Cause Investigation of Failure of the Challenge to World Record of Human-Powered Aircraft Flight: Operational Error and Disintegrating in Midair

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ABSTRACT: *Nihon University challenged world record of the human-powered aircraft flight based on the regulation of Fédération Aérionautique Internationale in Kasumigaura Lake, Japan, 2014. The wing fell off in midair immediately after take-off, the pilot landed to the lake for safety. So, the challenge failed. It guessed the operational errors were correlated with the wing falling in midair, which had not happened in our experience. The flight recording camera and the salvaged airplane were investigated. The fault tree analysis was conducted for cause investigation. The wing falling was the result as the chain destruction starting from the coupling parts being damaged in take-off. The defective take-off was caused by composite factors on only operational errors. The risk that the ultralight airplane might disintegrate in midair by only operational error became apparent.*

KEYWORDS –*Human-powered aircraft, World record, Failure investigation, Fault tree analysis*

I. INTRODUCTION

Nihon University has studied the human-powered aircraft since 1963 and succeeded in flying first in Japan. The challenge to the official record based on the regulation of Fédération Aérionautique Internationale (FAI) was started in 1990s. Nihon University set a Japan record of the straight flight in 1990, and broke the previous record in 2004[1]. The distance was 49.17km. In 2014, we challenged to world record of the closed triangle circuit course, which was added as a new category by revision of the FAI regulation in 2011. The airplane took off in Kasumigaura Lake in Ibaraki, Japan. The wing of the airplane fell off in midair immediately after take-off. The pilot made an emergency landing, so this challenge failed[2]. A human-powered aircraft is a low thrust and ultralight airplane, which is easily flapped by wind. The strength of a human-powered aircraft was sacrificed for weight saving, but the wing falling off had not happened in our experience. Why did this disintegration happen? In this challenge, the take-off was not normal due to operational errors on the take-off, so I guess that the wing falling off was caused by these errors. It is recently expected that a solar plane stays in high altitude and is used as a platform for wireless communication [3]. A solar plane is also an ultralight airplane same as a human-powered aircraft. The knowledge derived from the cause investigation of failure is able to contribute to develop guideline for operation. In this paper, it is investigated that the challenge failure and the wing falling off were caused by the operational error on the take-off.

II. THE EVENTS ON THE CHALLENGE FLIGHT

2.1 Airplane and runway

The airplane is shown in Fig. 1 and Table 1. This airplane was the Daedalus type, whose main structures were made in CFRP and wings were formed by using Styrofoam. The airplane was able to disassemble into a wing, a frame including a cockpit, a propeller, a vertical tail and a horizontal tail. The wingwas coupled with the frame by CFRP couplers and two stainless wire. The coupling section between the wing and the frame is illustrated in Fig. 2. The wing was bolted to the frame. Four bolts for front coupling and one bolt for rear coupling were used. At rear coupling, two coupling plates and a mount were coupled by one bolt and one nut.The vertical tail and the horizontal tail were movable, so each tail was also used respectively as a rudder and an elevator. A parking area near the Kasumigaura Lake and steel plates on the ground were used as a runway which is shown in Fig. 3. The whole distance of the runway was 105 m.

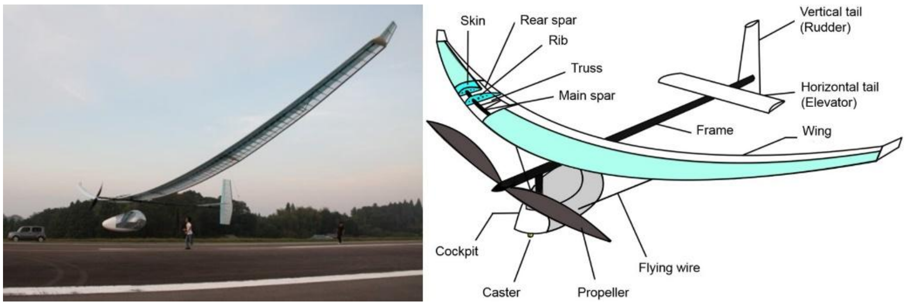


Fig. 1. The airplane

Table 1. Airplane specification

Name	Möwe 28
Wingspan	33.0 m
Wing area	31.0 m^2
Wing Aspect ratio	35.1
Empty weight	34.0 kg
Gross weight	96.5 kg
Cruising speed	7.4 m/s

