Simulator modeling of incidents related to emergency cargo release from the Mi-171 rotorcraft external cargo sling

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Abstract

According to the authors, the situations related to the rotorcraft externally slung cargo release have not been thoroughly investigated and described in scientific publications, and, hence, not reflected in the flight operation regulations.

The present Article contains the results of simulator modeled experimental studies of a special situation related to the emergency cargo release from the Mi-171 rotorcraft external sling due to the engine failure, in particular:

- engine failure during vertical cargo lift;
- engine failure during rotorcraft level acceleration.

Based on the objective data, namely records of phase coordinates of the “rotorcraft-cargo” system and pilot’s activities, the modeling results are analyzed.

The flight danger zones have been assessed in the coordinates “altitude-velocity” for the take-off for a rotorcraft with the maximum allowed takeoff mass and the externally slung cargo. The “safety” take-off profile for the rotorcraft with a cargo on the sling has been proposed.

Introduction

The Mi-8 family helicopters constitute the most wide-spread type of the medium class transport rotorcraft in the World with its various modifications operated presently in more than 50 countries.

One of the most distinctive features of these helicopters is a capability to transport bulky cargoes up to 4 thousand kg on the external sling (ES).

However, transporting cargoes on the sling is known to have a number of peculiarities that make piloting a rotorcraft more complicated, which requires specific training of flight crews.

When flying a rotorcraft with an externally slung cargo some specific situations may occur during which the crew incorrect actions may lead to catastrophic consequences. The flight operation manuals for the Mi-8 type rotorcraft specify the situations requiring the emergency release of the externally slung cargo (Refer to Fig. 1).

However, the authors believe that incidents related to cargo emergency release from the rotorcraft external sling have not been duly investigated and described in scientific publications, and, hence, not reflected in the flight operation regulations.

Evidently the reason for it, on one hand, is impossibility to conduct analytic studies of the complex ergatic system “pilot – rotorcraft – cargo on the sling”, and on the other hand – the danger of quite expensive flight tests. (Precisely due to the unique feature of such studies, worth mentioning is the experimental flight research conducted by PANH Helicopters (city of Krasnodar) in 2003 related to estimation of maximum permissible technical performances of the Mi-8 AMT (Mi-8 MTV) rotorcraft with cargo on the sling in case of one engine failure [2,3]).

Unlike the aforementioned flight research where under consideration was the possibility to continue the rotorcraft flight and / or to land it with a very important cargo the release of which is out of the question due to some social (people emergency evacuation) or economic reasons (unique expensive equipment) the present publication scrutinizes issues of the rotorcraft safety take-off (with the maximum allowed takeoff mass) with a cargo on the external sling in case of engine failure.

