BEA
Bureau d'Enquêtes et d'Analyses
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INVESTIGATION REPORT

Serious incident to the drone[1] DJI - Inspire 2

on 14 July 2019
at Barcarès (Pyrénées-Orientales)

Time	Around 00:40[2]
Operator	Fly Art Prod
Type of flight	Aerial photography
Persons on board	0
Consequences and damage	3 people on ground injured, drone damaged

This is a courtesy translation by the BEA of the Final Report on the Safety Investigation published in April 2021. As accurate as the translation may be, the original text in French is the work of reference.

[1] Other terms are used in the regulations, notably "unmanned aircraft".

[2] Except where otherwise indicated, times in this report are local.

Collision with an obstacle, uncontrolled descent, collision with people on the ground, during an aerial photography flight

1 - HISTORY OF THE FLIGHT

Note: the following information is principally based on a video taken from the drone along with the statements from the drone pilot, cameraman and witnesses in the public.

In order to film overhead a music festival, organized at Barcarès and lasting several days, the event organizer called upon the drone video production company, Fly Art Prod. The mission was performed by a team composed of a video cameraman and a drone pilot.

The first flight was carried out in the afternoon of 13 July 2019. The fourth flight started a few hours later, at around 00:35, from the left side of the main stage[3]. The aim was to film the public (a few thousand people) situated in front of the stage.

[3] For a member of the audience looking towards the stage.

The drone carried out to-and-fro movements between the left side and overhead the stage. During the fourth to-and-fro movement, on flying back towards the drone pilot, the drone quickly lost altitude and collided with a vertical structure on the left side of the stage (see Figure 1). It then progressively descended towards the festival-goers in front of the stage, before striking several people and creating panic in the crowd. A festival-goer then threw it onto the ground which brought the drone to a halt.

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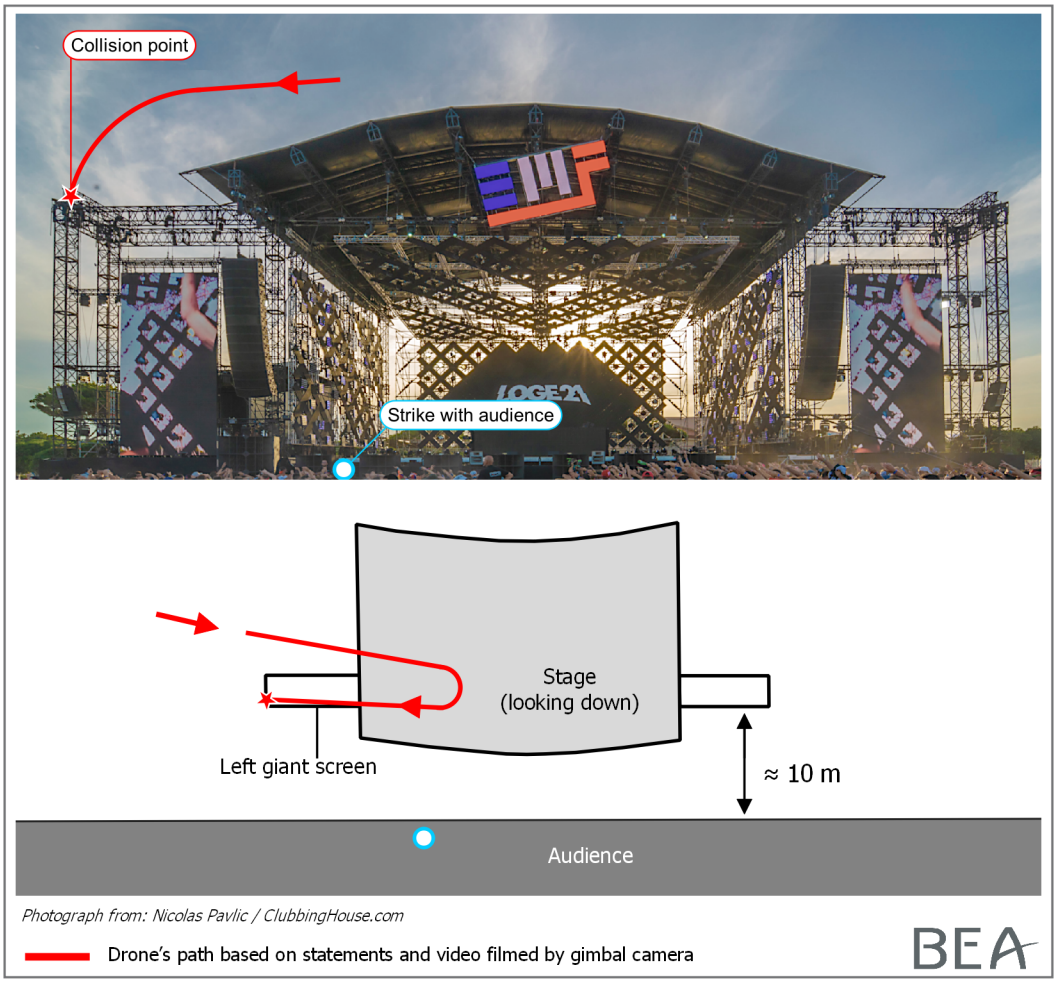

