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Mechanical and Structural Artefacts Used in "The Mystery of Elche"

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Abstract
In the city of Elche, every year, on the 14th and 15th of August, a sacred musical play about the death, the Assumption and the Coronation of the Virgin Mary is held. This event, known as the "Misterio de Elche", is unique in the world. Since the middle of the 15th century it has been performed in the Basilica of Santa Maria and in the streets of the ancient city of Elche, located in the Valencian Community. In this work, classified as a UNESCO World Heritage Site, the interior of the temple is transformed into 2 main stages, the scaffold, located in the lower part, and the aerial stage, located in the dome at a height of 27 m. The structure and the traction mechanisms located on the aerial stage allow the aerial devices that take part in the play, "El Araceli", "La Mangrana" and "La Santísima Trinidad", to be raised and lowered. It should be noted that between 2 and 5 singing actors are embarked on these devices. This article describes the main characteristics of the aerial stage structure, the 3 apparatus and the mechanical systems used. In addition, the age and modifications of "El Araceli" are analysed, as well as the results of a non-destructive test carried out on this device.

Keywords Mechanical lifting devices · Historic winch · El Araceli · Mystery of Elche · Heritage · Artefact

1 Introduction

In the city of Elche, every year, on the 14th and 15th of August, a sacred musical play about the death, the Assumption and the Coronation of the Virgin Mary is held. This event, known as the "Misterio de Elche", is unique in the world. Since the middle of the

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15th century it has been performed in the Basilica of Santa Maria and in the streets of the ancient city of Elche (Gironés, 2008; Massip i Bonet, 1991; Castaño, 1994; Ramos, 1956).

This theatrical work has outlived others of its kind that were celebrated in the Christian world centuries ago, despite the clauses established by the Council of Trent that banned them inside temples. It was protected by a papal decree granted in 1632 by Pope Urban VII (Pérez, 2008). This act has remained unchanged for five centuries and has only been interrupted by cases of force majeure, such as wars or epidemics like the one we are currently experiencing.

In this work, classified as a UNESCO World Heritage Site, the interior of the temple is transformed into 2 main stages, the scaffold, located in the lower part, and the aerial stage, located in the dome at a height of 27 m.

The lifting machines installed have undergone modification over time. The last modification, carried out in 1760, was undertaken by the architect, Marcos Evangelio, and, except for maintenance operations, these devices remain in their original state. Despite their "primitive" technology, these machines achieve a high degree of precision and efficiency.

2 The Aerial Stage

A part of the aerial rigging is situated into de cupola, and the other one is located on the superior terrace Fig. 1A. It is 28.6 m high from the floor. Participants of "La Festa" can access to the cupola through a huge window. This is an architectural feature of this basilica, that was designed around the representation.

Figure 1B shows the terrace, lateral access ladders, foundation slab designed to fix the winches and box and the access window to the dome.

The aerial rigging was designed adjusted to the Saint Mary Basilica measures and it was made up considering all the constructive elements. Since 1760 to these days, the aerial rigging has been installed in similar form. The board of The Mystery of Elche has tried to respect the shape, characteristics and assembly proceedings.

The aerial stage, shown in the upper part of Fig. 2A and B is formed by a large circular canvas that covers the base of the dome. This canvas is decorated with paintings depicting the sky with musical angels. Slightly offset from the circular perimeter there is a square opening covered with two sliding doors, which open to allow the passage of the aerial artefacts (Marco, 2014; Caprietti, 2003; Massip i Bonet, 1997; Mc Evoy Bravo, 2013; Pomares, 2004; Massip i Bonet, 1992).

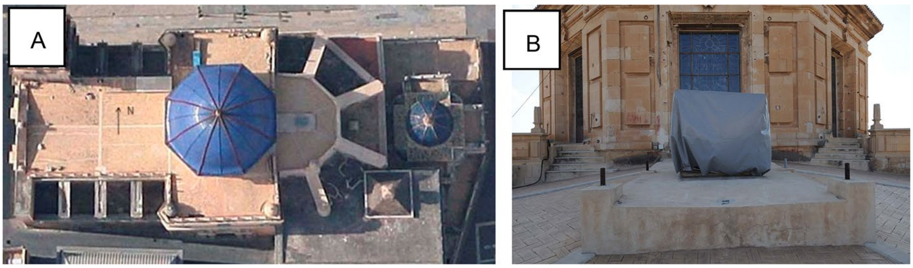


Fig. 1 **A** Aerial photo of the cupola and terrace of the basilica of Saint Mary of Elche. **B** Terrace. Foundation slab, winches anchors and cupola access

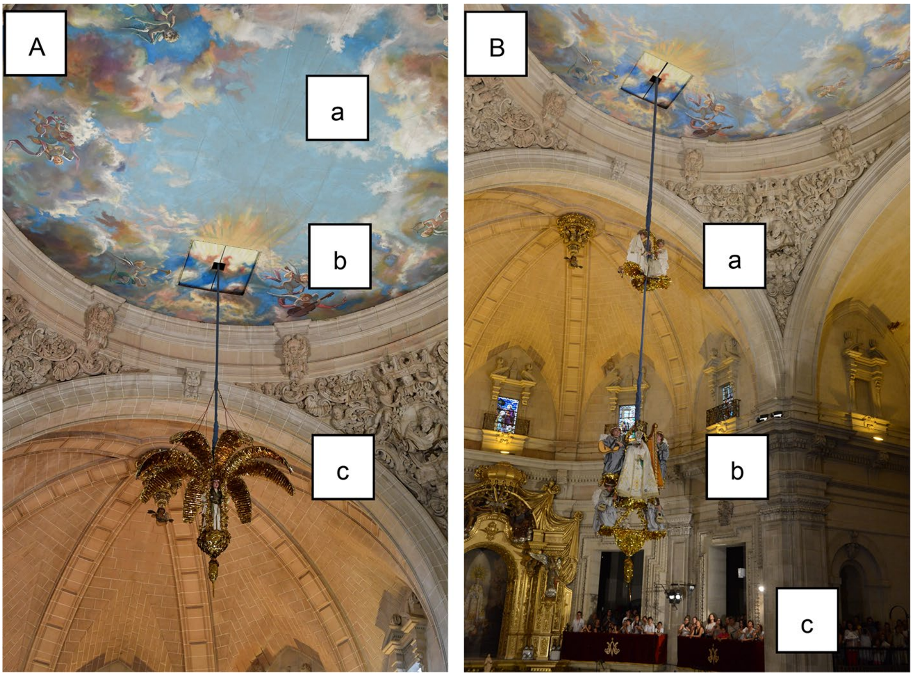


Fig. 2 Two views of the interior of the church of Santa Maria **A** Scene showing "La Mangrana" opened at the beginning of its descending trajectory. (a) The canvas on the sky, (b) The doors of the sky (access doors to the upper stage), (c) "La Mangrana". **B** Scene corresponding to "The Coronation", an act where 2 devices converge in the same act, (a) "The Araceli" and (b) "La Santísima Trinidad" and (c) Part of the audience on the balconies

2.1 The Canvas on the Sky

The canvas on the sky is a circular part used to cover the base of the dome an it is 13,350 mm of diameter surrounding the whole perimeter. There are several anchors to fix it to the interior cornice and a steel ring of 20 mm thick that offer support to the canvas. The area that is visible to the audience is decorated with blue-colored paintings, clouds and musical angels; in the script of the play it represents the sky. In the part located below the working platform, there is a square opening covered by two sliding doors, which open to allow the aerial elements to pass through. This piece can be appreciated in Fig. 3.

The canvas is located over the main altar. The burial is situated at the wooden platform just below the sliding doors on the sky. This mechanism consists of a square hole of 1770 × 1770 mm where the 3 aerial apparatus get in and get out to the stage.

The textile used is composed by pieces of 1200 mm width, a weight of around 400 g/m^2 and it is made up of natural and synthetic fiber (86% cotton and 14% polyamide). It is reinforced by 16 protective sheaths of 5500 mm length and 70 mm width radially arranged.

The tear resistance is about 165–175 N/mm and the elongation it is valued between 25 and 45% depending on the test forces directions. The perimeter of the canvas is drilled every 330 mm where there are brass buttonholes of 28 mm to fix it to the interior of the dome.