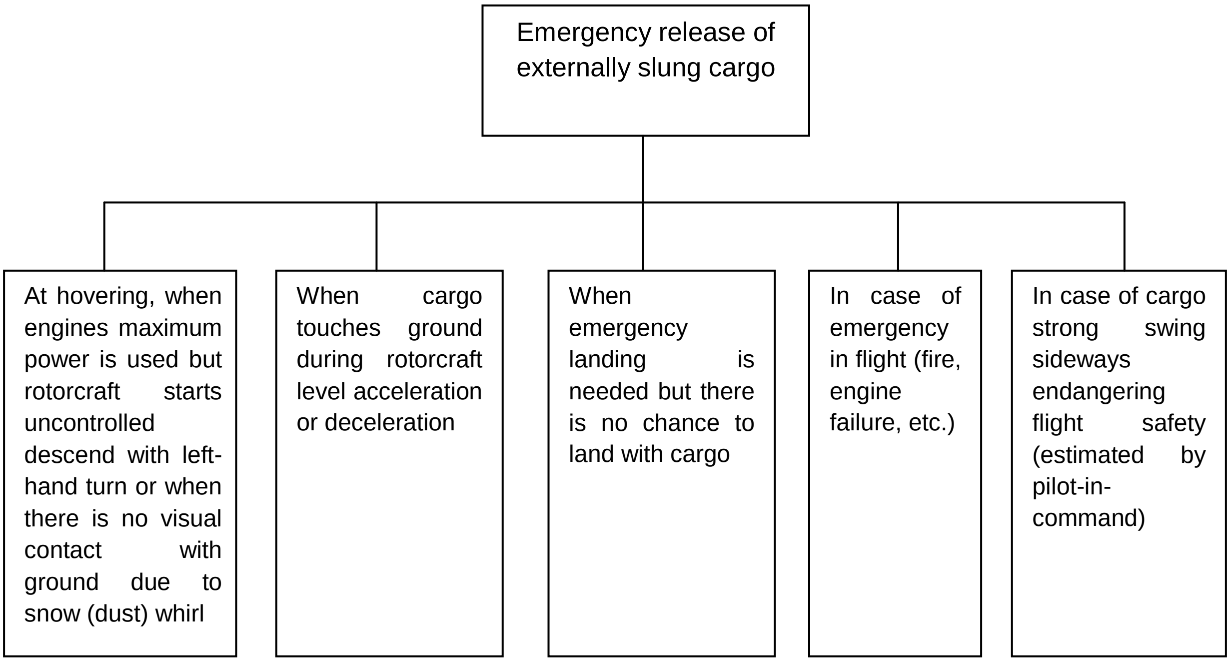

Figure 1 Situations requiring emergency release of cargo on the external sling from rotorcraft [1]

Thus, the present publication is aimed at the following:

- first, to conduct an experimental study of an incident related to the rotorcraft engine failure during take-off with a cargo on the external sling;
- second, to show a possibility of direct modeling of the aforementioned incident at the full mission simulator for the rotorcraft air crew and obtaining objective data of the “pilot – rotorcraft – cargo on the sling” system functioning during this emergency situation;
- third, to work out methodical issues of modeling the incident under consideration on the simulator in order to compose in the future “The training program (on the simulator) for the air crews to act during an incident related to the engine failure in flight with cargo on the external sling”.

1. Description of experimental studies

The experimental studies the results of which are presented in this publication, have been carried out on the full mission simulators for the Mi-171 rotorcraft air crew in the CSTS Dinamika (town of Zhukovsky, Moscow region) and in the Aviation training center of the FSUE “Avialesookhrana” (town of Pushkino, Moscow region).

1.1 The Mi-171 rotorcraft full mission simulators for air crew

The Mi-171 rotorcraft air crew full mission simulator comprises the following main parts:

- rotorcraft cockpit and cargo cabin mockup (Fig. 2,3);
- integrated computer system;
- ambient visual conditions emulation system for pilots (Fig. 4);
- ambient conditions emulation system for external sling operator (Fig. 5,6);
- operation station for instructor – head of training.

The nose part of the Mi-8MTV rotorcraft airframe (refer to Fig. 2) is used for the cockpit and cargo cabin mockup. The pilots’ cockpit mockup is equipped with two operator seats for the pilot and copilot. The instrumentation equipment is adapted to interact with the simulator computer system. Controls of main rotor cyclic and collective pitch and pedals are the actual control mechanisms of the Mi-8MTV rotorcraft. The cockpit mockup inside is completely identical to that of the rotorcraft cockpit (refer to Fig. 4).

These simulators feature an additional option that allows modeling the flight of a rotorcraft with a cargo on the external sling [4] and its use for extinguishing wildfires with helibuckets on the external sling [5,6]. Unfortunately, these simulators are fixed base simulators which decreases the adequacy of pilot’s feeling of the “flight” in certain important flight modes, for instance hovering, [7], but, nevertheless, allows to train the air crew actions without acquiring false skills.

Figure 2 Pilots’ cockpit and cargo cabin

Figure 3 Pilots’ cockpit inside

The digital computer system is based on the IBM-compatible personal computers integrated into a local computer network by means of high-speed network interface cards.

Communications of the cockpit analogue equipment and computer system is implemented by means of a special-purpose matcher of the equipment interface unit.