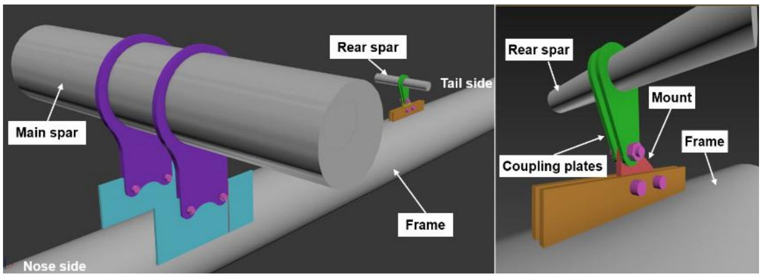


Fig. 2. Coupling section of the wing and the frame

Fig. 3. Panoramic view of the runway

2.2 Take off and flight

The description of the flight and the flight path are shown in Table 2 and Fig. 4, respectively. After assembly, the airplane started running in the condition of 1.6 m/s following wind. Although the airplanedid not takeoff by the end of acceleration section which was 80 m point of the runway, cancelation orders did not be called. The airplane passed the end of acceleration section with excessive speed.The take-off became a forced take-off that the pilot steered the elevator to maximum angle. The flying height was not enough, so the caster at the bottom of the airplane and the bottom of the rudder hit on a curb stone placed on the extended line of the runway. The caster fell off and the rudder turned to the pitching direction by this hitting. These are shown in Fig. 5. The airplane flied to the gate which was the starting line of the challenge flight. The rudder and the elevator were able to steer normally. After a strange shock and a sound happened, the wing oscillated. The oscillation is illustrated in Fig. 6. The pilot heard some breaking sounds during flight. The amplitude of the oscillation increased gradually. The wing fell off at the distance of 550 m from the runway, then the pilot landed to the lake. The wingfalling and landing to the lake are shown in Fig. 7.

Table 2. Overview of the flight

Date and time	Oct. 19, 2014 7:14 a.m.
Pilot	Tatsudo Tange
Temperature	10.4°C
Wind	1.63 m/s NW
Total flight distance	793.2 m
Total flight time	100 sec

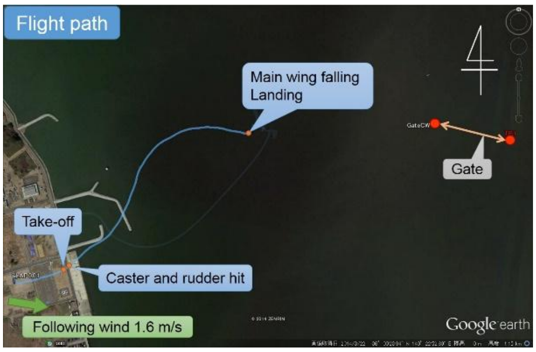
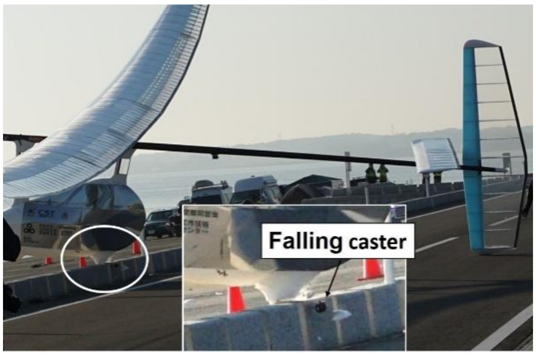


Fig. 4. Flight path



(a) Falling caster


(b) Rudder turning

Fig. 5. The hitting on a curb stone

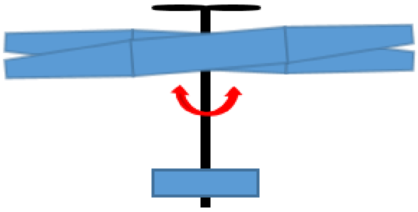


Fig. 6. Main wing oscillation


Fig. 7. Main wing falling and landing to the lake

2.3 Flight recording camera and salvagedairplane

The oscillation of the wing was obtained by using images of a camera installed into the frame. The camera frame rate was 29.97 fps. The positions of trailing edge of ribs nearest the frame and the axis of the frame, which are shown in Fig. 8, were obtained from camera images.The difference of the frame axis and the center of the wing was derived. The oscillation is shown in Fig. 9. The ordinate designates the difference in pixel of the frame axis and the center of the wing, the abscissa designates the frame number of the images.The ordinate value was processed by low-pass filer of threshold 6Hz. The positive value means that the center of the wing is at right side of the frame axis. From #7384 image, where a strange noise was heard from the video camera, the oscillation of the wing began to become strange. Since only the trailing edge turned, it guessed that the rear coupling section was broken. From #7655 image, where a big noise of crack formation was heard from the video camera, the amplitude of oscillation increased. It guessed that the rear coupling section was broken completely. From #7897 image, the amplitude of oscillation increased more and some damages, which is shown in Fig. 10, of the winglower surface at right side were recognized. At #8197 image, the wing fell off from the frame. Hence, the disintegration was separated into four phase.