Fig. 3 Canvas on the sky

2.2 The Platform

The platform, shown in Fig. 4, has the shape of a circular sector. It allows to handle correctly the aerial apparatus and a suitable actors access. It is fixed for one hand, to the bases of 3 windows situated on the East, Northeast and Southeast, and on the other hand, to the wall of the drum of the dome, with special metal parts fixed to the blocks.

The level is supported by a main beam and 2 secondary beams that are covered with wooden planks. In this case, it also is anchored with steel eyebolts fixed to the blocks to ensure the proper position. The main beam is made of steel, it has the shape of a double "T" section and 9290 mm length. Their extremes are supported on the Northeast and Southeast bases windows. The secondary beams are made of wood and they are 5950 mm length, separated 1800 mm each other. These beams are mounted perpendicular to the

Fig. 4 The platform

main beam forming a cantilever of 2800 mm. They are supported for one hand, to the main beam, and on the other hand, on a square section wood pillar. These beams are fixed with wedges. The parallel of the 2 secondary beams is ensured with another 2 beams. One of them is called "the pig", situated on the exterior and the other one is called "closing beam". This composition has the shape of a square. The platform is completed with 2 wooden beams of 4600 mm length. They are called "border beams" and they are supported on the cantilevers of the secondary beams. There is 600 mm high between the platform and the terrace, so 2 ladders are used to facilitate the access. To guarantee the safety, it is installed a handrail along the perimeter. The secondary beams are anchored in the extremes with a 35 mm hemp rope and tension cables fixed to the window lintel to avoid the hypothetic structure rollover.

2.3 The Hoist

Consisting of two pillars assembled at an acute angle, joined together at their apex and resting on the main ring, they are inclined towards the interior of the temple. A set of eight braces hold them in position, which is regulated by the length given to them. Two manually operated winches with parallel axes, each equipped with gear reduction systems, located on the terrace and separated from the pillars, are responsible for providing the force to lower and raise the devices; a force that is transmitted by means of thick hemp ropes guided by the pillars—see Fig. 5.

The whole assembly has, as a common support, the part of the building in which they are located: the terrace of the presbytery and the interior of the dome on the fourth floor of the basilica. These are sufficiently rigid to transmit the forces between the different members of the machine, and support the loads required, without any relative movement

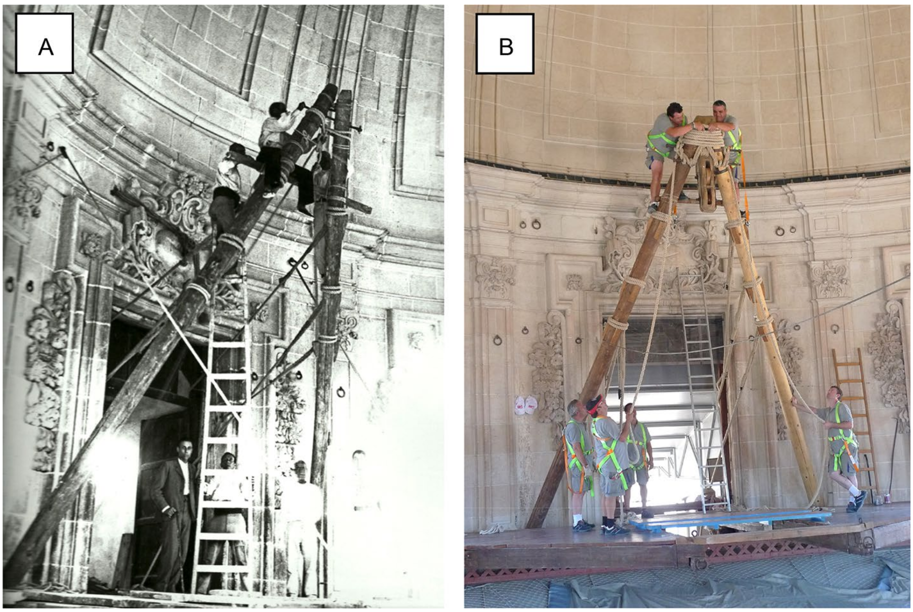


Fig. 5 The hoist with its components. Cupola, dome, pillars of the hoist, tensors, and platform

between their parts. The hoist is equipped with 2 double pulleys sets to drive the ropes from the winches. 2 of the pulleys are hung from the hoist vertex and the other 2 are located on the East window base. These pulleys allow the ropes to change the direction. At the hoist vertex are fixed the aerial artefacts (Fig. 6). Since this point, that is situated 24.3 m high, all the devices are lowered and raised.

The lifting and lowering movements of the aerial artefacts is managed with a rope actioned by 2 winches located on the terrace. The kinematic chain is composed of winches, gears and pulleys that transmit the muscular effort from stagehands.

The masts are made up of Soria pine wood. These masts have a conical-shape of 6460 mm length. The base diameter is 198 mm and 170 mm at the end. The bases are provided of rounded edges that fit perfectly in the spherical hole located in the transverse arch. At the upper end, there is an ironwork reinforcement that allows the vertex assembly and ensure its position. The fitting is built with a steel shield of 4 mm thick. This support wraps the wooden end that is 325 mm length with a maximum diameter of 195 mm. The shape is closed with 3 flat surfaces in different planes to facilitate the suitable position. The beams located at the top are fixed with nails, anchor bolts and straps.

To make the assembly easily, the set is fixed in the horizontal plane. Once all the parts have been joined, it is raised to the proper position with the help of a winch and a pulley. In this right position, the pillars form a 40° each other and the distance between the bases is 4420 mm.

2.4 The Ropes

Traditionally, the ropes used on site have been made of industrial hemp. More recently, the rope used for raising and lowering the artefacts with people has been reinforced with synthetic fibres to increase safety.

In the structure, the ropes function as turnbuckles. There are eight ropes attached to the upper half of both masts, symmetrically distributed and fixed to different points of the building, inside and outside the dome. Another rope fixes the apex to a ring anchored to the top of the lintel of the window, which allows its inclination to be adjusted. There is a

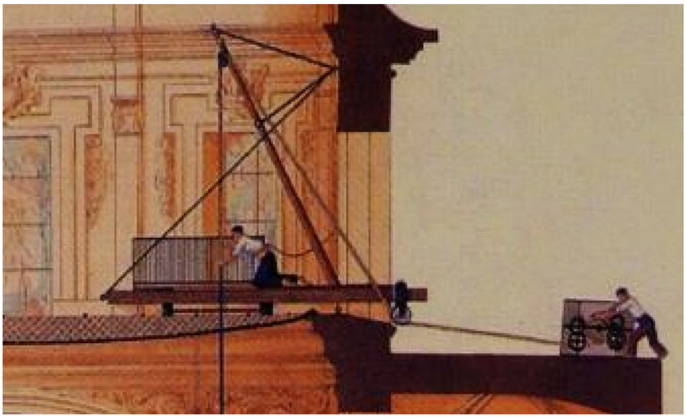


Fig. 6 Mechanical drawing of operation. Main parts: masts, pulleys, winches and rope

further rope whose function is to counteract the pull at the apex caused by the lifting ropes and the opposition caused by the passive forces on the apex pulleys.

The lifting ropes are the thickest and strongest of all the rigging. The overall rope diameter is 52 mm. The maximum working load for this rope has been estimated at 19,120 N, while its breaking load has been estimated at 180,000 N as the sum of the capacity of the hemp rope and the synthetic core.

2.5 The Pulleys

Pulleys are particularly important in this work. It can be argued that the most significant ones are those used to guide the lifting ropes from the winch to the lifting devices (Fig. 7). The lifting pulleys are located on the sill of the window that connects the inside of the drum to the terrace where the winch is located, consist of two bronze eye pulleys mounted in parallel with a shaft and a common steel frame. The vertex pulleys are particularly unique, being a pair of pulleys, made of wood, mounted on top of each other, the one with the largest diameter on top intended for heavier apparatus. Both in the same frame, also made of wood and all reinforced with forged steel.

2.6 The Winches

The force applied to the ropes has always been with manually operated winches. The current ones entered into service in 1971 and replaced others with similar dynamic characteristics, which entered into service in 1761. After they were removed, they were moved to the Casa de La Festa, where they can be seen today. Comparing the two machines, we

Fig. 7 Pulleys. **A** Fixing the pulley to the crane. **B** Double pulley designed to raise and lower 2 different devices

understand that it would be appropriate to present the hoist with the old winches given their special singularity.

