacting the motion of sporting silver fish as described in contemporary 18th and 19th century documents.

Hopefully, the information contained in this thesis could assist The Bowes Museum in the decision-making processes related to the ongoing maintenance and operation of the Swan. The preferred prototype and hypothetical re-arrangement of the water bearing bar could be considered in conjunction with implications of other issues such as audience expectation, cost and down-time during conservation. The physical implementation of the two alterations described above could be significant, with beneficial long-term cost benefits.

Given access to the machine and funding to implement suggested changes, revised profiles would if operated for sufficient cycles in the Swanulator, present different sets of wear values, due to the changes in the rate of angular momentum. This would manifest physically on parts of the track where the sector pin touches. Specific parts or sections could be photographed beforehand and after a predetermined number of cycles.
During the late 1960's/early 1970's restorations, a cycle counter was fitted to the Swan. In 2008 the counter read approximately 30,000 Cycles.
Given that one cycle lasts approximately 40 seconds, in continuously operation it would take approximately 12.5 days to complete this many cycles. It may therefore be possible to replicate this number of cycles during a reasonable testing period.
The analysis of the rate of angular velocity could be raised to a more technical level by building-in a torque meter (a type of strain gauge) into the lower neck joint.
In reality it proved impossible to carry out much of this research due to a lack of time. These points however remain valid and would warrant future investigation, especially if a new track were to be fitted to the Swan.

The process of close study and research related to the Swan and associated dynamic objects raised wider questions related to curatorial and conservation policy. Preliminary investigation through contact with professional colleagues and associates and the circulation of an informal questionnaire suggested policy making in this specialist field warrants further investigation. Valid reasons for and against operating the machine are laid out in this thesis with a range of views explored associated with the operation of dynamic historic objects. To pursue the documentation of living memory information in the form of radio interviews, a visitor book near the Swan or a questionnaire.

By suggesting physical and interpretive alterations to the current format of the mechanism an attempt has been made to respect the original intent of the maker in relation to physical action and audience engagement. These aspects are themselves open to many subtle interpretations yet it is hoped that the investigations carried-out and explained within this thesis will add to the safe, fidelitous operation, and longevity of the original mechanism.