

FLYING A 100m-LONG JUMBO KOINOBORI

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Prologue

Flying fabric carps called Koinobori has been a traditional event in Japan since long time ago (Fig.1). They have been flown in the breeze by very many Japanese families with children early in May every year, or more specifically, on the 5th of May, Children's Day, to celebrate the growth of their children and to pray for their health and success in future.

There is a small city in the suburb of Tokyo which is called Kazo that has been producing Koinoboris for a long time mainly using cotton as their material. Early in 1988 a group of volunteers of Kazo City had an innocent idea of making a fabric carp as big as 100m in length to advertize their city. They enlarged the pattern of a home-size carp to a size of 100m in length, cut the fabric along the pattern, sewed up the cut fragments of fabric to form a Jumbo carp, and painted it to finish the fabric fish.



Fig. 1: Koinoboris flying on Children's Day

When the carp was completed, the volunteers wanted to show it to the public, and, since they thought that the carp was too big to fly normally in the sky, they attempted to show the carp in a somewhat more moderate way. They put a wire rope through its stomach, and raised the rope by means of three cranes like the laundry being hung on the line. As soon as the hoist started, and the carp departed from the ground, it was fanned by the breeze, and suddenly its stomach skin was badly torn with a screaming noise (Fig. 2, from a



Fig. 2: The hoisted Jumbo Koinobori broken in the air

juvenile book). The reporters from several TV companies who had come to the site, expecting to witness the successful display of the carp, were all disappointed, and disappeared.

Will the Jumbo Koinobori Swim in the Breeze?

The volunteers of Kazo who had devoted themselves to making of the Jumbo Koinobori were very much discouraged by the failure, but they soon tried to recover from the shock, mending the broken Koinobori and starting to find an expert who might be able to advise them how they could display the carp more safely, and hopefully fly it in the air. After visiting those who were authorities in the fields of Fluid Mechanics and Applied Mathematics in vain, they finally came to the author in the middle of March of the same year for an advice.

Despite that the volunteers did not expect that the carp might fly normally in the air, after experiencing the miserable failure which occurred on just hoisting it for a display, their innocent and eager question to the author was if the Koinobori would swim normally in the air at all.

Dimensional Analysis

The author thought that this sort of questions might be answered most clearly by the theory of dimensions, or more specifically, the “dimensional analysis”, since we Japanese know very well that the carps of normal sizes (2 - 5m in length) celebrated at home swim in the mild breeze without problems, and the difference between the Jumbo carp and those home carps is only in their sizes, their shapes being “mathematically similar” to each other, to which we know that the dimensional analysis can be most conveniently applied.

Through application of the dimensional analysis the author could derive the following results (For details of the analysis refer to the reference [1]):

- 1) The Jumbo Koinobori swims in the breeze of the same speed as for the home carps, namely it begins to swim at the wind speed of 2 - 3m/sec.
- 2) The tensile stresses exerted on the skin of the flying Jumbo Koinobori is λ times as big as those for the home carps, λ being the ratio of the sizes. (If compared with a home carp of 5m in length, $\lambda = 100/5=20$)
- 3) The Jumbo Carp swims very slowly, taking the time of λ times as for the same action of the home carps.

The first result in the above was very welcome to those who were involved in the project. The second one was a serious caution that we should carefully examine the strength of the skin (fabric) of the Jumbo Koinobori where the stresses 20 – 50 times as high as those in the home carps may occur. The third was simple visual information about the movement of the Jumbo Carp.

Other Technical Issues

Among other technical problems to be solved before the Jumbo Koinobori was let in the sky the most important was the stresses that might occur in various part of its body. The

following three kinds of forces which might occur during the flight were foreseen to be most significant for design:

- 1) The circumferential forces that may occur in the skin of the carp due to the stomach air pressure.
- 2) The longitudinal forces that may occur in the skin due to the stomach air pressure and the wind flow along the carp.
- 3) The forces that may be produced in the mouth piece ring.

The first forces in the above are very essential, and most significant in design. A Koinobori is designed and manufactured in such a way that the diameter of the stomach is larger than that of its mouth for the purpose of inflating the stomach when swimming in the wind. The air stream which is separated from the main outside flow of the wind at the mouth goes through the stomach of the carp, and it joins again the outside stream of the wind at the tail. The speed of the airflow in the stomach is lower than that at the mouth and outside of the carp, since the sectional area of the stomach is bigger than that of the mouth. According to the Bernoulli's theorem the air pressure in the stomach is therefore bigger than that at the mouth which is the same as the outside air pressure. This means that the air pressure inside the stomach is bigger than that outside the carp. This was confirmed through a series of wind tunnel tests on 10m long model carp as shown in Fig. 3. This mechanism inflates the stomach of a carp swimming in the air, and the skin of the carp should stand the forces due to this pressure.