Figure 8 shows two independent winches, different from each other and mounted on a common frame made from profiles of forged steel. This set was accompanied, originally by a wooden box that contained it and which had, among others, the following characteristics: its shafts are parallel horizontally, they are manually operated with two input cranks per winch and the multiplication of the force is provided by two chains of gears and this chain means that the number of gears is the main differentiating element between the winches, one having three pairs and the other, two. Figure 8A shows the main winch, that allows the heavier devices, "El Araceli" and "La Mangrana", to be raised and lowered. Figure 8B shows the mechanism used to "La Santísima Trinidad".

They are mounted opposite each other on the frame, with the output drums at the same height, the gear trains positioned on opposite sides and the two cranks corresponding to the chain with the highest number of gears positioned higher than the others.

Until 1971, the whole assembly was anchored to the terrace of the basilica and positioned in such a way that its axes of rotation were orthogonal to the trajectory of the ropes. In this location, the winch with the chain with the highest number of gears, the most powerful one, was located at the part furthest from the dome and which it will consider as the rear part throughout this paper. As for the least powerful, the smallest and intended to lift the "Santísima Trinidad", it is located, according to the reference taken, at the front.

Originally, the frame consisted of a metallic structure reinforced on the outside with a wooden box. After the box was burnt in the 1936 basilica fire, what has survived is the internal part. Due to the poor condition it was left in after being dismantled at the terrace of the basilica, prior to being exhibited, some parts had to be reconstructed, which is why,

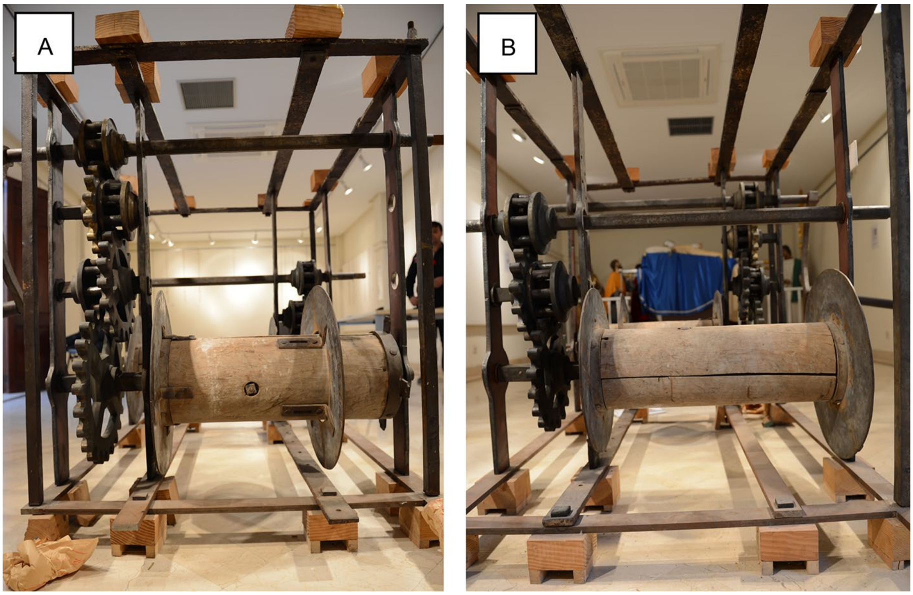


Fig. 8 Winches

today, many of them are not the originals, which are easy to identify as they are made of laminated steel.

In order to describe it, it will consider that it has a main part, made up of two rectangular frames, one located at the base and the other at the top, their vertices joined together by four vertical columns. This main part is joined by accessory parts such as: two longitudinal crossbars in each frame, formed by rectangular plates identical to that of the frame, and also has two sets of three secondary columns formed by plates that are the support points to the shafts. To this end, at their resting point, the plates, while maintaining their thickness, produce a widening so that the hole for the bearing does not weaken the column. At the outer limits, the assembly resembles the geometric figure formed by the twelve edges of a straight parallelepiped with external measurements of: 1556 mm long, 1095 mm wide and 1199 mm high.

The different parts that make up the structure, except for the frames, which are fastened with rivets, are joined using the system known in carpentry as notch-tenon on the lower right-hand side. Notches were made in each frame, four at the vertices and two on each side; the ones at the vertices being square and the rest, rectangular. The ends of both the main and secondary pillars, end in a tenon and, as an extension to it, has a threaded bolt to hold and support the wood of the box that encloses it. After tightening the nut to the bolt, the frame and the wood of the box would be securely fastened. The two remaining pillars are fastened using the same system as the four crossbars attached to the frames.

As we have just seen, the metallic part of the frame is entirely made up of parts arranged vertically and horizontally, without the presence of struts, cross braces, braces or cross-pieces capable of triangulating the structure, a function that was assigned to the parts of the wooden box.

The groups of secondary pillars are arranged with their broad faces parallel to each other; each group having one pillar contained in the plane of each of the side faces of the parallelepid. The distance that remains from the axes of each group with respect to the plane of the rear part is 227 mm for the first and 1177 mm for the second. The central pillar of the first group is separated from the left side faces by a distance of 426 mm, the second being separated by the same distance, but from the right-side plane. Each of these pillars is attached in the same way as the side pillars, but on each of the crossbeams arranged in the upper and lower frames.

All the bearings are friction bearings and are attached to the secondary pillars. They are flanged bushings, made of bronze, on which the different shafts of the winch rest. Originally, the bushings of the hub were square on the outside and the flange was circular. After being repaired, some of them were replaced with bushings with a circular outer section.

The shafts start from a forged square section and have rods, both front and transverse, for both winches, which are roughly the same. The input shafts have a length of 1546 mm and a square section at their ends, intended for coupling the cranks. On the output side, those supporting the drums have a maximum length of 1122 mm and those corresponding to the intermediary gears of the kinematic chains have a maximum length of 300 mm.

As for the cranks, they consist of a main bar with a rectangular cross-section in the form of an arch. The length of the arch cord that forms the profile is 350 mm for the two corresponding to the small winch and 450 mm for the large one. All four have a square tube at the end intended to be attached to the shaft which coincides with the square shape given to the four ends of the two input shafts. At the opposite end, the one intended to be gripped by the hands of the operators, the plate was bent into a right angle. This end was forged into a cylindrical shape. These days, this cylinder has a steel tube on the outside that rotates concentrically on the forged cylinder.

The drums, both of which are the same, are where the ropes are wound. Attached to the shaft that supports them is the wooden matrix that forms a revolving cylinder on which the ropes are wound. To contain them within the cylinder, two circular crowns are fastened to it, the planes that contain them being parallel to each other and perpendicular to the axis of the cylinder. Due to the arrangement of the gear train of the small winch, only two thirds of its total length can be used on the drum of the large winch, which means it requires greater effort. The torque is provided by the force from the kinematic gear chain applied to the last gear, which is attached to the drum shaft.

The transmission of forces between each input shaft and its corresponding output shaft is effected by means of two ordinary straight gear trains located between each of the central columns and the corresponding one on the outside; to the left of the output drum in the large one and to the right in the small one.

The gears, formed from cast bronze, have turned side faces and the teeth, which are fitted by hand, are of the oblique, or so-called double point, type. The pinions are all lantern, and the head of the other gears describe the curve that results from tracing the envelope of the positions of the roller when its centre travels through the positions of its profile—see detail of Fig. 9A.