The ambient visual conditions emulation system for pilots is a six-channel projection and screen system with a spherical screen and 220º horizontal and 70º vertical look-up angles. The ambient conditions image generation system has a 1600x1200 pixel resolution and image frequency of not less than 50 Hz (refer to Fig. 4).

Figure 4 Ambient visual conditions emulation system

The development of the ambient visual conditions emulation system for the external sling operator faced certain difficulties as his position is inside the cargo cabin and the ambient situation is observed both from the cargo hatch opening and from the cargo cabin side door; and the look-up angles have to match the real values. As a result the following solution has been found and implemented: the external sling operator watches the ambient space via virtual reality goggles (an imitation of protective goggles used in actual flight) with look-up angles ~32ºx24º in the glance direction, which is defined by means of the UM-16 ultrasonic tracker system [8]. A transmitter unit is mounted on the operator's crash helmet and receivers are fixed inside the cargo cabin. Processed data of the distance from the transmitter unit to the selected group of receivers will allow obtaining values of both the operator's head position and orientation in space inside the cargo cabin (refer to Fig. 5,6).

The operation station for instructor – head of training is a console with three (3) monitors, keyboard, communications headset that allows him to control the training process as follows:

- to monitor trainees actions by watching TV images from the cameras installed in the simulator cockpit and cabin;
- to monitor the rotorcraft flight both from aside and from the pilot's seat;
- to introduce operational changes into the training session scenario, including failures of rotorcraft systems adverse weather conditions, etc.;
- to perform voice communication with trainees in the simulator cockpit and cabin.

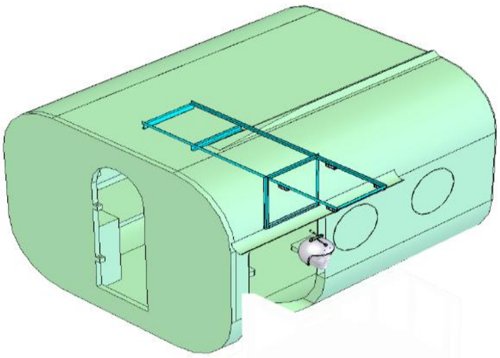

Figure 5 The UM-16 ultrasonic tracker system

Figure 6 The emulation system for the external sling operator

1.2 Rotorcraft cargo on the external sling

A standard 20-foot shipping container with dimensions height x width x length: 2350 x 2330 x 5867 mm and full weight $m_{cont} = 3200\,kg$ (Fig. 7) is considered a typical cargo.

In order to determine aerodynamic forces and aerodynamic moment couples affecting the container, the values of experimental studies on airflows around different bodies were used [9, 10]. The resulting approximation dependencies have been obtained which allows estimating the forces and moment couples influencing the parallelepiped formed body depending on its geometry parameters and space orientation with respect to the incoming windstream velocity vector.

Figure 7 Standard 20-foot shipping container

The container is fixed to the external sling upper lock by means of a 20-meter flexible steel rope and four 5-meter hoisting slings.

1.3. Methods of conduct of experiments

In order to enhance the engine failure effect while staying within the operational limits stated in the Flight Operations Manuals, the loaded rotorcraft takeoff weight was taken as $m = 10100\,kg$, and the ambient air temperature $t = 30^{\circ}\,C$

Figure 8 features a typical trajectory of the rotorcraft take-off with an externally slung cargo recommended by the Flight Operations Manuals.

The most critical to the engine failure part of the take-off trajectory (after the cargo is attached) consists of two sections, namely the cargo vertical lift and rotorcraft level acceleration to the velocity of 60-70 km/h with a subsequent climb and lasts for about 40 seconds. Exactly within this time interval (after the cargo is lifted from the ground) the instructor would issue a command to act during one engine failure. The moment to issue the command was accidental with an even distribution.

In accordance with the Flight Operations Manual requirements, when such an emergency situation occurs, the pilot is to release the cargo from the sling by pressing the Emergency Release button on the Collective pitch lever and to land the rotorcraft with one engine running.

The mission was considered failed if:

- the landing was rough which means that prescribed limits on maximum vertical descend speed and rotorcraft overloads during landing were acceded $V_y \le V_y^{max}, n_y \le n_y^{max}$
- the cargo touched the ground before the moment of its detaching.

