

Human Powered Aircraft of Japan

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Introduction

The department of Aerospace Engineering at Nihon university started the study of man powered aircraft as a student project under the guidance of professor Hidemasa Kimura in 1964. Their Linnet made the first man powered aircraft flight in Japan on the 25th of February 1966, beginning what has become a tradition at the university. In January 1977, Professor Kimura led the research team that set the world distance record of 2093m with the Stork. Since then Nihon University has made six human powered aircraft and four human powered helicopters. Today many teams challenge Nihon University for the distance record at the annual Birdman Rally. The purpose of this paper is to introduce some of the aircraft and helicopters built in Japan over the last 30 years.

Ibis (1978 - 80)

The students at the Kimura laboratory of Nihon University began building the Ibis with hopes of capturing the Kremer figure of eight prize. The Ibis was smaller, lighter and more manoeuvrable than the Stork. With a wing stressed 2.7g, it was also stronger. Kimura's team remained determined to see the Ibis fly in spite of the fact that the Gossamer Condor had won the Kremer prize in August 1977, before the Ibis had left the ground. Lecturer Naito took over the research laboratory from Professor Kimura in 1980. Naito replaced the plane's spruce and balsa spar beam with CFRP and aluminium honeycomb. This was the first time that Nihon University used composite materials in an HPA structure. The Ibis's longest flight was 1100m and lasted 2 minutes and 15 seconds.

Milan 81 and 82 (1981 - 83)

These planes were built by the Naito laboratory to win the Kremer prize for the first non-American aircraft to fly the figure of eight course. Both these aircraft had wire braced tubular carbon fibre and styrofoam structures and hence a very low wing loading. The Milan 81 had swept back wings with twin tail booms and vertical fins. The Milan 81 crashed from a height of 4m because of high aileron drag. The Milan 82 differed from the Milan 81 in having a single vertical fin and no ailerons. Its propeller was designed by Professor Akira Azuma's research team at Tokyo University. The pilot, Masahi Suzuki, one of the famous Suzuki brothers, tried for the Kremer prize in March 1983. He fell into the grass after flying 1500m from the starting point.

Swift A, B and C (1983 - 86)

These three aircraft were constructed at the Naito laboratory to win the Kremer speed prize. They used rubber strip to store the pilot's energy. The rubber motor provided half of the power needed for flight. All the Swift aircraft used model aircraft servos to control their ailerons and had winglets. Both Swift A and B had 4 skeins of rubber inside their fuselages. The Swift A had

a KFRP fuselage, whereas Swift B used CFRP. Both aircraft had recumbent pilot seating with the pedal cranks placed higher than the seats, and stick type controls. Swift B originally had a five speed transmission (for winding the rubber) and a variable pitch propeller, however, the transmission did not work well and was later removed. Swift C's rubber motor was divided into only two skeins that weighed 6kg. The fuselage was built from CFRP around an upright pilot position. The pilot used an 'H' type control lever that pivoted on three axis to control the aircraft. The Swift C made a straight flight of 1406m on January 2nd 1986. Only the length of the runway at the Shimofusa self defence force base prevented it from flying further.

The Naito laboratory was renamed the Munakata laboratory on the retirement of lecturer Naito in 1986. Professor Munakata took over the laboratory and initiated a programme of basic research and has for example conducted wind tunnel experiments with the Stork B. Lecturer Noguchi now runs the laboratory.

The Japan International Birdman Rally

The Birdman Rally was first held in 1977. It is sponsored by the Yomiuri T.V. station and was inspired by the Selsey Birdman Rally held in England. The rules are very simple: pilots fly from a 10m high platform out over lake Biwa, and the longest flight wins. There are sometimes over 90 entrants. Lake Biwa, the sight of the Rally, is about 20km from the ancient capital of Kyoto. 17km wide at its narrowest eastern end and with an area of 674 km², it is the largest lake in Japan. Several thousand spectators attend the rally and its television ratings are very high. The number of participants has grown along with the rally's popularity. Today many teams compete, some of the most successful are from: Nihon University, Team Aerospace, Waseda University, Toyota, Kawasaki, Japan Airlines and All Nippon Airlines (ANA). The 15th rally was held last year. In the beginning all of the entries were gliders. The first HPA took part in 1982, in the 9th (1984) rally an HPA flew 290m and set a new distance record for the competition. The following year HPAs and gliders were divided into separate classes, progress since 1984 has been rapid and many people expect to see an HPA fly the 17km across lake Biwa within the next few years.