For the large winch, the kinematic chain is made up of three lower pairs and four members; the first is attached to the input shaft and the last to the output drum and the two intermediate ones, are attached to two shafts which rest on the central and outer

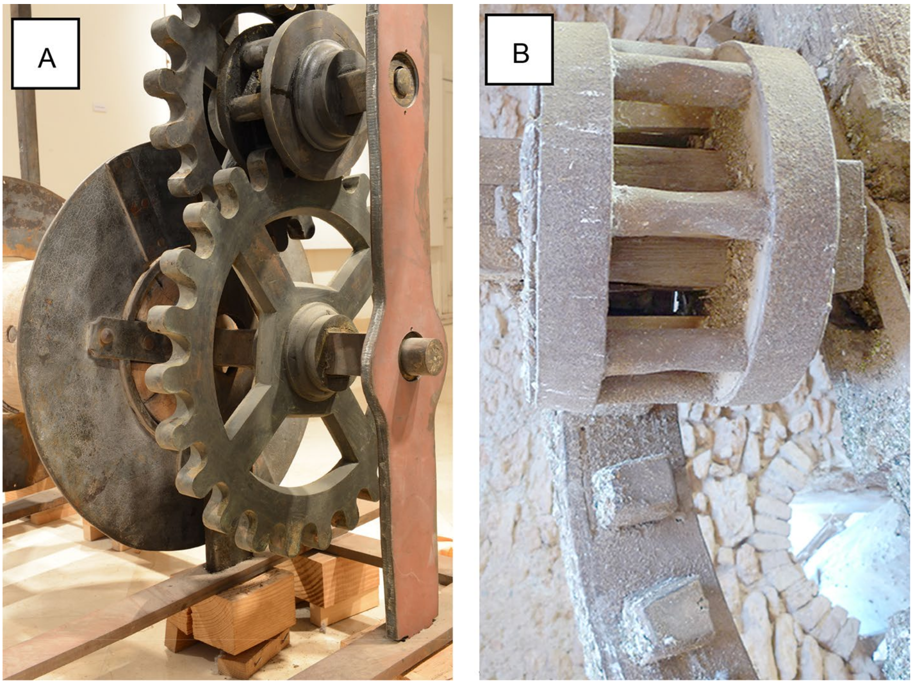


Fig. 9 Figure composed of the 1761 winch gears referenced as (**A**) and a gearing system, from the same era as the previous one, comprising a wooden wheel with wooden teeth and a lantern with steel cylinders attached to wooden discs reinforced with steel straps and attached to a wooden shaft and belonging to a windmill from the Cartagena countryside referenced as (**B**)

column of the frame and are held in place by friction bearings housed in holes made in the columns.

The input shaft is fitted with a lantern pinion made up of eight rounds of steel attached to bronze crowns. It engages with a 14-tooth cast bronze sprocket that is closest to the outside and to this wheel, an 8-tooth cage pinion identical to that of the input shaft. The wheel and the pinion were attached to the shaft by inserting the shaft through the square holes made in them and tightening them together.

The second shaft, similar to the one described above, is located further down and its position is reversed. The wheel, which has 18 teeth, is at the same distance as the previous pinion so that the mesh between them is perfect. The pinion is in the right position to engage with the 24-tooth wheel attached to the output shaft.

The chain ratio is therefore 8/14 for the first pair, 8/18 for the second and 8/24 for the third, which means a total gear ratio of 1/0.0847; in other words, for every 11.8125 turns of the cranks, the drum does one turn. The module is slightly variable for the different gears, being roughly 18, the lanterns are all the same, with a primitive diameter of 140 mm and a pitch of 55.4 mm. Regarding the wheels, there is a primitive diameter of 447 mm with a circumferential pitch of 55 mm for the 18 teeth; a primitive diameter of 245.8 mm and a circumferential pitch of 64.4 mm for the one with 14 teeth. The thickness of the wheels is 28 mm and the geometry of its teeth is of the so-called point type, in which the point has been replaced by a cylinder (De Lamadrid, 1969). They are made of cast bronze, with the teeth filed down and the faces turned.

As for the small winch, the kinematic chain comprises two lower pairs and three members with similar characteristics to the chain of the large winch. The location of the chain in this machine is to the right of the drum and the ratios for the pairs are 8/14 for the first one and 8/18 for the second, which means a total transmission ratio of 1/0.253968; in other words, for every 3.9375 turns of the cranks, the drum does one turn. Regarding the large winch, in the case of having the drum width limited to 464 mm, a width that has always been used since the date it was installed in 1761, even without the delimiting disc as can be seen in the first photographs we have of it, the force on the handles from each of its operators varies from a minimum of 87.8 N, corresponding to the turns of the third layer, to a maximum of 107.2 N, corresponding to the turns that are placed on the fourth layer and the torque required in the input shaft for the first situation is 161.7 Nm, and a maximum value of 197.4 Nm.

If the large winch were to work with the full width of its drum, with a width of nearly 700 mm, with only two layers of rope and only two riggers, the values would be between 129.4 N for the minimum and 146.6 N for the maximum, and for the first situation, the input shaft required a torque of 119.0 Nm and a maximum of 136.0 Nm.

These days, and with the new winches, the time it takes to raise el Araceli is 7 min, 48 s, to travel a distance of 27 m at a speed of 0.05756 m/s.

With regard to the work carried out by the riggers during the lifting of el Araceli, when the whole drum is not used, a workload value of 270 kJ is obtained and the power developed by each rigger would be 144.22 W. Under these conditions, the efficiency of the winch would be 0.58.

If the whole drum were used, with only two layers of rope, and two riggers, the workload would be 247.2 kJ and the power developed by each rigger would be 263.55 W. Under these conditions, the efficiency of the winch would be 0.59.

In order to evaluate the power supplied by a single rigger, we have consulted a specialised book on the subject (Burke, 2000) and it establishes average power values by age groups in different sports. It gives values for different sports and ages, and they are quite a lot higher than this figure. They did not have to be athletes, were generally young people, so we understand them to be figures, for both strength and power, so that, with only two people, the most arduous operation involved in the Mystery of Elche could have been carried out.

2.7 Transmission Ratios in the 1760 Mechanism

In order to clarify the transmission ratios that take place in the mechanism, it has been considered appropriate to describe by means of tables and drawings the main winch. This section analyzes the calculation of the gear ratios of the winch without considering possible internal resistances of the mechanism.

Table 1 shows the characteristics of the main winch sprockets and their gear ratios.

Figure 10 shows a drawing of the transmission box used for the lifting and lowering of the heaviest aerial apparatus, "El Araceli".

Starting from the number of teeth of each sprocket involved, the gear ratio of the main gearbox can be calculated:

$$Tr_{gear\ box} = \frac{8}{14} \cdot \frac{8}{18} \cdot \frac{8}{24} = 0.0847$$

This means that 1 turn of the crank equals 0.0847 turns of the winch that raises or lowers the aerial device. Or it can be said that, for every 1 crank turn, the winch rotates approximately 30 degrees.

On the other hand, if the transmission ratio is calculated according to the actual effort exerted, it is necessary to consider the diameter of the hand crank where the operators exert the force and the diameter of the drum where the rope is wound.

$$Tr\ total = Rt\ hand\ crack \cdot Rt\ gear\ box \cdot Rt\ drum$$

$$Tr\ total = \frac{\text{Ø}_{hc}}{\text{Ø}_{p1}} \cdot Rt_{gear\ box} \cdot \frac{\text{Ø}_{p6}}{\text{Ø}_{d}}$$

$$Tr\ total = \frac{140}{900} \cdot 0.0847 \cdot \frac{263}{420} = 8.246 \cdot 10^{-3}$$

This result indicates that for every 1 Nm of input, 121.27 Nm of output is obtained.

The secondary transfer box, responsible for lifting the "La Santísima Trinidad", which is lighter than "El Araceli", has also been analyzed (Table 2).

Table 1 Gear ratios on the main winch

No. gear	No. of theeth	Original diameter	Ratios
1	8	140	Rt_{1-2}=8/14
2	14	246	
3	8	140	Rt_{3-4}: 8/18
4	18	447	
5	8	140	Rt_{5-6}: 8/24
6	24	420	