Figure 1: Drone's path

2 - ADDITIONAL INFORMATION

2.1 Video read-out

The drone was equipped with a Zenmuse X5S gimbal camera for filming purposes.

The BEA was able to read out a video recorded by this camera.

The recording starts at the beginning of the fourth to-and-fro movement between the left side and overhead the stage. It ends just after the collision with the top of a vertical structure on the left side of the stage.

At the beginning of the video, the drone flies over the stage gaining height.

Travel stops at 0:28[(4)] when the drone had flown over around one third of the stage. From 0:28 to 0:32, the drone starts returning to the left side of the stage without changing altitude. From 0:32, it continues its return, descending quickly. At 00:43, the drone strikes the top of a vertical structure on the left side of the stage.

From 0:43 to 0:47, the drone is practically hovering. From 0:47 to 0:48, it swerves to the middle of the stage and the public. The video stops at 0:48.

(4) This corresponds to the time which has elapsed from the beginning of the video recording: here 28 s.

At the beginning of the video, the people who were the closest to the drone were the festival security guards. They were situated between the stage and the audience safety barriers.

Based on the video, it was possible to estimate that some of them were at a horizontal distance of less than 10 m from the drone manoeuvring zone. Furthermore, the closest members of the audience were at a horizontal distance of less than 20 m.

2.2 Regulatory framework of flight

At the time of the occurrence, French regulations[5] made a difference between three types of drone use: model aircraft, trials and specific activity.

Four operational scenarios (S-1 to S-4) were defined for professional operation or "*specific activity*".

The Fly Art Prod mission was carried out in the scope of scenario S-3, i.e. operation over a habited area (congested areas of cities, towns or settlements or over an open-air assembly of persons) during which the drone has to remain in line of sight and at a maximum horizontal distance of 100 m from the drone pilot. Flight over a third-party is prohibited in this scenario.

In the scope of a scenario S-3 mission, drones between 4 kg and 8 kg must be equipped with a system associating a power cut-off and a parachute operated by an independent control. The occurrence drone, weighing 4.3 kg with all its equipment, was equipped with such a system.

The European regulations[6] implemented on 31 December 2020 will lead to the disappearance of scenario S-3 between now and 2 December 2023 (transition period from French regulations to European regulations). However, they include an equivalent operational scenario: the European Standard Scenario STS-01 in the "*specific category*" grouping all moderate-risk operations.

2.3 Information about company's organization of flights

2.3.1 Flight preparation information

Before carrying out a mission in the scope of scenario S-3, a file must be systematically sent to the prefecture of the *department* in which the site is located.

The manager of Fly Art Prod had sent a flight request file (flights not limited in number) to the Pyrénées-Orientales prefecture which had approved it. The file included a map on which four flight sites were shown (see Figure 2).