In order to mobilize the pilot’s actions in the modeled emergency situation, a delay was used from the moment of pressing the Emergency Release button to the external sling unlock ВП $\tau_0 \approx 2.5\sec$.

In process of experimental studies the pilot had to accomplish the following tasks:

- to lift the rotorcraft off, to approach a container located nearby and, following the on-board operator's commands, to hover over it at an altitude that would ensure the cargo attaching;
- after the cargo is securely attached to lift it off the ground and to perform a vertical lift to the altitude prescribed by the experiment conditions H_{hl} (with the prescribed parameters of the external sling and container dimensions the cargo had to be lifted off the ground at the altitude $H = H_{lift} \approx 29.3\,m$);
- to perform the level acceleration to the speed of 60-70 km/h with a subsequent climb;
- in case of the emergency situation "engine failure", to act according to the Flight Operations Manual.

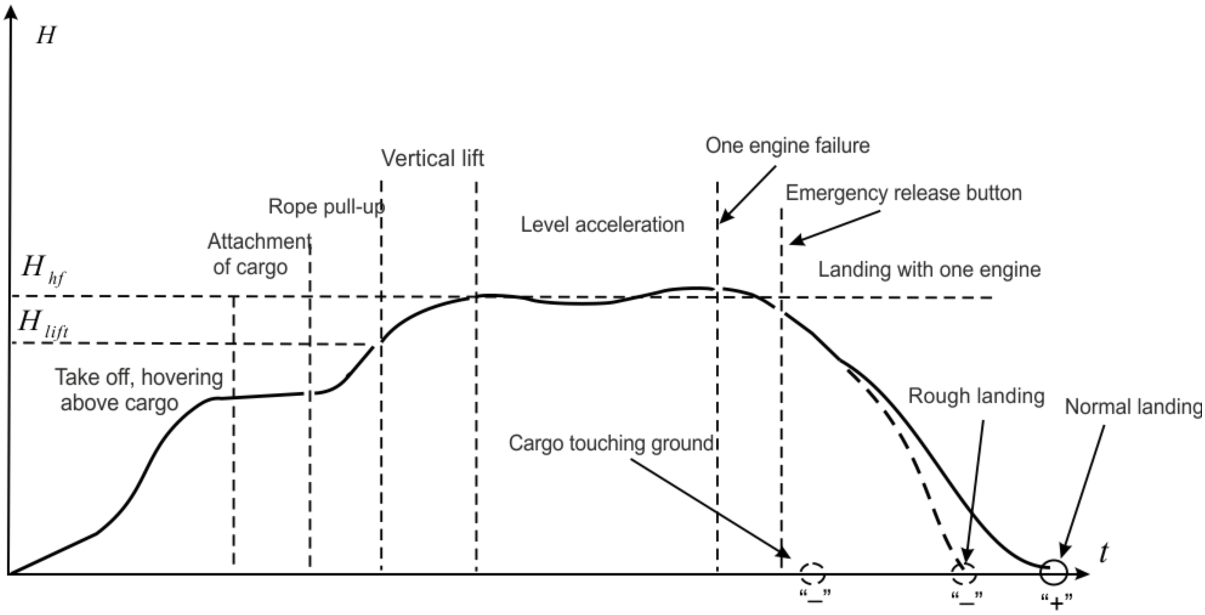

Figure 8 Trajectory of the rotorcraft take-off with an externally slung cargo

2. Results of experimental studies

Three series of 20 flights each have been carried out with altitudes ($H_{hl} = 30, 35, 40\,m$). The results are shown in Table 1 and Fig. 9-11.

The results of the 1-st series of flights (refer to Fig. 9) are quite evident: in case of the engine failure at the vertical flight portion or at the start of level acceleration ($V \le 30\,km/h$) – zone "A "- the rotorcraft performs a rough landing.

The engine failures at the level acceleration portion – zone "B" – generally ended with the cargo touching the ground.