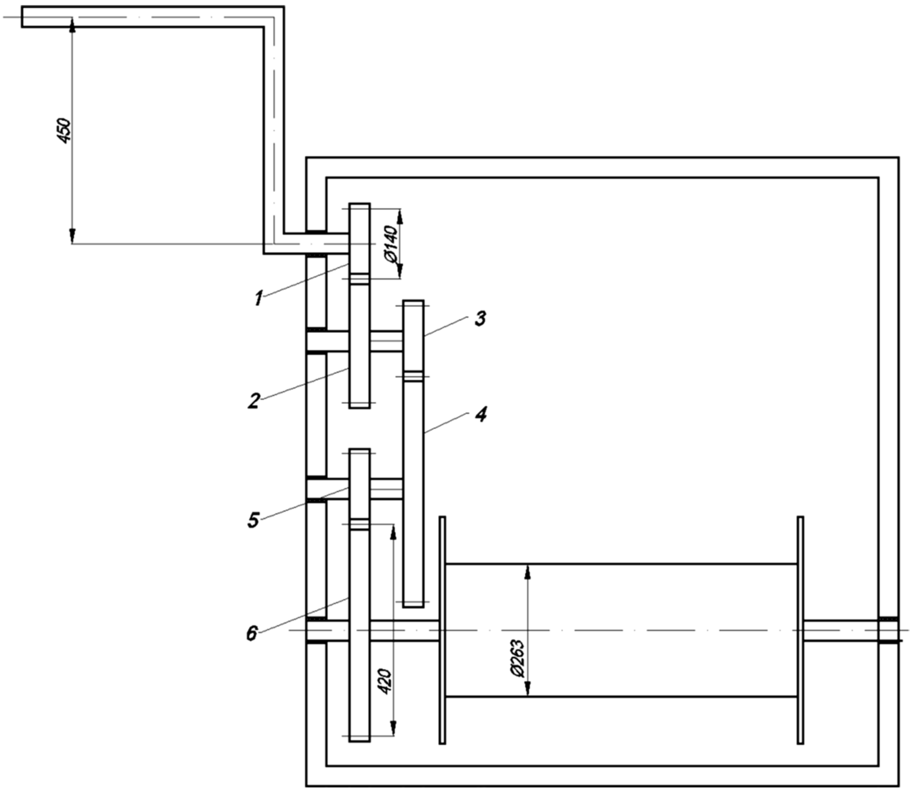


Fig. 10 Sketch of main winch gear box

Table 2 Gear ratios on the secondary winch

No. gear	No. of theeth	Original diameter	Ratios
1	8	140	$Rt_{1-2}=8/14$
2	14	246	
3	8	140	Rt_{5-6}: 8/18
4	18	447	

$$Tr = \frac{8}{14} \cdot \frac{8}{18} = 0.2540$$

The other pulleys used in the winch do not produce any transmission ratio. They are used only to achieve a change of direction of the rope according to the desired trajectory.

3 Aerial Artefacts

3.1 "El Araceli"

"El Araceli" is the aerial apparatus where two of the most important scenes of "La Festa" takes place. On the one hand, the assumption of Mary into the sky and, on the other hand, the coronation by "La Santísima Trinidad" (Marco and La, 2014; Marco, 2018).

Figure 11 shows the artefact in operation in 2 of its interventions during the performance. The lateral ends are occupied by angels carrying stringed instruments, who remain kneeling, throughout their intervention, on ledges arranged in each house. The two lower positions are occupied by two children who pretend to play a guitar without strings. The two upper positions are occupied by two adults. The central location may be represented by the High Angel, played by a priest, or the Virgin of the Assumption, depending on the act of the play.

As for the main dimensions of "El Araceli", it is 2475 mm high, 1510 mm long and 600 mm wide. The free space of the lower side platforms limits the height of the actors to 1.170 m and is therefore intended for use by children. The central and upper side ledges situated at mid-height are intended for use by adult actors as they are not limited by their upper part.

Its unladen mass is 130 kg and its maximum theoretical load weight assigned on stage is 6000 N. It should be noted that its maximum weight in service is currently 4550 N.

(a) "El Araceli" with the High Angel. (b) "El Araceli". The Assumption of Mary

Fig. 11 "El Araceli" in its two interventions during the performance

3.1.1 Antiquity and Restorations

It is known that "La Festa" exists since the last third of the 15th century by several historical documents and it is also known that several authors mention an incident about an apparatus called "Ara-Coeli" on 14 August 1502.

If it is analyzed the script of the drama, it is deduced that, on the beginning, this apparatus was used, but it is not known how was the original shape. Over the years, the artefact has suffered possible structural improvements to guarantee the actors safety. To find out how was the original, it has been studied the document register and the materials and technology applied over the course of its history to this artefact.

In July 2010, and during the assembly of the high rigging, certain problems were detected in "El Araceli". In the lower part of the gospel's side, signs of decomposition were observed. On the terrace of the temple itself, the action required was taken to guarantee its correct operation in safe conditions for the tests planned. After the analysis, the notch-tenon-wedge joints were perfected. Figure 12a shows the previous design of the wedges that hold the tenons. Figure 12b shows the redesign made, which consisted of opening the wedge at its end, which ensured that it was attached in the right position.

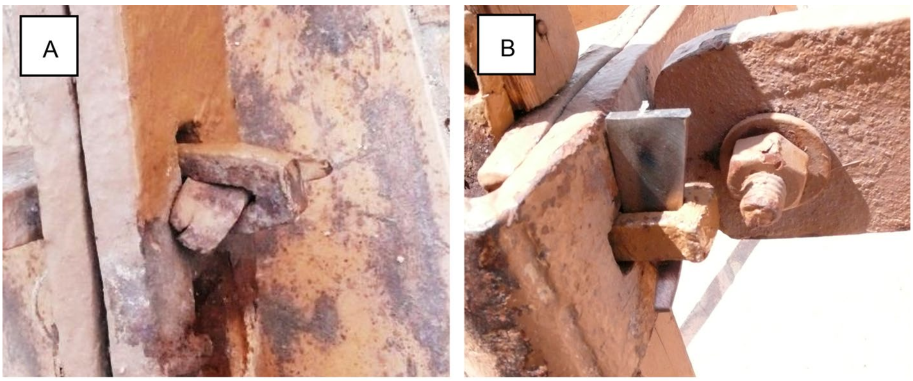
After the site tests were completed, the event organizers commissioned a major review. The apparatus was transferred to a suitably equipped workshop, where photographs, detailed sketches, functionalities of its parts, etc., were recorded in order to study it in detail.

From this situation, the need to perform a series of tests arose, which gave rise to the study presented later.

Towards the middle of the 20th century, the inferior bars that form a triangle (colored in red), and the harp support (colored in green) were fixed to the structure. These parts were joined with electrical welding, so it can be deduced that it was made up on the 20th century (Fig. 13).

On 1805 it is documented the last action. It was joined 2 steel plates of 10 span (2087 mm), located outside of the parabola. Hex head bolts were used to join them.

On 1801 exists a written evidence that mentions that it was added an arch of parabola outside and parallel to the original and it was extended to the branches. This join was solved with a screw at each extreme. It can be inferred that the superior eyebolt was



(A) Traditional wedge (B) Redesigned wedge

Fig. 12 Notch/tenon/wedge fastening system belonging to the device's locking crossbar

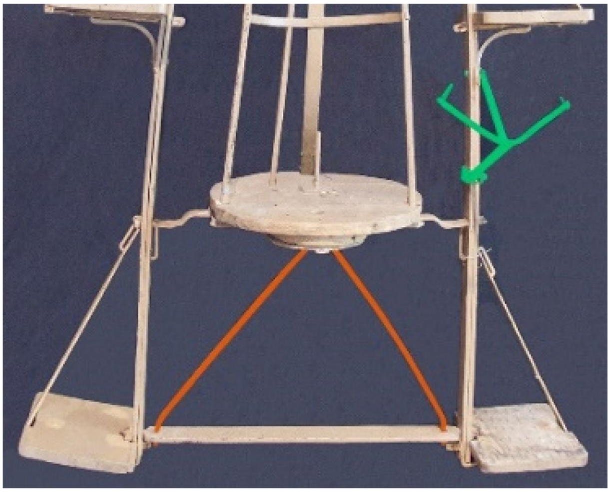


Fig. 13 Inferior bars (red) and harp support (green). (Color figure online)

added in the same actuation. If it is looked closely, it is easy to deduce that this solution could cause a rotation, so it can be understood that, in this epoque, was added the rope to fix the new arch to the original. It can be seen at Fig. 14A. It can be also thought that the 2 supports, situated under the superior lateral ledges and fixed by screws, were added in this epoque (Fig. 14B).

On 1749 it is documented that the structure was cut and extended 1.5 span (313 mm). If it is analyzed the apparatus once again, it can be deduced that, the lateral branches were cut to a 466 mm from the vertex and it was added 2 parts of steel plate. The join was solved with a fastener (nut/screw) reinforced with a latching.

At this point, it can be deduced that the artefact might be very similar as the recreation showed at Fig. 15B. It can be affirmed by 2 reasons: for one hand, it is not any registered data about repairs from the date to the origin, and on the other hand, the existing joints technology (notch/tenon/wedge) it is suitable to the 15th century.

Fig. 14 **A** Forged steel plates fixed with screws and rope added. **B** Forged steel support situated under the lateral ledges

Fig. 15 **A** Current structure. **B** Original structure

It is noted that after the date of publication of the book "L'art de tourner, ou de faire en perfection toutes sortes dóuvrages au tour" by Charles Plumier (1646–1704), the notch/tenon/wedge unions were abandoned in favor of nut/screw joint.