The Team Aerospace HPA

The Aerospace team is regarded as one of Japan's leading producers of HPAs. It has more than ten members who work in many different sections of the Yamaha company. Some design motorcycles, some boats and some remote control agricultural helicopters. The majority are former students of professor Naito. The Aerospace team is led by the Suzuki brothers and designed the following HPAs to compete in the Birdman Rally:

The Seagulls (1-5), Seagull, Gokuraku Tombo (Blissful dragonfly) (1-2) and the Sindbad.

Seagull I and II

The Seagull 1 was the first HPA to participate in the Birdman rally and although it did not win, making a flight of only 55.2m, it was significant because it encouraged other HPA builders to enter the competition. All of the Seagull series aircraft were canards with an upright piloting position. The Seagull 2 flew 114.8m and took 7th place in 1983.

Seagull III

The Seagull 3 took 4th place in the 1984 rally with a flight of 159.7m.

Seagull IV

The Seagull was an improved version of the Seagull 3, the centre of gravity was moved and the number of bracing wires increased resulting in improved control.

Gokuraku Tombo

The Gokuraku Tombo had a conventional, aft tail, configuration and was designed for high speed to combat the gusty wind conditions typical of the rally. Its wings and vertical tail were swept forwards and its primary structure was of CFRP. In the 10th, 1986, rally the Gokuraku Tombo and Seagull flew for 512.2m and 286.1m respectively, capturing 1st and second places. The Seagull can now be seen displayed at the Hamamatu Science Museum in the Shizuoka Prefecture.

Super Gokuraku Tombo 1 and 2

The Super Gokuraku Tombos had CFRP structures and propellers 2m in diameter. Their wing spars were CFRP beams. The leading edge sheeting of the Super Gokuraku 1s wings was skinned with CFRP (see note 1) to improve the wings torsional stiffness. The wing used the FX72MS-150B airfoil. Whereas the Super Gokuraku 2s leading edge was skinned with GFRP, to reduce the weight. It's wing used the SYMI-C (see note 2) airfoil. Unfortunately high winds caused the cancellation of the 1989 rally, however the Super Gokuraku Tombo flew 513.6m the following year and took 3rd place.

Endnotes

1 Wing unit ~ Fujigiken Co. made the wings. Fujigiken used a mould to manufacture the wing in 800mm long prefabricated sections. Ribs were cut from 10mm styrofoam and the skin which was made from 1mm styrene paper was bonded to them in the mould. This moulding technique simplified wing construction, the only work left to do was to thread the finished wing sections onto the spar.

2 Airfoil ~ The YSMI-C airfoil was designed by Dr. Masao Yamana. It had a high CL_{max} .

Sindbad

The Sindbad had a wire braced wing structure built around a CFRP tube spar. The fuselage was built of CFRP but this was later changed to wood. Its propeller was 3.2m in diameter. It made more than 80 test flights to measure L/D, propeller RPM and torque and the pilots heart rate. Flow visualization was carried out with wool tufts. During the rally it managed to fly only 64m in the heavy rain.

The Team N.A.S.G. HPAs

These aircraft were made by the aeronautics club at Nihon University, (N.A.S.G), to compete in the Birdman rally. The aeronautics club has members from Freshmen, Sophomore and Junior years in many different departments. It has access to the Universities 628m runway and hangars and has been very successful in the competition.

The Mowe I (1984 - 5)

The Mowe I was the only aircraft of the series to have a canard configuration and wooden wire

braced structure. It flew only 14.1m in the rally.

The Mowe II (1984 - 85)

The Mowe II used a tubular CFRP structure with strut braced wings. (This construction continued to be used until the Mowe VI was built.) Its competition flight was cut short because of transmission problems but nonetheless it did fly 52.8m.