The average time of pilot's response to the engine failure (up to pressing the Emergency Release button) is $\tau_p \approx 0.4\,sec$. Lets note, that accomplishment of the task required from a skilled pilot (total amount of flight hours is more than 4000) considerable efforts and concentration; it is not expedient to conduct more than 20 "flights" on the simulator at a time.

The 2-nd series of flights (refer to Fig. 10) are also characterized by distinctive zones "A "and "B", but there comes an area of the flight modes – zone "C", where the engine failure did not lead to an emergency (successful landings – about 30%). One can see that during all successful flights there was an altitude reserve of $\Delta H \approx 2\text{-}3\,m$.

In the 3-rd series of flights (refer to Fig. 11) the engine failures at the level acceleration portion were successfully managed by the pilot: the cargo was released from the sling, the rotorcraft landed successfully with one engine running (zone "C" – 70%). Engine failures at the vertical lift portion ended with rough landing (zone "B" - 30%).

Summing up the results gained (refer to Fig. 12) one may formulate certain recommendations concerning the structure of a "safety" trajectory of the rotorcraft take-off with an externally slung cargo. While lifting the cargo, the rotorcraft is within the flight mode zone which is recommended to be avoided if possible by the Flight Operations Manuals (red lines refer to Fig. 12). Thus, most probably, it is expedient to move the rotorcraft into zone "C" as soon as possible, which minimizes chances of the engine failure in zone "A".

Table 1

H_{hl}, m	Arithmetic average $\hat{H}_{hl}$, m	Results			Total
		Done	Rough landing	Cargo touching	
30	32.8	3	7	10	20
35	33.5	6	8	6	20
40	39.5	13	7	-	20