Once the dates have been analyzed, it can be deduced that, "El Araceli" showed in Fig. 15B would correspond with the original used since the last third of 15th century.

3.1.2 Load Test of "El Araceli"

These days, any machine or mechanism is subject to compliance with strict regulation in terms of safety, use and periodic maintenance. These regulations are even stricter in the case of apparatus for lifting persons, which are designed with redundant safety systems and with significantly high design safety coefficients.

To put this in context for the reader, we believe it necessary to mention that the elements that form part of the "Mistery of Elche" are exempt from the application of current regulations (Directiva 2006/42/CE, 2006; R. D. 2291/1985, 2013), due to the fact that it is a device for transporting actors during artistic performances and because it is an artefact made up of parts that are more than 550 years old. The conservation of these elements was one of the values that led to "La Festa" being proclaimed a World Heritage Asset by UNESCO.

Historically, the inspection protocol for machines and apparatus used in the performance of this type of event was limited to a visual inspection (Riggio 2018). In 2010, the possibility of performing non-destructive tests on the most critical elements that could affect the safety of people, was raised. Information is available on non-destructive or semi-destructive heritage assets (Kloiber, 2015; Niemz, 2012). Most of the structures studied are made of wood although not much information exists about structures similar to those analyzed in this paper.

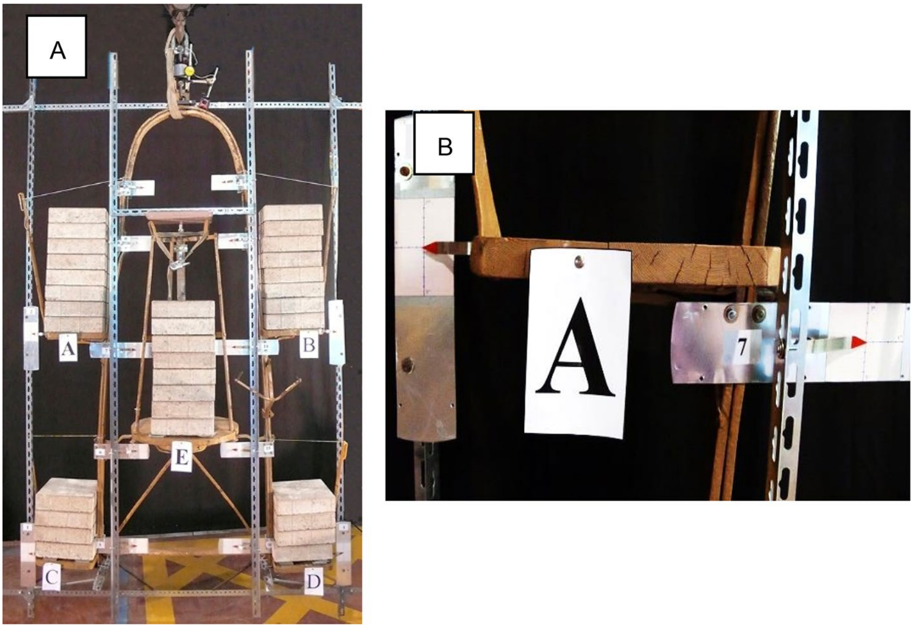


Fig. 16 "El Araceli" test. **A** Loaded device. **B** Data acquisition system

Although the current regulations on types of apparatus do not apply, the "Mystery of Elche" technical team studied the possibility of performing a non-destructive test. It was decided that it should be of the non-destructive type and its main objective was the integrity of the device and people. This course of action was well received by the trustee, who is responsible for its proper conservation.

It was determined that it would be advisable to subject the mechanism to a non-destructive, loading the apparatus to roughly 1.5 times the maximum load mass allowed.

The test was performed in conditions similar to real life. Figure 16 shows the apparatus attached to a frame by the upper eyebolt. This was fitted with 6 dials suitable to record deformations in the *y* axis, according to the load conditions.

The test performed was of the static traction type (Ramírez, 1996). On the one hand, the apparatus was pulled by its own weight and the loads superimposed. On the other hand, it could be assumed to be static since the operating speed of the apparatus is roughly 0.035 m/min, a speed which, for the purposes of the test, was deemed not to be significant. Traditionally, this speed was used to eliminate possible adverse effects of uncontrolled inertia. It is worth mentioning that this particularity also exempts it from regulations relating to lifting apparatus (Riggio, 2018).

Regarding the load for the test, it should be noted that the device was originally designed with 5 places: for two children and three adults, but no weight limit either in total or per actor had been established. It was only recommended that a certain symmetry in weight and volume be maintained to ensure the balance and aesthetics of the staging. Thanks to data from previous experiences, the maximum masses of the actors were set: 42 kg (412 N) for a child and 80 kg (785 N) for an adult. Considering the proposed safety coefficient (1.5), the total value of the load on the device should not be less than 4770 N.

Table 3 Load applied at each location

Loading place	Nominal weight (N)	Load on the device (N)	Safety coeffient applied in each place
Adult left	785	1296	1.65
Adult right	785	1296	1.65
Child left	412	648	1.57
Child right	412	648	1.57
Central figure	785	1296	1.65
Total	3179	5184	1.63

Table 4 Test loads and displacements at points of interest

Order	Total weight increase	Point A		Point B		Point C		Point D		Point E	
	(*N*)	*q*2	*y*	*q*3	*y*	*q*1	*y*	*q*4	*y*	*q*5	*y*
0	0	0	0	0	0	0	0	0	0	0	0
1	810	16.2	−1	16.2	0.4	16.2	−1	16.2	−1	16.2	0
2	1620	32.4	−2	32.4	−7	32.4	−2	32.4	−2	32.4	0
3	2430	48.6	−4.5	48.6	−10	48.6	−4	48.6	−3	48.6	0
4	2916	64.8	−6.5	64.8	−12	48.6	−3.5	48.6	−3.5	64.8	0
5	3402	81	−8	81	−15	48.6	−4	48.6	−4	81	−1
6	3888	97.2	−10	97.2	−16	48.6	−4	48.6	−4	97.2	−4
7	4692	113.4	−11	113.4	−18	64.8	−5	64.8	−4	113.4	−4
8	5178	129.6	−12	129.6	−18	64.8	−6.5	64.8	−4	129.6	−4
0	0	0	0	0	0	0	0	0	0	0	0

To carry out the test, concrete parallelepipeds or load units (hereinafter referred to as l.u.) were used. These parts fitted into the dimensions of the ledges and had a unit weight of 162 N. The weight of the l.u. was quite illustrative as 3 l.u. added up to 486 N (slightly more than the weight of a child) and 5 l.u. added 810 N (roughly the weight of an adult). From these data, it can be deduced that, in order to ensure the load conditions expected, the ledges reserved for the children had to be loaded to 4 l.u., 648 N and those for the adults to 8 l.u., 1296 N. All this is shown in Table 3.

At the top of the apparatus, the upper eyebolt was fitted with a touch probe with a scale division of 0.01 mm and a dynamometer to record the load exerted.

Before loading the apparatus, the dials on the control points of interest were set to zero. These dials had a scale division of 0.5 mm.

The acquisition of the data of greatest interest, due to the apparent deformation, were the ends of the upper and lower side ledges and the central seat, points A, B, C, D and E. Other unremarkable displacements were also recorded in the recesses of the side ledges and around the arch and branches.

Table 4 shows the displacements of the points of greatest interest as a function of the load conditions applied. Once the maximum load has been reached, according to the procedure detailed in the previous point, the apparatus was unloaded in reverse order until it was no longer under load.

The fastening rivet of the eyebolt that supports "El Araceli", reached an acceptable safety coefficient of Cs = 1.45. The touch probe fitted to the eyebolt recorded a deformation of barely 0.02 mm at maximum load, returning to zero when the apparatus was unloaded. It was concluded that it did not make sense to load the apparatus further to verify a higher safety coefficient for the rivet. Loading the apparatus further could lead to the deterioration of other parts.

In Table 4, it is worth noting the last row, which shows the value of the residual displacements when the apparatus was unloaded. The value (0.0) in all the records indicates that there was no permanent deformation and, in no case, was the elastic limit exceeded.

The graphical results of the displacements as a function of the load applied, experienced by the side ends of points A, B, C, D y E, are shown below.

