UDC 629.7.015
DOI: 10.26467/2079-0619-2019-22-4-91-99

RECKONING TECHNIQUE OF PASSENGER AIRPLANE APPROACH PROCEDURE IN CASE OF ALL MAIN ENGINES FAILURE

M.A. KISELEV[1], S.V. LEVITSKY[2], V.A. PODOBEDOV[2]
[1]Moscow State Technical University of Civil Aviation, Moscow, Russia
[2] JSC Irkut Corporation, Moscow, Russia

Cases of failure (shutdown) of all the main engines of a multi-engine powerplant in flight, unfortunately, occur both in Russia and abroad. The causes of such situations may be, for example, a flying in volcanic ash cloud, as in the case of the incident with Boeing 747 over the island of Java in 1982, or the cessation of fuel supply, as in the cases of an emergency landing of Boeing 767-233 in 1983 on an unused military airfield Gimlii and Tupolev-204 in Omsk in 2002. At the same time, in the management documentation, the crew's actions for this case are either not prescribed at all, or spelt out so concisely that they do not imply a specific list of actions, or, in other words, they require the crew to search for the necessary aircraft control actions within the circumstances of time shortage and increased stress levels. The proposed article reveals the content of the methodology that provides for the withdrawal of an aircraft with an inoperative power plant in a safe landing environment at every airfield with an outer marker. A distinctive feature of the considered approach is the absence of the need to bind the parameters of aircraft movement to explicitly stated landmarks. In addition, this approach is simple to implement and at the present stage of development of automatic control systems may well be implemented on board an aircraft in an automatic or director mode. The minimum information required for the calculation of the landing approach is limited to three parameters: the minimum drag airspeed in the landing configuration, the height of the flight over an outer marker before the landing and the height loss on turn spiral on the pre-landing manoeuvre. The content of the method in the article is illustrated by the results of the calculation of landing in case of failure of both engines of the power plant for the prospective domestic short-medium-range aircraft MS-21.

Key words: flight dynamics, aircraft engines failure, modeling, piloting, special case in flight.

INTRODUCTION

The powerplant of most passenger aircraft comprises two main engines, as a rule they are bypass turbojets or turboprops. The actions of the flight deck crew in case of one engine failure at different stages of flight and within different operating conditions are prescribed by the actual circulars and governing documents[1] and have been subjected to a detailed research in a great number of papers [1–6]. The multiple engine failure is considered to be of minimum likelihood. However, the history of aviation spells the intimidating degree of even the least likely incidents occurrence. What are the crew members supposed to do in such a situation? The AFM (Aircraft Flight Manual) instructions for multiple engine failure state:

1) Adjust speed to provide the maximum gliding distance in accordance with the aircraft aerodynamic configuration

2) Proceed using the algorithm of altitude adjustment depending on the distance to the aerodrome chosen for the landing (the method of fixes/checkpoints)

However, the AFM does not mention the ways of this particular algorithm implementation, and the success of the flight in this case depends on the captain's intuition, skills and, to a great extent, on his bare luck.

[1] Aviatsionnyye pravila. Ch. 25. Normy letnoy godnosti grazhdanskikh samoletov trasportnoy kategorii [Aviation Rules. Part 25. Civil airworthiness requirements for transport category airplanes]. (2013). Mezhgosudarstvennyy aviatsionnyy komitet [Interstate Aviation Committee]. Moscow: Aviaizdat, 266 p. (in Russian)

RESERCH METODS AND METODOLOGY

In military aviation, where a considerable number of combat aircraft are equipped with a single-engine powerplant, the problem of engine failure landing was solved in the eighties of the twentieth century. The team of researchers from the Flight Dynamics Laboratory of Zhukovski Aviation Academy led by Professor Radchenko M. I. developed the reference height method for single engine combat aircraft. The method is listed in the AFMs of a number of military single engine aircraft.

The main feature of the method (reference height method) is that it does not require the knowledge of landmarks or ground fixes and allows to land the airplane at the nearest airport available considering it has the locator outer marker. In other words, the reference height method allows to reckon approach and land the aircraft with the multiple engine failure having no visible landmarks in sight.

The essence of the method is as follows (Figure 1).

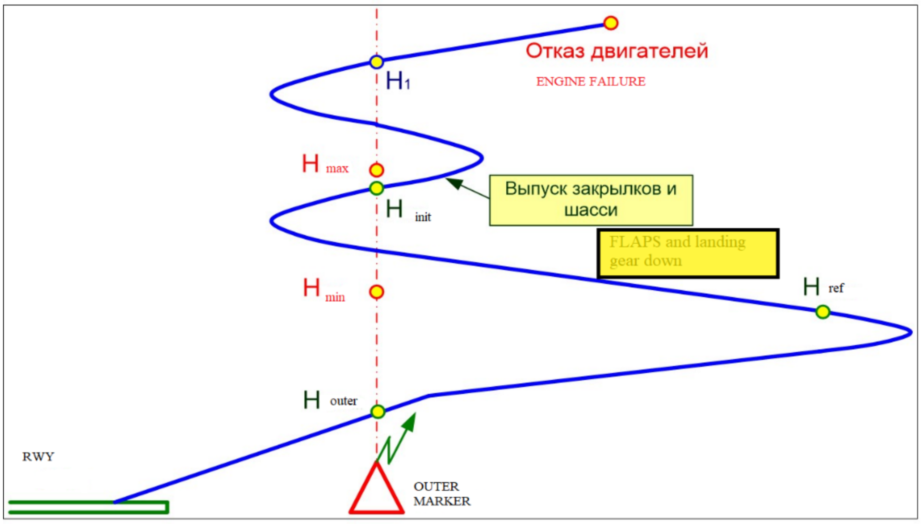

Fig. 1. Approach procedure according to the reference height method

In case of the powerplant failure the pilot adjusts the aircraft speed as the most favourable for this particular type, turns and banks the aircraft at 30º towards the outer marker in order to pass it with the course closer to the runway heading – Ψland.