[5] Order of 17 December 2015 on the design of unmanned civil aircraft, the conditions of their use and their operator capacities. See https://www.legifrance.gouv.fr/loda/id/JORFTEXT000031679906/2019-07-14/

[6] For more information, refer to the following DSAC document: https://www.ecologie.gouv.fr/sites/default/files/Presentation_reglementation_europeenne_drones.pdf

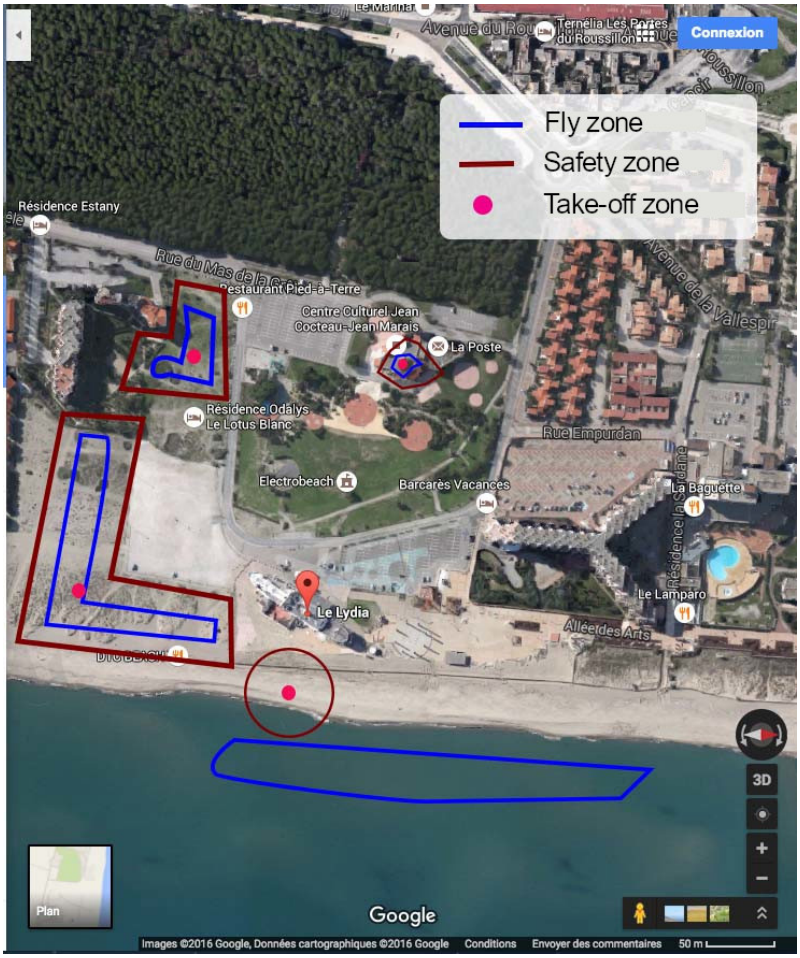

Figure 2: Map sent to prefecture

This map did not show the position of the stages and the various areas assigned to the festival's audience.

Neither did it show the holiday residence on the site shown with a reverse letter L[7]. On arriving at Barcarès, the company manager and the drone pilot decided to carry out certain flights from a children's playground, situated close to the holiday residence (see Figure 3). The playground was closed to the public.

[7] The map, produced using a Google Maps satellite view indicated the date 2016. However, it was inexact as the holiday residence was already being built and was visible on photos taken in 2014.

Figure 3: Position of zones, stage and children's playground

No flight site over the children's playground or main stage had therefore been declared.

2.3.2 Occurrence flight information

As the flights planned for the festival were to be carried out partly at night, a derogation had to be obtained. The Pyrénées-Orientales prefecture had asked the DSAC-Sud (civil aviation safety directorate - south office) for their technical opinion. The latter had approved the flights subject to compliance with certain criteria, including a minimum horizontal distance of 30 m between the aircraft and persons not linked to the operations (third party exclusion zone).

The prefecture had adopted this criteria in a prefectural order covering the night flight authorizations for Fly Art Prod.

2.4 Drone operator information

2.4.1 Company manager information

The 44-year-old company manager was a professional drone pilot. His drone pilot certificate permitted him to carry out flights in the scope of scenarios S-1 and S-3.

He was the cameraman for all the planned flights during the festival and had participated as drone pilot during the same festival in 2018.

2.4.2 Company manager statement

The company manager explained that he was the cameraman and that he could control the gimbal camera installed on the drone via a mobile application (DJI GO 4) installed on his mobile phone. DJI GO 4 was used in "slave" mode. This mode permitted him to orient the camera, irrespective of the drone's path, and take photos and videos.