It can be seen in Fig. 17, points A, B y E, intended for one adult, were loaded with 8 l.u.'s or 1296 N. The minimum safety coefficient obtained was 1.65. The weight of an adult has been assessed to be 800 N according to the Occupational Risk Prevention Act.

Points C and D shows the behaviour of the structure intended for children. These platforms were loaded with 4 load units, corresponding to 648 N. Compared to the nominal weight requirement for a singing child, 421 N, a safety coefficient of 1.57 was obtained.

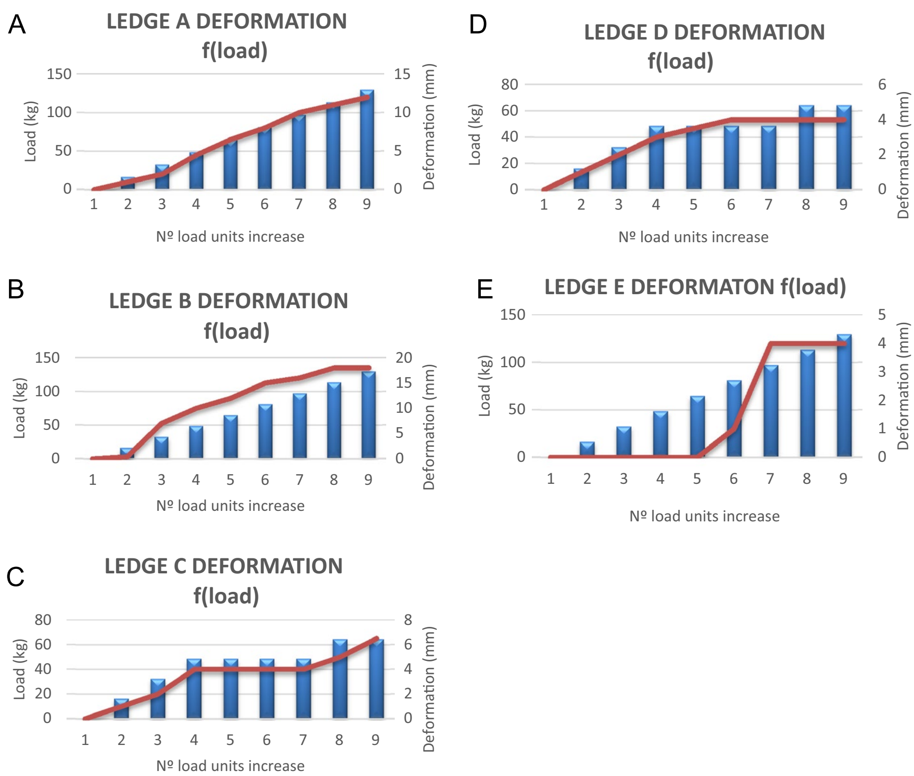


Fig. 17 Deformation/Load graphs at points A, B, C, D y E

3.2 "La Mangrana"

This apparatus is also called "Granada" or "Núvol". This artefact is occupied by an angel that takes a golden palm. When it goes down from the sky, the angel communicates the Virgin her next death in 3 days. Once the mission is accomplished, the angel returns to the sky.

When the doors of the sky are opened, the spectator visualize a revolution ellipsoid shape truncated on the superior pole. This solid is painted in garnet red and decorated with valances and drawings with different geometries, colored in green lime, green grass and gold yellow. It can be seen shapes of wheat spikes and bunches of grapes in gold. 8 circular rosettes painted in gold are distributed around the equator. It can be also appreciated 8 ornament with a bouquet of flowers shape displayed in the lower part. From the inferior pole it can be seen a spherical cap and a tassel covered with tinsel. This apparatus is hung with a blue rope.

This aerial artefact is 3303 mm high, where 1850 mm correspond to the ellipsoid (Fig. 18A). The total diameter is 1329 mm and the vertical speed is about 0.05 m/s.

When the apparatus begins to lowering to pass the doors in the sky, the exterior surface is opened in 8 ellipsoids sectors. These parts are known as "the wings" (Fig. 18B). The wings movement is actioned by several specific ropes. "La Mangrana" is kept opened during the representation until it comes back to the sky.

About the structure, it can be discerned 2 different parts: the frame and the cover. For one hand, the frame is made up with 2 straight prims of 8 faces built in wood and separated by 4 forged steel pillars. To guarantee the safety, there is a belt to hold the angel. On the other hand, every wing is built with a forged steel frame (Fig. 19). Over this framework it is fixed a painted canvas with the decoration made up in papier mâché (Fig. 18A).

The opening and closing mechanism of this apparatus can be considered the most interesting thing. This is absolutely necessary to pass the doors on the sky. When "La Mangrana" cross the gate and begin the lowering, it is done with their wings folded and, at the moment it has pass the hole, the stagehands spread their wings.

Fig. 18 "La Mangrana". **A** Folded wings and **B** Spread wings

Fig. 19 "La Mangrana" frame

This process is made totally manual. To do it, the stagehands have to be lying face down and controlling the spread movement. They are in charge of catching the hook of every wing and fixing it to its corresponding ring, that it is attached to the rope.

In the process of rising, when the apparatus reaches the doors of the sky, the operation is effected inversely.

3.3 "La Santísima Trinidad"

"La Santísima Trinidad" or "Coronation" is an apparatus seemed to an altarpiece and similar to "El Araceli" but smaller. It is equipped with 3 ledges, 1 central and 2 laterals. The central sitting is occupied by a priest, that represents "God Father". The laterals are occupied by 2 children that stay on their knees along the work and represent the other 2 components of the "Holy Trinity".

This artefact appears in the last act, when "El Araceli" remains static at the middle of the trajectory. In a specific moment, the doors on the sky are opened and "La Santísima Trinidad" is lowered. When the distance is about 3 m each other, the priest aboard the "Holy Trinity" sends down the crown to "El Araceli". The angels situated on the superior ledges aboard "El Araceli", adjust the crown to the Virgin Mary (Fig. 20). After that, "La Santísima Trinidad" returns to the sky and later "El Araceli" do the same. This act close "La Festa".

Fig. 20 The Coronation **a** "La Santísima Trinidad" and **b** "El Araceli"

This apparatus is manufactured with materials and technologies similar to "El Araceli". It is built mainly with frame and an arch. At the frame are fixed 3 wooden ledges cushioned and it has several rings to attach some accessories and the safety belts. The artefact is 1756 mm high, 1136 mm width and 670 mm length. The superior arch has a diameter of 555 mm and their branches are 1125 mm length. The frame is protected to the corrosion by oil-based paint.

The frame is made up with rectangular forged steel plate, with a section about 45 × 14 mm and 52 × 16 mm. It forms 3 semicircles where the central sitting is over the laterals. This ledge has a special shape of kidney that allows the passing of the rope through the center of the apparatus. The arch is made up with a unique part of forged steel plate, with a variable section rectangular-squared. On the top it can be seen a bridge of 24 mm of thickness fitted with a hook of 80 × 64 mm and with a rectangular eye of 68 × 30 mm.

4 Conclusion

The studies carried out on the Mystery of Elche deal fundamentally with the social, cultural and historical aspects of this representation. The research carried out by the authors focuses on the mechanical aspects of the elements and artefacts that are used and have been used in “La Festa”. Its main mechanical characteristics, its operation and its design have been analyzed in detail.

The main aspect to highlight is the design of each mechanical elements and aerial artifacts. In addition, the restorations carried out over the centuries, the modifications, added reinforcements and design details allow dating and corroborating the age of the main mechanical elements of the Mystery of Elche.

There is extensive documentation and information on religious aspects and representation from 1761 to the nowadays. However, there is little information in earlier times, especially aspects of mechanical details. From these existing documents, it has been possible to identify and verify some important changes, repairs and restorations.

The aerial rigging has been documented in detail. The current winch has been compared with the one designed in 1760 by the architect Marcos Evangelio and it has been able to verify their great similarity. After rank the different types of known winches, it has been concluded that, the winch previous to 1760, could correspond to a type in which twenty or more men would be necessary to lift the same load. There is hardly any information about that previous winch, so it is just a guess.

From the analysis of the winch designed by Marcos Evangelio, it has been achieved data that is was unknown.

Firstly, the winches suffered the fire of the Basilica of Saint Mary in 1936 (in the Spanish civil war), which caused a great amount of damage. Second, it has been determined that the winch was well designed, but it was not properly assembled. That explains why the architect could not fulfill his prediction, and instead of two men, four men were employed to carry out the work. And, finally, the winch that came into operation in the year 1761 is made up with a technology well ahead of its time, at least compared with the available in its surrounding. And, what is so striking for us? Quite simply, the technology used in metallic gears and the manufacturing process.