The Mowe III (1985 - 86)

The Mowe III had three axis controls which were found to be difficult to use. It flew 90.2m in the rally.

The Mowe IV (1986 - 87)

The Mowe IV was built with a rugged structure. It had winglets to reduce the take off power and made over 100 test flights. The Mowe IV flew an impressive 435.5m against a 3-4 m/s wind in the 11th rally and took first place.

The Mowe V (1987 - 88)

The Mowe V used a hollow CFRP box spar across the outer wing panels as a test of this form of construction. The flanges and webs of the spar were made from CFRP and the internal stiffening from balsa wood. The Mowe V was intended to fly in the 12th birdman rally, but because of bad weather it was brought back to the University and test flown from the Munakata lab by towing it behind a car. From these tests the Aeronautics club learned that its actual power requirement was 375 Watts whereas they had calculated a cruise power requirement of only 293 watts.

The Mowe VI (1988 - 89)

The Mowe VI's wing was braced by wires attached close to the wing root. The wires served to stiffen the fuselage wing joint and were not structurally necessary as the wing was stressed for 2gs. Bolts were replaced with pins at the wings joints to reduce weight. All subsequent Mowe planes used this type of wing structure. The Mowe VI's fuselage was designed for an upright, conventional cycling pilot position and the control linkages were run internally in the tailboom. Unfortunately the 13th rally was cancelled because of high winds so the Mowe VI could not set a new distance record there.

The Mowe VII (1989 - 90)

The Mowe VII used the spars from Mowe VI but the airfoil was changed to the DAE11 and the leading edge sheeting was made from 1mm styrene paper; it extended back to 60% of the chord on the upper surface. The pilot was seated in a recumbent position. The Mowe VII flew 1810.5m in the 14th rally and took first place.

The Mowe VIII (1990 - present)

The Mowe VIII has a CFRP box beam over the inner wing panels and CFRP tube spars at the tips. It used a driven wheel for take off with a rope and spool transmission. The Mowe VIII was scheduled to fly in the 1991 rally but the team elected to abstain because of heavy rain.

SAKUZO 1 and 2

These aircraft were made for the Birdman rally, many of the builders were graduates of Nihon University who had worked on the Mowe aircraft. The SAKUZO 1 used the Swifts wingspar and the fuselage from the Mowe VI. It flew 649.1m to take second place in the 14th rally. The SAKUZO 2 used Mowe VII's wing, its propeller was of single piece CFRP construction. The estimated minimum power was 221 Watts at 7 m/s. The SAKUZO 2 took 1st place in the 15th, 1991, rally with a 500.2m flight. The pilot believed that the actual flight power was 750 watts, but it should be realised that this flight was made in the rain.

The challenge of the HPA distance record

Bad weather forced the cancellation of the 1988 - 89 Birdman contest and Japanese human powered flight clubs used this time to make many trial runs in preparation for challenging the Japanese distance record. The first attempt at the record was made by the Mowe V which flew 1700m in eight minutes 30 seconds at the Mienuma airfield. The second attempt was made on August 10, 1989 in an improved version of the Mowe VI (the Mowe VI-B) which only managed to fly 1400m against a 2-3m/s wind. Further improvements were made to the Mowe VI-B before a third attempt was made on March 30th 1990. And the distance record was finally broken with a flight of 3708.2m. New members in the Mowe and Aeroscepsy teams are now preparing to break the Mowe VI's record, and the number of human powered flight teams are growing yearly in Japan.

HPAs of the Future

All the HPA teams research the performance of their aircraft, they have all observed a large difference between the predicted and measured powers. So it seems that attention will turn to the following areas of construction in order to improve performance in the future:

- Smaller tail volumes
- Improving wing profile accuracy and surface quality
- More efficient drive trains, such as drive shafts
- Improving handling characteristics

Human Powered Helicopters

'A Day Fly' (1984 - 86)