It also permitted him to check the flight parameters such as the height, or the charge level of each battery, but not to pilot the drone.

He explained that the occurrence flight, the fourth of four, was the second flight to be carried out from the children's playground.

The drone had flown back and forward between the children's playground and the stage. The drone was never more than 50 m away from him and the drone pilot, and the wind was light. During the fourth back and forward movement, judging that he had filmed enough, the company manager asked the drone pilot to make the drone fly back to land. A few moments later, when the drone was overhead the stage and flying towards them, he indicated that he received an alert on the DJI GO 4 application of his telephone indicating "battery fault". He immediately warned the drone pilot of this. The latter then told him that he no longer had control of the drone.

The landing gear had extended. The drone considerably descended until it touched something. The cameraman first thought that it was a cable. He then instinctively stopped the video recording in progress.

Following the collision, the drone yawed 180°. The cameraman than asked the drone pilot to shut down the motors, but the action was ineffective. The drone descended while flying, from left to right, around the left giant screen. It ended up in front of the stage, its path coming to an end in the audience. The cameraman added that when he recovered the drone, just after the occurrence, one battery indicated 40% and the other 60%. He specified that the batteries were fully charged at the beginning of the flight.

2.4.3 Drone pilot information

The 34-year-old drone pilot held a drone pilot certificate permitting him to carry out flights in the scope of scenarios S-1, S-2 and S-3. He had been a professional drone pilot since 2015 and had logged more than 400 flight hours.

He controlled the drone with a remote controller on which a tablet was mounted. The tablet used the DJI GO 4 application in "master" mode. He also had a control to cut off the power supply and activate the twin parachute.

2.4.4 Drone pilot statement

The drone pilot indicated that the batteries had been used during one of the three previous flights and had then been fully recharged.

He was flying the drone back and forth between the left side of the stage and the stage itself. On the outward leg, the drone climbed without ever exceeding 30 m with respect to the ground. On the return leg, the drone descended.

During the fourth back and forth movement, after three or four flight minutes, the cameraman told him that the charge of one of the batteries was dropping. He then decided to bring the drone back to land. But on the return leg, the drone started an uncontrolled descent towards a 15 m-high vertical structure on the left side of the stage.

The drone pilot reported that on the DJI GO 4 application on his tablet, one battery was in the red with a charge of 10% to 12% whereas the other battery was in the green with a charge of 40%. He could not remember if he had received any audible or visual alert concerning the batteries.

The drone continued its descent towards the vertical structure until striking it at three-quarters of its height. He explained that the drone had first yawed 180°. The cameraman then asked him to shut down the motors. He did this by pushing the two joysticks of his remote controller as shown below:

He specified that the action lasted one second.

Parallel to this, the drone started slowly descending again while yawing about itself, as far as he could remember, in an anticlockwise direction. The drone pilot lost visual contact once the drone was in front of the stage.

He explained that he and the cameraman asked themselves whether they should cut off the power supply and activate the twin parachute. The height of the drone seemed insufficient to them and ultimately, they did not do it. The drone pilot considered that the twin parachute would not have been effective and that the drone could have fallen on someone. He hypothesized that the loss of control before the collision with the vertical structure was due to the sudden problem on a battery. He added that the drone, no longer responding to the controls, then decided of its own accord to land and struck the vertical structure.

2.5 Drone information

The DJI Inspire 2 is a quadcopter drone principally used for professional purposes. Its propellers have a diameter of 38 cm. Its two TB50 type batteries each have a capacitance of 4,280 mAh.

Figure 4: DJI Inspire 2 equipped with Zenmuse X5S gimbal camera

[8] Version 2.4 dated July 2019 (in English) was used for the investigation.

The user manual[8] specifies that the maximum flight time with the two batteries is around 25 min for the models equipped with the Zenmuse X5S gimbal camera. It does not give information about the possibility of continuing the flight in case of a failure on one of the two batteries. Contacted, the manufacturer specified that the two-battery system is redundant and that it is possible to continue the flight with a single battery.

The drone is equipped with an anti-collision system, the operation of which is not guaranteed at night.