As for the construction process, about the frame, there is nothing special it. The forged parts can be better or worse finishing, depending on the blacksmith skills. Regarding to the shafts, the situation is similar to the frame, but it should underline that is has a very good manufacturing tolerance.

However, the manufacturing of the gears, the truncated cone-shaped parts that reinforce their position on the shaft and the shaft rods required a special care on the part of the blacksmith and a special machining equipment, that was not available in the town or Elche or surrounding area.

The gears were cast, the teeth were adjusted manually and the sides of the discs with the cone-shaped trunks that reinforce their position, were finished by means of a turning process.

The technology developed around the town of Elche was very different to that used in the construction of the winches. It can be seen in the wind and water flour mills of the Cartagena countryside, where the designers of the winches came from.

Cartagena, after being named the headquarters of the Maritime Department of the Mediterranean in 1728 must have been one of the places in Spain with the greatest concentration of technology at that time. After its nomination the region experimented a significant demographic growth and the need to feed its new inhabitants, so there were constructed a total of 81 windmills to supply the population in the area.

A flour mill has a set of gears that transmits the force from the sails to the grinding wheel or via water extraction. The structure of the mills was its own building, built with wooden parts and reinforced with steel. As well, the gears were manufactured with wooden parts and steel. It was not until 19th century that flour mills began to be constructed with parts of steel.

In light of all this, the question arises: where was the winch built? As a hypothesis, we can point to places where, at this time and much earlier, this technology was already in use. For example, in cathedral bell towers, where at the end of the 15th century, as in the case of Wells cathedral in England, which are on display at the London Science Museum, similar mechanisms were already being used to operate the chimes and to support the corresponding weights.

It is important to note that the greatness of "La Festa" is recognized by the conservation and maintenance of its elements, including music, staging, rigging system and artefacts. The organizers of the Mystery of Elche consider it very valuable to keep the artistic legacy alive, so they insist on the use and maintenance of traditional artefacts.

Until 2010, the inspection of the apparatus before use was based on a visual examination. During 550 years of use, no accidents worth mentioning have been recorded. Such antiquity means that the devices used today are relics of great value and cannot be subjected to destructive tests.

From the engineering point of view, replicas of "El Araceli", "La Mangrana" and "La Santísima Trinidad" could be made with better mechanical characteristics. Calculated and tested to guarantee the safety. However, it has already been mentioned that one of the main values of the Mystery is the use and maintenance of traditional artefacts.

A detailed study of dating and tests has been carried out in the Araceli, which has made it possible to verify its safety. The results of the tests allow us to conclude that the device has sufficient rigidity and elasticity to guarantee its continued use under traditional test conditions and suitable safety conditions for people have been established.

The minimum safety coefficient achieved is 1.57, which is deemed to be a sufficient guarantee. The eyebolt from which the apparatus is suspended was tested until a safety coefficient of 1.42 was obtained. This point was reinforced with bolted braces by way of a bracket and completed with four 10 mm lengths of hemp rope tied to the arches of the parabola. All this ensures improved mechanical resistance. Lower value load units could have been used to obtain a better graphic resolution and to enable behaviors not picked up in this study to be appreciated. This aspect will be considered in future analyses.

The other two aerial devices have been analysed and described in detail. And the intention of the authors is to proceed in the future to carry out tests that allow analysing the mechanical safety of each of them.

Regarding the study of the age and historical evolution of the Araceli, we can highlight that its origin is possibly from the last third of the 15th century. There is mechanical evidence to affirm it. In 1746 an important restoration and adaptation was carried out that is documented and agrees with the evidence found. A minor modification was made in 1801, which is also documented and agrees with the evidence.

We can affirm that the Araceli is the oldest element of those used today to carry out the representation of La Festa.

5 Future Work

The future lines of research proposed by this study group are:

To analyse, study and improve the mechanical system for the assembly of the aerial rigging stage (Díez, 2016). 5 prototypes of this system have been made, and the most suitable solution is being sought.

To study the possible restoration of the metallic parts not subject to stress by applying filler for formal reintegration.

Given the antiquity of the metallic parts that form the structure of "El Araceli", it would be interesting to characterise the steel used for future renovations.

And finally, in order to preserve the historical and geometric representation of the site, the mechanisms and the cultural heritage, it would be appropriate to investigate the creation of a 3D BIM heritage model, to try to overcome the difficulties involved in preserving a medieval theatrical representation.

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References

Burke, H., et al. (2000). *B. Rendimiento deportivo máximo*. Paidotribo.

Caprietti, E. (2003). *Le machine scenotecniche per le sacre rappresentazioni*. Brunelleschi. Giunti Editores.

Castaño, J. (1994). *Repertori bibliogràfic de La Festa d'Elx*. IVEI—Ajuntament d'Elx.

De Lamadrid Martínez, A., & De Corral Saiz, A. (1969). *Cinemática y Dinámica de Maquinas*. E.T.S. Ingenieros Industriales. Servicio de Publicaciones.

Díez, R., Marco, S. M., Navarro-Arcas, A & Velasco, E. (2016). Diseño de sistema mecánico para el montaje de la jácena de la tramoya aérea del Misteri d'Elx. In *Actas del XXI Congreso Nacional de Ingeniería Mecánica* (pp. 452–458). Elche.

Directiva 2006/42/CE (2006). del parlamento europeo y del consejo de de 17 de mayo de 2006 relativa a las máquinas y por la que se modifica la Directiva 95/16/CE (refundición).

Gironés, G. (2008). *El Mystery of Elche*. Patronato del Misteri d'Elx.

Kloiber, M., Drdacky, M., Machado, J. S., Piazza, M., & Yamaguchi, N. (2015). Prediction of mechanical properties by means of semi-destructive methods: A review. *Construction and Building Materials., 101*, 1215–1234.

La, R. R. (1956). *leyenda del Mystery of Elche*. Graficas Asín.

Marco, S. M., & Velasco E. (2014). La cabria de la tramoya aérea del Mystery of Elche. In *Actas del XX Congreso Nacional de Ingeniería Mecánica*. Málaga.

Marco, S. M. (2014). *Análisis de la tramoya aérea de La Festa o Mystery of Elche*. Tesis Doctoral. Universidad Miguel Hernández.

Marco, S. M. (2018). *La restauración de "El Araceli o Rescèlica* (Vol. 59, pp. 217–226). Regidoria de cultura Ajuntament d'Elx.

Massip i Bonet, F. (1991). *La Festa d'Elx i els misteris medievals europeus*. Institut de Cultura Juan Gil-Albert—Ajuntament d'Elx.

Massip i Bonet, F. (1992). *El Teatro Medieval. Voz de la divinidad, cuerpo de histrión*. Montesinos.

Massip i Bonet, F. (1997). *La ilusión de Ícaro: Un desafío a los dioses*. Comunidad de Madrid-Consejería de Educación y Cultura.

Mc Evoy Bravo, R. (2013). Filippo Brunellechi y los ingenios aéreos florentinos. El Misterio de Elche y sus antecedentes en el arte, la cultura y la escenotenica italiana (pp. 159–176). *Festa d'Elx.*

Niemz, P., & Mannes, D. (2012). Non-destructive testing of wood and wood-based materials. *Journal of Cultural Heritage., 13S*, S26–S34.

Pérez, J. A. (2008). *El rescripto del Papa Urbano VIII sobre La Festa o Misteri d'Elx*. Tirant lo Blanch.

Pomares, J. (2004). *La "Festa" o Mystery of Elche*. Patronato del Mystery of Elche.

Ramírez, F., Fernández, M. A., Alonso, A., Delojo, G., Valdecantos, C., & De los Ríos, J. M. (1996). *Métodos de ENSAYOS NO DESTRUCTIVOS, Tomo I*. I.N.T.A.

Real Decreto 2291/1985 (2013). de 8 de noviembre, por el que se aprueba el Reglamento de Aparatos de Elevación y Manutención de los mismos, sus ITC y actualizaciones.

Riggio, M., D'Ayala, D., Parisi, M. A., & Tardini, C. (2018). Assessment of heritage timber structures: Review of standards, guidelines and procedures. *Journal of Cultural Heritage, 31*, 220–235.

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