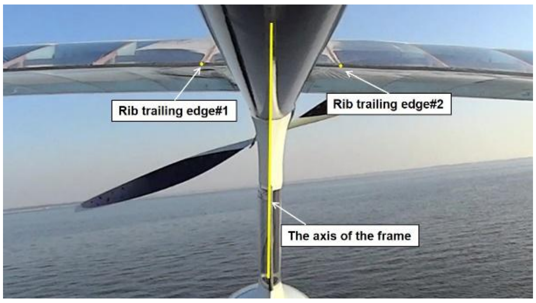


Fig. 8. Tracing point of rib trailing edge and the frame axis

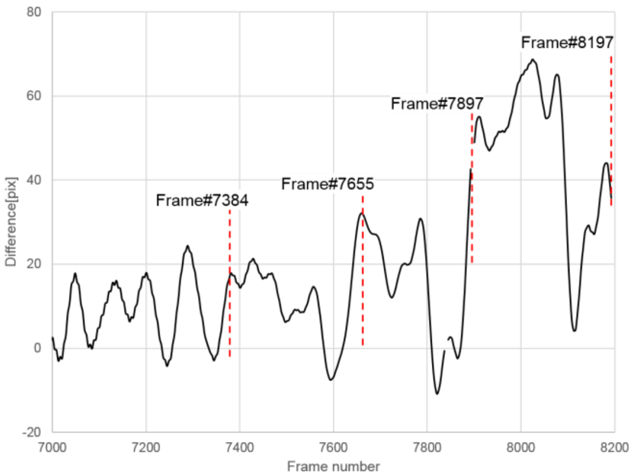


Fig. 9. Time evolution of the wing oscillation

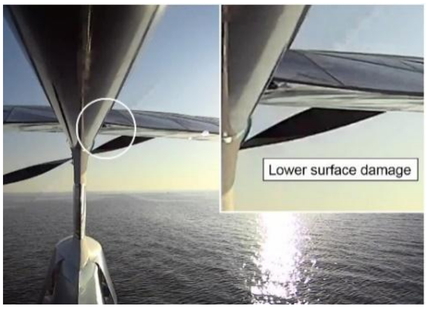
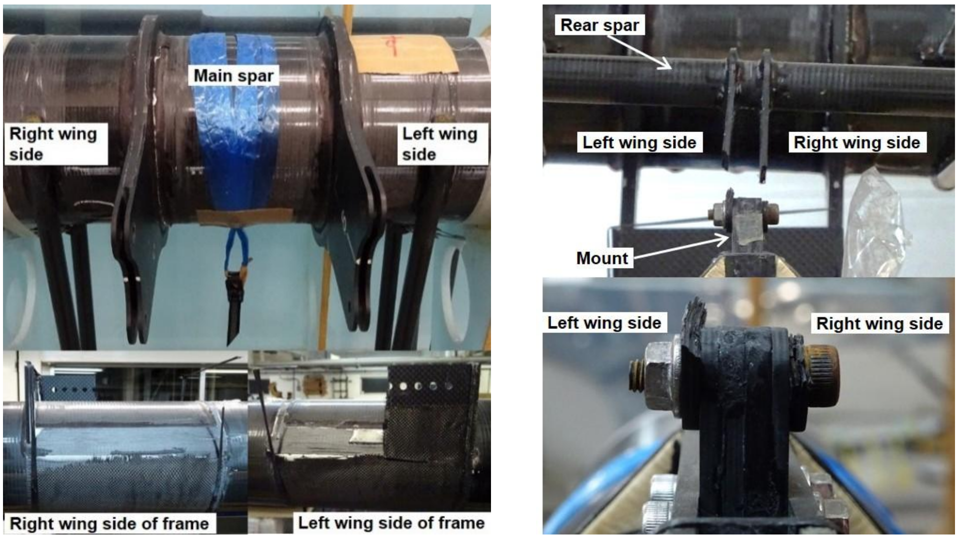


Fig. 10. Damage on the winglower surface

The front and rear coupling section after salvage is shown inFig. 11. The couplers of the main spar did not break. The coupler at right wing side of the frame fell off completely. The coupler at left wing side of the frame split from the center. Both rear coupling plates broke completely and each broke position was different. The position of the fracture surface at left wing side and right wing side was corresponding to the top of the mount and the bolt head, respectively. The cross section area of the fracture surface at the right wing side was less than the cross section area at the left wing side. The force for breaking the coupling plate at the right wing side is less than the one at left wing side, so the coupling plate at right wing side previously broke. Hence, the wing falling was a chain destruction which started from the breaking of the rear coupling plate at right wing side, then the rear coupling plate at left wing side, the front coupler at right wing side and the front coupler at left wing side broke subsequently. The sequence is illustrated in Fig. 12.