2.5.1 Previous problem with TB50 and TB55 batteries

A few incidents concerning drones equipped with TB50 and TB55 batteries (these two models share the same architecture) had been reported to DJI.

In October 2018, the West Midlands police (United Kingdom) reported an incident during which a problem on the batteries had led to all the motors shutting down in flight. No one was injured. The investigation carried out by the manufacturer found that a certain number of TB50 and TB55 batteries had a fault resulting in the incorrect charge level being sent to the drone computers.

The United Kingdom Civil Aviation Authority (CAA) published a Safety Notice on 31 October 2018 (SN-2018/009) substantially limiting the operating possibilities of drones using these batteries. In the United Kingdom, DJI Inspire 2 flights were prohibited:

- within 50 m of any persons;
- within 150 m of an open-air assembly of more than 1,000 persons.

[9] https://www.dji.com/newsroom/news/dji-advises-customers-to-fly-with-caution-when-using-tb50-and-tb55-batteries-in-drones?fbclid=IwAR1fervJ9ip79RvgArrQL2yOGfTvyRROPkkarc6pmS8dJhI86hiiABZT9wU

Pending the update of the drone firmware, DJI published a communiqué[9] on its website on 31 October 2018 advising DJI Inspire 2 users worldwide to check the battery voltage.

Furthermore, users were asked to check (via DJI GO 4):

- before take-off, that the charge of both batteries was more than 4.25 V (complete charge);
- during the flight, that the charge of both batteries was more than 3.7 V; if this was not the case, users were asked to land the drone.

On 16 November 2018, an update of the Inspire 2 firmware (v01.02.0300) corrected the fault identified and the limitations imposed by the CAA were progressively lifted.

2.5.2 Firmware version

After the Barcarès occurrence, the company manager recovered the drone and returned to his place of residence the same morning. Having been notified of the event several days after its occurrence, the BEA was only able to analyse the data recorded by the drone from 25 July 2019, i.e. 11 days later. Checks found that the firmware version was v01.02.0300, i.e. the latest version available. It was not possible to determine at what moment this update was carried out.

2.5.3 Automatic emergency landing

In the event of a short remaining endurance, the drone can initiate an automatic emergency landing.

The drone pilot keeps the possibility of modifying the drone's path. This is described in the "Aircraft" part of the user manual.

An automatic emergency landing is only initiated when the Critical Low Battery Warning is activated. The drone pilot sets the activation threshold parameters of this alert.

The drone pilot reported having selected 10% on the DJI GO 4 application. According to the manufacturer's logic, this means that the alert will be activated as soon as the mean level of the two batteries is less than 10%.

Even when one battery is faulty, it would suffice for the other battery to have more than 20% for the mean of both levels to exceed 10%.

The battery charge values read by the company manager just after the occurrence (40 % and 60 %) and confirmed by the gendarmes who arrived on site are not compatible with the activation logic of an automatic emergency landing.

2.5.4 Motor shut-down in flight

After the drone struck the top of a vertical structure on the left side of the stage, the cameraman asked the drone pilot to shut down the motors. The latter then pushed the two joysticks of his remote controller as shown below:

According to the user manual, this action corresponds to starting the motors. The motors were not therefore shut down.

To shut down the motors in flight, the drone pilot had two possibilities:

- use his remote controller to carry out the procedure described in the user manual: "*Pull the left stick to the bottom inside corners and press the RTH button at the same time*."
- use his separate control to activate the system associating the power cut-off and twin parachute.

Once the system associating the power cut-off and twin parachute has been activated, it is mandatory to replace it. This system, quite expensive in comparison with the cost of the drone, must always be operational in scenario S-3.

It is not easy to activate this system or carry out an in-flight shut-down of the motors in training as this could result in substantial damage to the drone.

Generally speaking, the left and right joysticks control the path of the drone.

The left joystick is used to manage:

- altitude, joystick from down to up;
- yaw, joystick from left to right.

The right joystick is used to move the drone:

- forward, joystick up;
- back, joystick down;
- to the left, joystick to left;
- to the right, joystick to right.

If the drone was controllable, the drone pilot's action to cut off the motors would have resulted in:

- making the drone descend;
- the drone yawing to the right (clockwise direction);
- making it back up leftwards.