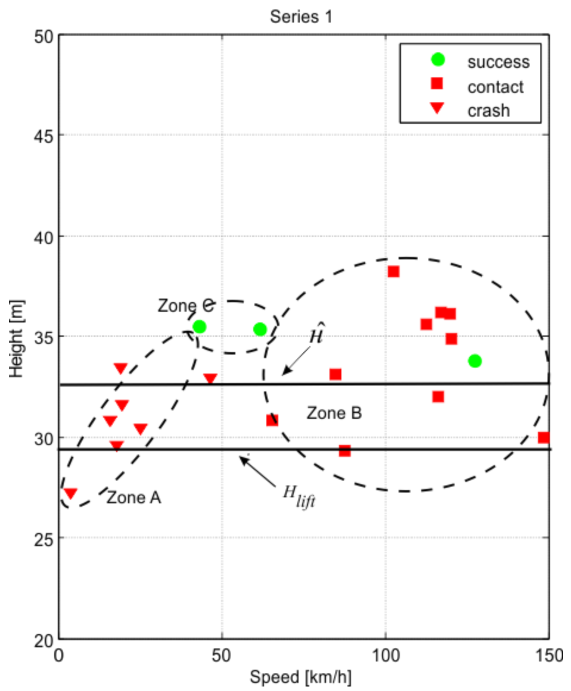

Figure 9 Series 1 - $H_{hl} = 30\,m$

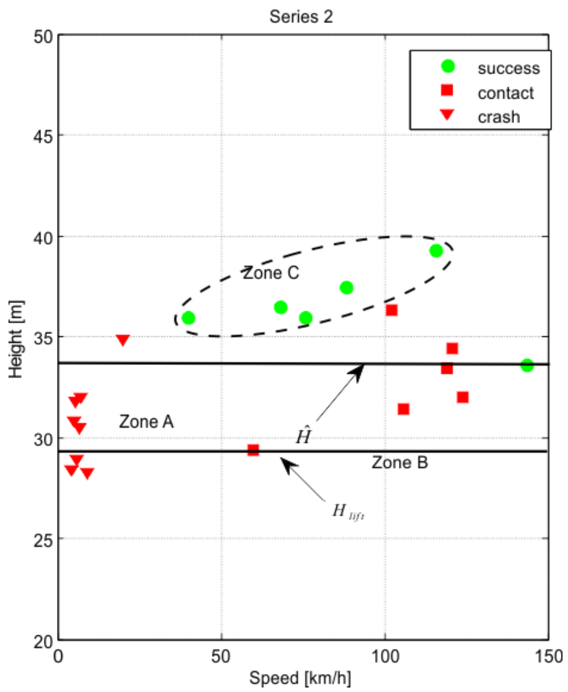

Figure 10 Series 2 - $H_{hl} = 35\,m$

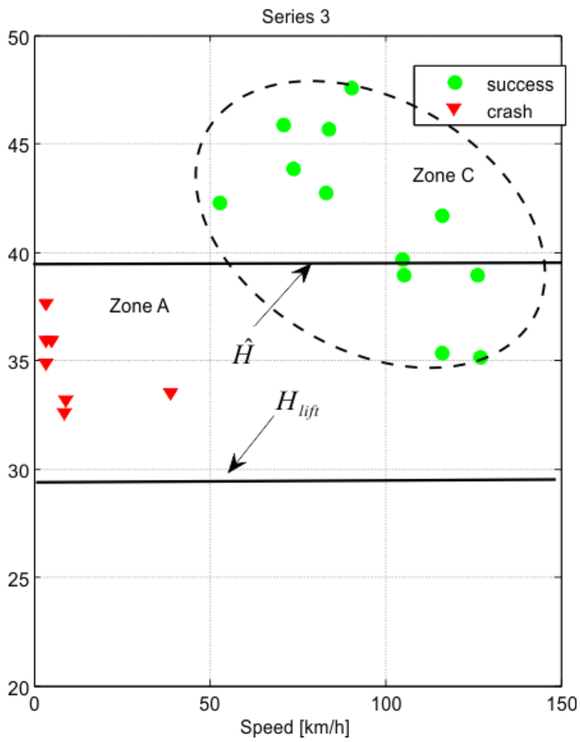

Figure11 Series 3 - $H_{hl} = 40\ m$

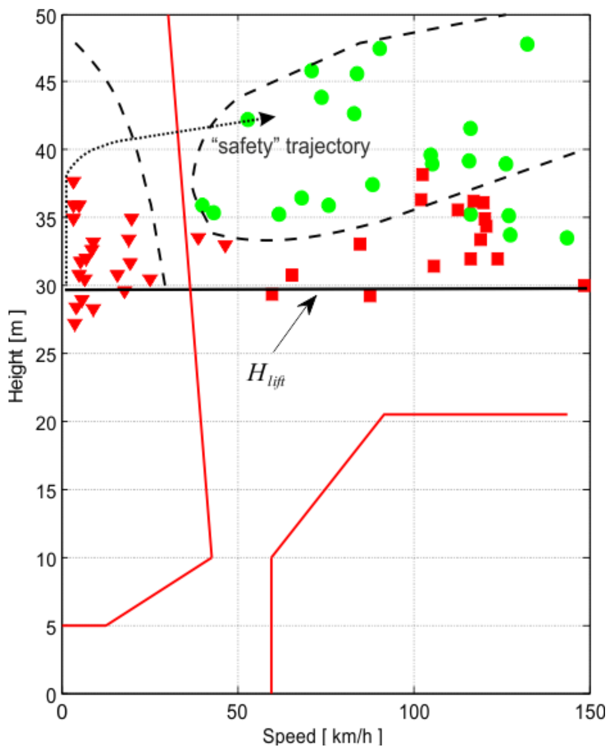

Figure12 "Safety trajectory"

Then, the nominal trajectory of the rotorcraft take-off with an externally slung cargo can be as follows:

- cargo vertical lift with a maximum allowed speed (taking into account the available engine power) to an altitude of 7-10 meters above the ground;
- change to a horizontal flight increasing speed to 50-60 km/h;
- further acceleration with climbing.

Of course, the results presented in the given publication, are estimation and require further clarification, but, considering that the experiments were aimed at modeling critical operational limitations, they can be used as starting point for the future research.

In the end it is worth mentioning that the experimental studies conducted on the simulator clearly confirm the expediency to use up-to-date full mission simulators not only as training facilities but also to carry out applied research and development studies.

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