The 'A Day Fly' was built by the Naito laboratory of the College of Science and Technology at Nihon university to try to capture the Sikorsky human powered helicopter (HPH) prize. The 'A Day Fly' had 10m radius contra rotating blades with the pilot seated above the rotor in a conventional cycling position, this ensures dynamic stability of the helicopter whilst placing the blades close to the ground to take advantage of ground effect. The transmission used a double chain and six bevel gears. The pilot of A 'Day Fly' generated power with his legs, bicycle style. The rotor velocity varied due to lack of torque at the top and bottom positions of the crank during the pedal cycle. Oval gears were used to smooth out these velocity fluctuations but they did not work well and the 'A Day Fly' flew only once for a few seconds on December the 6th 1985 although there is no documented evidence to prove this. The development of 'A Day Fly' ended in March 1986 with the retirement of Professor Naito.

Papillion A, B and C (1988 - present)

The Papillion series was produced by the engineering club of Nihon University with the advice and encouragement of Emeritus Professor Naito. The Papillion A was of the same configuration as the 'A Day Fly' but differed in having top and bottom rotors of different diameters, this configuration was chosen after a series of tests carried out with 1/10th scale models. Papillion A used cam springs to smooth out the dead points in the pedal cycle, this did not work well and it did not fly. Figure 4 explains the cam spring drive mechanism. The Papillion A was tested by attaching a electric motor to the drive shaft, this test had to be abandoned because of vibration. The Papillion B used a swinging lever drive, Figure 5 explains the swinging lever drive mechanism. The pilot was placed under the rotors to decrease the pilots anxiety. (It was found that the pilots did not like the pedalling position used on the 'A Day Fly' and Papillion A, high above the ground and rotors.) The pilots position below the rotors caused a choice of rotor anhedral to increase the ground effect. The centre of gravity of the pilot was offset from the rotor axis in the Papillon B, a result of choosing to place the pilot beneath the rotor. According to calculations, the Papillion B needed a small counter weight to correct this problem, however it actually needed a large counter weight and was then too heavy to fly. The Papillion C is still under construction. It has a single main rotor and twin tail rotors and employs a swinging lever drive.

Additional information about HPH development in Japan can be found in the following papers:

1. Kouichi Nakamura, 'The MITSUBACHI Human Powered Helicopter', The Human Powered Aircraft Group Symposium, Held at the Royal Aeronautical Society, London, 16th January 1992.
2. Naito, A. 'Review of Developments in Human - Powered Helicopters'. HUMAN POWER Technical Journal of the International Human Powered Vehicle Association. Vol.9, No.2 Summer 1991.

A conclusion and the future of Human powered flight in Japan

After setting the world record with Stork, the research team at Nihon university worked to win the Kremer figure of eight and speed prizes. They failed to do this, but they had started a tradition that continues to this day. They have participated in the Bird Man rally, set a high standard and given spirit to the event. They are now planning to capture the world distance record for human powered flight. Meanwhile other students and graduates of Nihon university have been working on the development of human powered helicopters. So far they have made only one unobserved flight of a few seconds, but they expect to fly for a longer time in the near future. The greatest achievement of the Bird Man rally has been to bring human powered flight to the attention of the Japanese public. This has stimulated many ordinary people and students of other universities to take up the challenge of human powered flight and enter the rally. Reductions of the price of high tech materials and the availability of information from European and American HPA designers reinforces this trend. At the moment Japan is behind America but the Japanese are building up a large pool of design experience and research data that will enable them to make outstanding aircraft in the future.

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Human Powered Aircraft of Japan 1961 - 1991

Team	Other groups	Nihon University Aeronautics club (N.A.S.G.)	Aeroscepsy	Nihon University College of Science & Technology <u>Kimura Laboratory</u> Linet (first flight) EAGLET Stork (world record) Ibis <u>Naito Laboratory</u> Milan '81 Milan '82 Swift A Swift B & A DAY FLY Swift C & A DAY FLY	Nihon University College of Engineering.
1966					
1977 (1st)					
1981					
1982					
1983 (7th)			Seagull I		
1984 (8th)			Seagull II		
1985 (9th)	Le Soleil Levent II	Mowe I & II	Seagull III		
1986 (10th)		Mowe III	Gokuraku Tombo & Seagull		<u>Kanno Laboratory</u> Human powered helicopters
1987 (11th)		Mowe IV			Papillon A
1988 (12th)		Mowe V			Papillon B
1989 (13th)		Mowe VI	Super Gokuraku T. I		
1990 (14th)	SAKUZ0 1	Mowe VII	Super Gokuraku T. II		
1991 (15th)	SAKUZ0 2	Mowe VIII	Sindbad		Papillon C