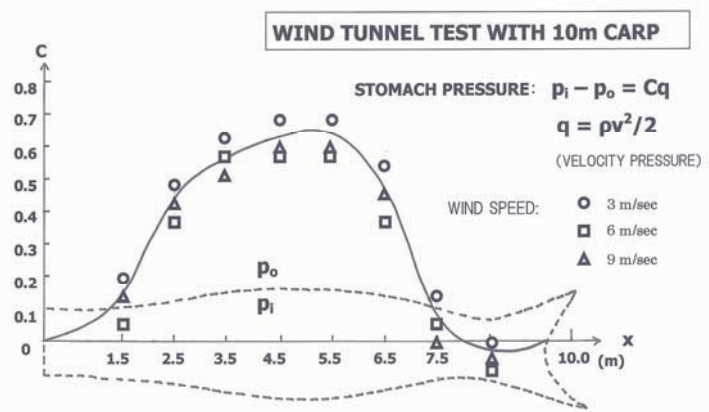


Fig. 3: Distribution of stomach air pressure coefficients

Assuming that the carp is in the shape of a cylinder, the circumferential as well as longitudinal stresses are found easily by membrane analysis. The results of calculation revealed that the fabric used for Kazo Jumbo Koinobori was strong enough to stand the stresses described above, but the strength of the seams was totally lacking. The seams were then re-sewn and consolidated by means of portable professional sewing machines voluntarily offered by a tent company.

The third forces which occur in the mouth piece were also important. The mouth piece is indispensable for a carp to introduce air stream smoothly into the stomach. For family-size carps the mouth pieces of bamboo are often used. As shown in Fig. 4, the ring for the mouth

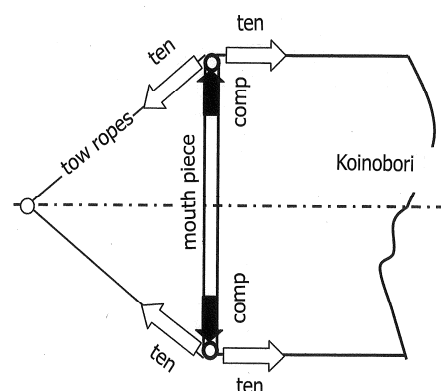


Fig. 4: Forces in a mouth piece

piece is subjected to a compressive force while the carp is swimming, and if we design the ring to avoid the danger of buckling due to the compression, we have to use a steel tube as heavy as some 300 kg which is nearly half the total weight of the Koinobori, making the whole project infeasible.

This problem was solved by adding twelve ropes arranged on the diameters of the mouth piece, and connected to the ring at their ends in a similar way to the spokes of a bicycle wheel. The resulted design was a ring of aluminum tube with a diameter of 50mm, the total weight of the mouthpiece being as light as 30kg (Fig. 5).

Launching the Jumbo Koinobori

For a Koinobori to fly in the air normally it should be hoisted to a height that is approximately the same as its length. So every family which celebrate flying home Koinoboris has a pole which is temporarily built in May every year for hoisting the carps.

For the Jumbo Koinobori of Kazo we did not design any pole to hoist it, but instead we decided to hire a crane that could hang up the Carp to the height of 100m. It was easy to find a crane which had a boom of sufficient length, capable of carrying the weight of the Carp, and standing the lateral forces due to the wind.

On a fine day toward the end of April in 1988, the Jumbo Koinobori was extended on the field beside the Tone River of Kazo City (Fig. 6). The weight of the Carp was some 700 kg, its length being 100m, namely ca. 1.5 times as long as a 747 Jumbo jet plane. The weather was really fine, but we had no wind in the morning. We had to wait for several hours before a gentle breeze began to blow on the field. When the speed of the breeze reached 3m/sec, the crane began to drive, slowly hoisting the mouth piece of the Carp. Then the Carp lying flatly on the field as if it had been sticking to the ground, began to take in the air, its stomach being slowly inflated to take a three dimensional shape. The crane continued to raise the mouth piece, and when the tail of the Koinobori took off the field, it began to fly elegantly in the air (Fig. 7). The spectators sitting on the field and waiting for the flight of the Koinobori were excited at the sight of its graceful swim high above in the sky, and a great clapping of hands was produced.



Fig. 5: Aluminum mouth piece set up in the site



Fig. 6: Jumbo Carp extended on the ground



Fig. 7: Jumbo Koinobori soaring in the breeze

Epilogue

Flying the Jumbo Koinobori was established thereafter as one of the most important annual events of Kazo City. It has been celebrated on the third of May, the Constitution Day, every year. The recorded flight of the Jumbo Koinobori has been telecast on the fifth of May, the Children's Day. The people of Kazo are very much proud of showing the graceful flight of the biggest flying thing in the world every year. The story of how the dream of flying the Jumbo Koinobori came true was recorded as a 45 minute TV program, and included in the archives of NHK, Japan Broadcasting Corporation, so that everybody could get an access to the information. The Jumbo Koinobori travelled abroad to successfully show its elegant flight, twice in Hawaii and once in Kaiserslautern, Germany [2].

References

- [1] Kawaguchi, M. Flying a Jumbo Carp in the Breeze. *Journal of Wind Engineering*, No.66, pp.53-58, 1996. (in Japanese)
- [2] Kawaguchi, M. Flying the Jumbo Koinobori in the German Sky. *Wind Engineers*, JAWWE, Vol. 31, No. 4, pp. 205-211, 2006. (in Japanese)