(a) Front coupling section (b) Rear coupling section

Fig. 11. The coupling section of salvaged airplane

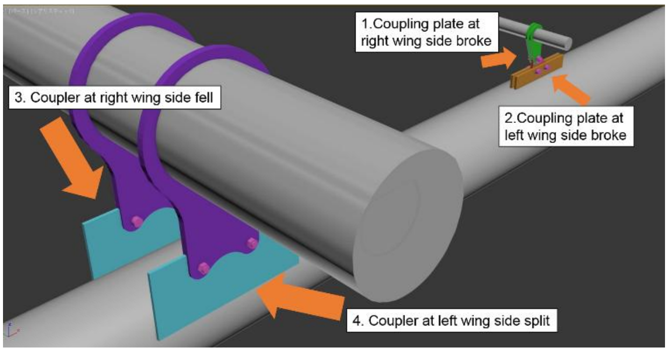


Fig. 12. The sequential order of coupler break

III. CAUSE INVESTIGATION OF THE WING FALLING OFF

3.1 Fault tree analysis

The fault tree analysis was created on the destruction of the coupling of the wing and the frame as the top event. The fault tree is shown in Fig. 13. On designing, manufacturing and maintenance, there were no error. From the flight camera images and a weather monitor, an unexpected gust and a bird strike were not recognized.The airplane was inspected visually before assembly and was not damaged during assembly.So, the shock by hitting on a curb stone on defective take-off caused the coupling damage.

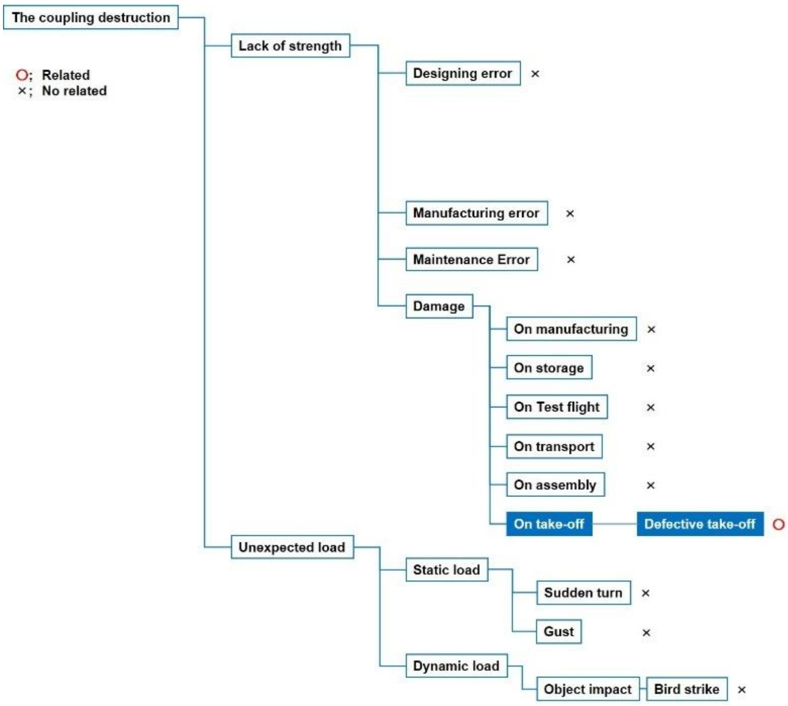


Fig. 13. Fault tree on the coupling destruction

The fault tree analysis was created on the defective take-off as the top event. The defective take-off was defined as cancelation orders did not be called though the airplane did not accelerate to the air speed enough to take-off in the runway. Thefault tree is shown in Fig. 14.The pilot performance and the airplane ability were no related with the defective take-off.The runway and some operations were related with the defective take-off.The defective take-off was caused by composite factors which were margin deficiency of the runway distance, Go/NoGo judgment error for take-off permission and take-off cancelation judgment error during running. Hence, the take-off was permitted under weather condition exceeding the margin because judgment manual was not found though the runway distance margin was little. The suitable cancelation order was not able to be called because cancelation operating manual was not founded, then the take-off was forced.