Notes

The first Birdman Cup Rally was held in 1977

The Seagull I was the first HPA to enter the rally in 1983

The Mowe VI-B set a new Japanese distance record of 3708.2 m on March 30th 1990

The A DAY FLY, built at the Naito Laboratory, was the first Japanese HPH

Table 1. Human-Powered Aircraft of Nihon University

Aircraft	Ibis	Milan '81	Milan '82	Swift A	Swift B	Swift C
Construction team	Kimura Lab	Naito Lab ---->				
Development time	'77.4 - '81.3	'81.4 - '82.3	'82.3-'83.3	'83.4-'84.3	'84.4 - '85.3	'85.4 - '86.3
Challenge	Kremer figure of eight competition	Kremer figure of eight competition		Kremer speed competition		
Pilot position	upright	upright	recumbent	recumbent	recumbent	upright
Wing span (m)	19.4	25.0	25.0	19.4	17.5	17.5
Length overall (m)	7.8	11.4	10.3	9.7	7.4	—
Height overall (m)	2.6	4.8	5.6	2.7	2.7	—
Tail span (m)	3.5	4.0	4.0	3.0	3.8	—
Wing area (m ²)	18.0	37.5	37.5	19.0	17.8	—
Airfoil	FX72MS-150A	NACA 4412	NACA 4412	Eppler E-393	Eppler E-393	Eppler E-393
Aspect ratio	20.9	16.7	16.7	19.8	17.2	17.2
Taper ratio	0.40	0.45	0.48	0.4	0.45	0.45
Dihedral (degrees)	10.0	2.0	3.0	3.0	6.5	6.5
Structure	cantilever	wire braced	wire braced	cantilever	cantilever	cantilever
Propeller position	pylon	pusher	pusher	pylon	pylon	tractor
Propeller diameter (m)	2.4	3.8	4.2	3.0	3.0	3.0
Propeller rpm	210	120	110	200	206	180
Flying speed (m/s)	8.5	5.7	5.4	11.0	10.8	10.8
Power (Watts)	256	—	265	390	502	—
Empty weight (kg)	38.8	34.0	27.3	51.9	51.0	—
Total weight	92.0	92.0	85.3	105.9	105.0	100.0
Wing loading (kg/m ²)	5.1	2.5	2.3	5.6	5.9	5.6
Control system	r/e/a	r/e/a	r/e	r/e/a	r/e/a	r/e/a
Horizontal tail volume	—	—	—	0.50	0.48	0.48
Vertical tail volume	—	—	—	0.020	0.015	0.020
Longest flight distance (m)	1100	590	1500	—	590	1406

Table 2. Human-Powered Aircraft Built by Team Aeroscepsy

Aircraft	Seagull I	Seagull II	Seagull III	Seagull	Gokuraku Tombo
Development time	'83.3 - '83.7	'84.3 - '84.8	'85.3 - '85.8	'85.11 - '86.8	'85.11 - '86.8
Configuration	canard upright	canard upright	canard upright	canard upright	conventional upright
Wing span (m)	14.0	—	18.0	18.0	18.0
Length overall (m)	5.5	—	5.1	5.1	7.1
Height overall (m)	3.6	—	4.2	4.2	3.9
Tail span (m)	3.0	—	3.0	3.0	3.0
Wing area (m ²)	22.4	—	24.3	24.3	24.3
Airfoil	Lissaman 7669	Lissaman 7669	Lissaman 7669	Lissaman 7669	Go624, Go535R
Aspect ratio	8.75	—	13.3	13.3	16.0
Taper ratio	1.0	—	0.6	0.6	0.55
Dihedral (degrees)	—	—	3	3	6
Structure	wire braced	wire braced	wire braced	wire braced	strut braced
Propeller position	pusher	pusher	pusher	pusher	tractor
Propeller diameter (m)	3.5	3.5	3.5	3.5	3.5
Propeller rpm	—	—	—	—	—
Flying speed (m/s)	—	—	8.0	8.0	—
Control system	s/e	s/e	s/e	s/e	s/e
Horizontal tail volume	0.23	—	0.25	0.25	0.40
Vertical tail volume	—	—	—	—	0.012
Result of Bird man rally	7th	8th	9th	10th	10th
Distance flown in rally (m)	55.2	114.8	179.6	286.1	512.2
Ranking in Bird man rally	—	7th	4th	2nd	1st