2.6 Tests and research

2.6.1 Flight data

The drone, in its internal memory, and the DJI GO 4 application record the flight parameters in a "log" format. In particular, this permits the behaviour of the drone to be studied in case of a malfunction.

Logs are systematically created for each flight. The data recorded includes:

- drone's path (data based on built-in GPS computer);
- height;
- distance with drone pilot;
- horizontal and vertical speeds;
- state of battery: charge percentage, overall voltage, voltage of each battery cell;
- alerts;
- drone pilot's inputs on the two joysticks of his remote controller.

For the occurrence flight, logs would normally have been created on:

- DJI GO 4 application on the drone pilot's tablet;
- DJI GO 4 application on the cameraman's mobile phone;
- drone's internal memory.

It was not possible to recover any of these logs:

- the drone pilot explained that he had not managed to recover the logs and that following this failure, he formatted his tablet;
- the cameraman indicated that he did not have them on his mobile phone;
- the oldest data on the drone's internal memory went back to 19 July 2019, i.e. five days after the occurrence. The drone records the flight logs in a cycle, by writing over the oldest ones.

2.6.2 Flights carried out by the BEA

The BEA carried out two flights.

- the first one was carried out with the participation of DJI and with an Inspire 2 drone equipped with the two batteries used during the occurrence flight;
- the second one was carried out with the drone of the occurrence flight and its batteries.

No anomaly was observed during the two tests. The landings were carried out when the two batteries indicated 0 % on the DJI GO 4. The two test flights could have lasted longer. Furthermore, no battery failure alert was received.

The flight logs were correctly created and were analysed.

2.7 Protection of third parties on ground

2.7.1 Final path of drone

A festival-goer described the final path into the public. He was situated at the front of the audience, between the middle of the stage and the left giant screen. The safety barriers preventing access to the stage were one metre in front of him.

He explained that the aircraft seemed to be in perfect working order and that its four propellers were turning. The drone first struck the head of a festival-goer situated near him, without injuring him.

The aircraft then collided with another person, inflicting cuts to the face and a thigh. The drone then remained in flight, level with the heads of those in the audience. A festival-goer who had his arms in the air was struck and suffered cuts to his two forearms. Another festival-goer then kicked the drone to the ground with his foot. He brought the flight to an end but suffered cuts to his foot.

All of the injuries were linked to the rotation of the propellers.

2.7.2 Regulatory framework

[(10)] See para. 2.2

The order of 17 December 2015[(10)] applicable at the time of the occurrence specified the following points:

2.7. Specific conditions for untethered aerodynes weighing more than 2 kg used in the scope of scenario S3.

2.7.1. Untethered aerodynes weighing more than 2 kg used in the scope of scenario S3 must be equipped with a third-party protection system.

2.7.2. The third-party protection system is automatically activated in the event of an automatic landing following a loss of the command and control link in accordance with paragraph 2.5.1.d) unless this automatic landing can be programmed so as to ensure that no third parties are in the landing area.

2.7.3. In addition, for aerodynes weighing more than 4 kg:

a) The drone pilot has information about the ground speed of the aircraft.
b) In addition to the conditions defined in paragraph 2.2.5, the third-party protection system meets the following additional conditions:

- ❒ the activation of the system causes the motors to shut down;
- ❒ the control link of the system is independent from the aircraft's main command and control link;
- ❒ the electrical power supplies of the system and its remote control are independent from the aircraft's main power supplies and its command and control system;
- ❒ the system indicates the fall of the aircraft by an audio warning;
- ❒ if the system is composed of a parachute, it must include an active ejection or extraction system not solely based on gravity;
- ❒ the correct operation of the system activation mechanism can be checked on the ground by the drone pilot, before the flight.

The French scenario S-3 which was used for the occurrence flight is the operational equivalent of the European scenario STS-01 in the "specific category" grouping the moderate-risk operations (see § 2.2).

To carry out a flight under scenario STS-01, the drone shall belong to class C5 and bear this marking. The conditions for obtaining this marking are described in regulation (EU) 2019/945 (consolidated by regulation (EU) 2020/1058) which sets out the design and manufacturing requirements of UAS[11] intended to be operated in the European airspace.

[11] Unmanned Aircraft Systems (UA designating a drone here).