3.2 Scenario of the failure of this challenge

On flight day, the weather condition was following wind 1.6 m/s. The margin of the runway distance was little, which meant the airplane was not able to take off under following wind condition. The Go/NoGo judgment permitted the take-off because the criteria had not been founded. Although the airplane did not accelerate enough to take-off by the end of the acceleration section due to strong following wind and margin deficiency of the runway distance, the cancelation order was not called because the cancelation criteria had not been founded.The airplane had passed the end of the acceleration section with excessive speed.This forced defective take-off caused that a caster at the bottom of the airplane hit on a curb stone placed on the extended line of the runway. The shock by the hitting damaged the coupling plate. The damaged coupling plate broke without standing the flying load due to reduction of load capacity.The wing started oscillating after the coupling plate breaking. The remaining coupling parts broke in sequential order of the rear coupling plate at left wing side, the front coupler at right wing side and the front coupler at left wing side. The coupling section of the wing and the frame broke completely, the wing fell off. The pilot landed to the lake for safety. Consequently, this challenge failed. The scenario is illustrated in Fig. 15

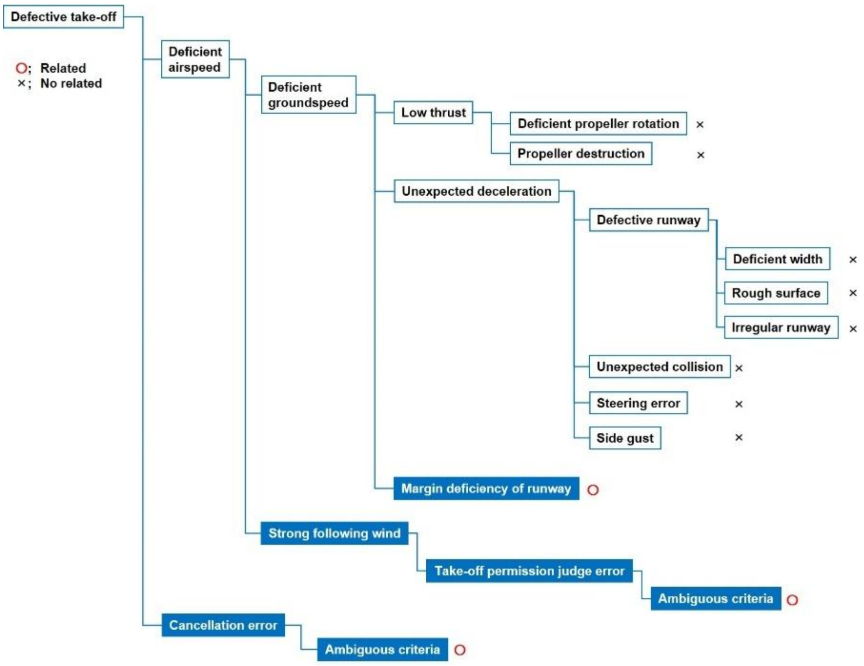


Fig. 14. Fault tree on defective take-off

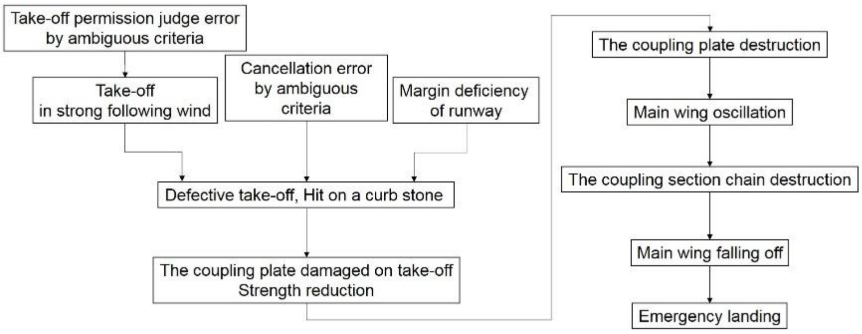


Fig. 15. Scenario of the failure of this challenge

IV. CONCLUSION

The mechanism of the wing falling off on the challenge to the world record of human-powered aircraft flight was investigated from analysis of flight recording camera images and the salvaged airplane. The wing falling was a result of a chain destruction starting from the rear coupling plate at right wing side. The fault tree analysis investigated that the chain destruction was caused by the defective take-off, which was caused by composite factors related with operational errors. The risk that an ultralight airplane having enough strength could disintegrate by operational error became apparent. This knowledge may contribute on designing and operating a human-powered aircraft and other ultralight aircrafts.

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