Table 2 continued Human-Powered Aircraft Built by Team Aeroscepsy

Aircraft	Super Gokuraku	Super Gokuraku	Sindbad
Tombo I Tombo 11			
Development time	'89.3 - '89.8	'90.3 - '90.8	'90.8 - '91.8
Pilot position	conventional	conventional	conventional
Wing span (m)	20.0	22.0	27.0
Length overall (m)	7.0	7.0	7.0
Height overall (m)	—	—	3.6
Tail span (m)	2.4	2.4	3.4
Wing area (m2)	18.0	17.8	23.9
Airfoil	FX72MS-150B	YSMI-C	DAE11,21,31
Aspect ratio	22.2	27.9	30.5
Taper ratio	1.0	1.0	0.45
Dihedral (degrees)	7	7	Aeroelastic dihedral
Structure	cantilever	cantilever	wire braced
Propeller position	pylon	pylon	pylon
Propeller diameter (m)	2.0	2.0	3.2
Propeller rpm	—	—	124
Flying speed (m/s)	—	—	7.0-7.5
Control system	r/e	de	de
Horizontal tail volume	0.4	0.4	0.5
Vertical tail volume	0.013	0.013	0.013
Result of Birdman rally	13th	14th	15th
Distance flown in rally (m)	called off	513.6	64.6
Ranking in Birdman rally	called off	3rd	8th

notes on the tables
Control system
r = rudder
e = elevator
a = aileron
s = spoiler

Table 3 Human-Powered Aircraft Built by The Aeronautics Club of Nihon University (N.A.S.G)

Aircraft	Mowe I	Mowe II	Mowe III	Mowe IV	Mowe V	Mowe VI
Development time	'83.9 - '84.4	'83.9 - '84.4	'85.9 - '86.8	'86.9 - '87.8	'87.9 - '88.8	'88.9 - '89.8
Configuration	canard upright	conventional upright	conventional upright	conventional upright	conventional upright	conventional upright
Pilot position	upright	upright	upright	upright	upright	upright
Wing span (m)	16.0	18.0	18.0	19.0	22.0	22.0
Length overall (m)	—	—	—	—	8.63	7.45
Height overall (m)	—	—	3.7	3.3	3.5	3.5
Tail span (m)	—	—	3.0	—	4.0	3.1
Wing area (m ²)	—	24.9	24.9	26.6	29.7	22.1
Airfoil	NACA 63-615	NACA 63-612	NACA 63-612	NACA 4412	NACA 4412	NACA 4412
Aspect ratio	—	13.0	13.0	13.6	16.3	21.9
Taper ratio	—	0.62	0.62	0.56	—	—
Dihedral (degrees)	—	—	3	3	3	1
Structure	wire braced	strut braced	strut braced	strut braced	strut braced	cantilever
Propeller diameter (m)	—	—	3.8	3.2	3.4	3.4
Propeller rpm	—	—	190	190	180	154
Flying speed (m/s)	—	7.2	7.8	7.3	7.3	8.1
Power required (Watts)	—	—	308	315	293	285
Empty weight (kg)	40	30	37	32	33	33
Flying weight (kg)	—	—	92	86	92	93
Wing loading (kg/m ²)	—	—	3.7	3.2	3.1	4.2
Control system	s/e	s/e	r/e/a	r/e	r/e	r/e
Horizontal tail volume	—	—	0.49	0.47	0.45	0.28
Vertical tail volume	—	—	0.022	0.020	0.020	0.020
Result of Birdman rally	9th	9th	10th	11th	12th	13th
Distance flown in rally (m)	14.1	52.8	90.2	435.5	called off	called off
Ranking in Birdman rally	—	—	4th	1st	called off	called off