For class C5, the regulatory requirements (part 16 of consolidated regulation (EU) 2019/945) indicate that untethered UAS must provide a means to terminate the flight remotely. This means must:

> "*a) be reliable, predictable and independent from the automatic flight control and guidance system; this applies also to the activation of this means;*
> *b) force the descent of the UA and prevent its powered horizontal displacement; and*
> *c) [...] reduce the effect of the UA impact dynamics.*"

This means must limit as much as possible the consequence of an in-flight emergency stop.

For classes C3, C4[12] and C5, there is no design constraint concerning the propellers.

[12] Classes C3 and C4 are composed of drones with a maximum take-off weight of between 4 and 25 kg and which can be operated in the "*open category*" (which groups low-risk operations).

3 - CONCLUSIONS

The conclusions are solely based on the information which came to the knowledge of the BEA during the investigation. They are not intended to apportion blame or liability.

Scenario

The company had received the prefectural authorization to film at night, with a drone, a music festival gathering several thousand people. This authorization was accompanied by a requirement to comply with a third-party exclusion zone of a radius of 30 m. Once at the festival, the drone pilot and the cameraman decided to carry out the occurrence flight from an undeclared site.

The drone had flown back and forward between the take-off site and overhead the stage. On the video taken by the drone's gimbal camera, third parties can be seen at a horizontal distance of less than 10 m from the aircraft manoeuvring zone.

The drone pilot and the cameraman explained that a problem on one of the two batteries had resulted in a loss of control just before the collision with a vertical structure on the stage. None of the examinations carried out on the drone and its batteries were able to reproduce the failure described.

The battery charge values read after the flight were not compatible with the activation logic of an automatic emergency landing.

As the flight logs were no longer present on the drone, on the drone pilot's tablet and on the cameraman's telephone, the BEA was not in a position to obtain additional information about a possible battery failure.

After the drone had struck the vertical structure, the drone pilot tried to shut down the motors in flight. However, the action on the remote controller was not the right one and the motors were not stopped. Assuming that the drone was still controllable, the action could explain the beginning of the drone's path after its collision with the vertical structure.

Contributing factors

The following factors may have contributed to the drone's path coming to an end in the audience and the drone coming into contact with third parties:

- Carrying out a flight over an unspecified zone.
- The decision to carry out a flight which did not comply with the third-party exclusion zone imposed.
- The drone pilot carrying out an unfitting procedure to bring the drone's flight to an end: the drone pilot used an inappropriate procedure to shut down the motors in flight and did not activate the system associating the power cut-off and twin parachute.

The following factors may have contributed to the seriousness of the injuries inflicted on the festival-goers:

- The absence of protection around the propellers. No protection of this type is imposed by either French or European regulations.

Safety lessons

Compliance with third-party exclusion zone

Drone flights above urban areas or close to crowds is possible with scenario S-3. Compliance with the third-party exclusion zone ensures a minimum distance between the drone and third parties in order to limit the consequences of a loss of control, which may occur following a technical failure or a handling error by the drone pilot.

Emergency procedures to avoid injuries to third parties

The activation of the system associating the power cut-off and parachute, or the in-flight shut-down of the motors cannot be carried out in training as this could result in substantial damage to the drone.

Nevertheless, knowledge of and the review of the associated procedures would facilitate the above in an operational context during which decision making is more difficult.

Compliance with emergency procedures and with the third-party exclusion zone constitutes the main safety barriers with respect to third parties. It is thus essential that these two measures are strictly implemented.

Preservation of evidence

After the occurrence, the company manager recovered the drone and returned to his place of residence the same morning. The logs recorded by the drone and the DJI GO 4 application were deleted. In the absence of this data, it was not possible to understand the exact circumstance of the occurrence and to determine if the drone had experienced a failure. The safety lessons which might have been of benefit to drone operators were thus limited.

Protection of propellers

When the drone's path came to an end in the audience, several festival-goers were injured by the propellers. The installation of protections around these propellers would have limited, indeed prevented these injuries. DJI proposes a retail solution for the Inspire 2 but such devices are rarely installed.

To limit the consequences of a collision between a light multicopter drone and a person, the development of systems limiting cuts should be encouraged.

In this respect, a physical protection around the blades could be generalized.