Table 3 continued Human-Powered Aircraft Built by The Aeronautics Club of Nihon University

Aircraft	Mowe VI-B '88.9 - '90.3	Mowe VII '88.11 - '90.8	Mowe VIII 90.9 -	SAKUZO 1 '90.3 - '90.8	SAKUZO 2 '91.3 - '91.8
Development time	conventional	conventional	conventional	conventional	conventional
Pilot position	recumbent	recumbent	recumbent	upright	upright
Wing span (m)	25.0	22.0	25.0	24.5	24.5
Length overall (m)	7.45	7.50	7.50	7.45	7.45
Height overall (m)	3.5	3.3	3.3	3.5	3.5
Tail span (m)	3.5	3.3	3.3	3.1	3.1
Wing area (m ²)	24.0	22.7	22.6	22.8	22.5
Airfoil	NACA 4412	DAE11	DAE11	DAE11	DAE11
Aspect ratio	26.0	21.4	27.7	22.2	26.6
Taper ratio	0.5	—	0.45	0.48	0.42
Dihedral (degrees)	1	1	0	0	0
Structure	cantilever	cantilever	cantilever	cantilever	cantilever
Propeller diameter (m)	3.4	3.2	3.2	3.4	3.4
Propeller rpm	144	132	132	154	113
Flying speed (m/s)	7.7	7.6	7.6	8.5	8.0
Power required (Watts)	263	248	259	400	263
Empty weight (kg)	34	36	34	43	33
Flying weight (kg)	94	94	94	104	94
Wing loading (kg/m ²)	3.9	4.4	4.1	4.6	4.2
Control system	de	r/e	r/e	r/e	r/e
Horizontal tail volume	0.37	0.29	0.30	0.24	0.30
Vertical tail volume	0.014	0.017	0.017	0.018	0.014
Result of Birdman rally	—	14th	15th	14th	15th
Distance flown in rally (m)	—	1810.5	withdrew	649.0	500.2
Ranking in Birdman rally	—	1st	withdrew	3rd	1st

Note

SAKUZO 1 & 2 were built by students of Nihon University after graduation

Table 4. Japanese Human Powered Helicopter data

Helicopter	A DAY FLY	Papillon A	Papillon B	Papillon C	MITSUBACHI
Development time	'84.4 - '86.3	'88.4 - '89.3	'89.4 - '90.3	'90.4 - present	'88.9 - present
Configuration	cr	cr	cr	sr	cr
Pilot position	above rotors	above rotors	under rotors	above rotor	above rotors
Pilot cycling style	conventional	conventional	recumbent	recumbent	conventional
Top rotor diameter (m)	20.2	13.6	12.8	24.0	24.0
Bottom rotor diameter (m)	20.2	19.6	18.8	24.0	24.0
Rotor chord (m)	0.7	0.9	0.7	1.4-0.7	1.2-0.55
Top rotor rpm	19.9	22.9	22.9	11.4	8.1
Bottom rotor rpm	10.9	11.2	11.2	11.4	8.1
Top rotor tip speed (m/s)	11.4	15.4	14.4	10.2	
Bottom rotor tip speed (m/s)	11.4	11.0	11.0	14.4	10.2
Airfoil	NACA63-615	FX72-MS-150B	FX72-MS-150B	DAM 1	DAE21 and modified DAE21
Empty weight (kg)	30.0	38.0	42.0	35.0	36.0
Flying weight (kg)	85.0	93.0	97.0	87.0	93.0
Disk loading (kg/m ²)	0.3	0.33	0.32	0.19	0.21
Transmission	chain and bevel gears	V-belt later modified to chain	wire swinging lever	cord	chain and cord
Comments	oval gear	cam-spring		swinging lever twin-tail rotors (2.5m dia)	hand and leg power

Note on configuration

cr = contra rotating coaxial rotors

sr = single rotor