When passing the outer marker, the pilot makes a fix of the initial height (H_{init}) and makes a 180º turn from the landing course and then makes a straight-in descent to reach the reference height (H_{ref}).

Upon reaching the reference height the aircraft turns final and makes a runway alignment to reach the best height over the outer marker (H_{outer}).

The minimum safe height for this approach procedure is determined by the height loss on turn spiral within the landing configuration. The initial height over the outer marker must not be below H_{min}, which is calculated as

$$H_{min} = H_{outer} + H_{sp}$$

Where H_{outer} is the height the aircraft must have over the outer marker on final to touchdown at the given point of the runway, H_{sp} is the height loss on turn spiral with the 30º bank angle at given speed.

The reference height approach method is possible from any height $H > H_{min.}$ However, the more H_{init} is, the farther is the distance of the point of H_{ref} from the airdrome. At the same time, the longer is the approach trajectory, the more is the difference in the radius and the height loss at turning downwind and crosswind, the reckoning fault level increases, the wind influence becomes more significant, and, accordingly, the approach precision decreases. Thus, there is an optimum range of heights, the initial landing maneuver height must fit into – $H_{init.}$ The top of this range is limited by H_{max}, which is calculated as

$$H_{max} = H_{min} + H_{sp}.$$

If the height during the first entry onto the outer marker is substantially above that of H_{max}, then immediately after passing the outer marker the pilot should turn spiral with the bank angle of 30º at the given speed. After the spiral turn the height over the marker must be reviewed, and in case if fits the range of H_{min} and H_{max}, the landing maneuver may be executed. The landing configuration must be obtained before entering the outer marker.

Thus, to make a multiple engine failure landing, the pilot must follow the procedure sequence

1) At the moment of passing the outer marker remember the Hinit and enter the 180º turn from the RWY heading with $\gamma = 30º$ at the given speed;

2) While performing a 180º turn calculate the reference height using the formula $H_{ref} = 0.5\,(H_{init} + H_{outer})$;

3) Having finished the 180º turn, glide with the course opposite to the RWY heading to reach H_{ref};

4) Having reached H_{ref}, turn base and final for RWY alignment.

The diagram of multiple engine failure approach is shown in Figure 2.

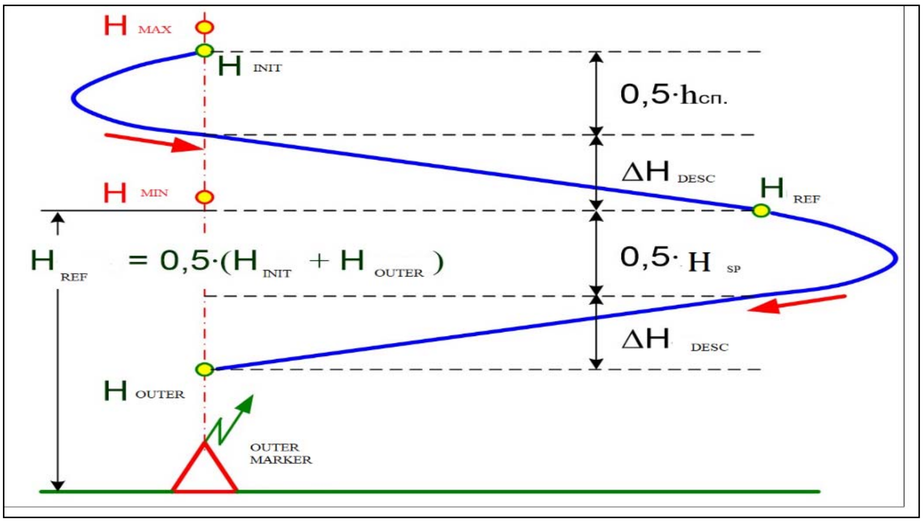

Fig. 2. Approach manoeuvre

The maneuver comprises four legs:

– Turn Ψ_{land}+ 180º with height loss equal to 0.5 H_{sp}
– Straight-in descent to the height ΔH_{desc} till reaching H_{ref}
– Turn Ψ_{land} with height loss equal to 0.5 H_{sp}
– Straight-in descent to the height ΔH_{desc} till reaching H_{outer}

When approaching from the minimum height the straight-in descent leg is absent ($\Delta H_{desc} = 0$).

RESEARCH RESULTS

Let us illustrate the application of the method using, for instance, the multiple engine failure landing approach procedure of the prospect Russian short/medium range airplane MS-21.

It is obvious, that to calculate H_{min} it is reasonable to choose the aircraft landing configuration with minimum flap angle (δ_f = 10º, landing gear down (GD)) as it will provide the best aerodynamic performance for HLD extended, and, as follows, the longer gliding distance. The optimum speed for the spiral in this case will be V_{ind} = 260…265 km/h, the climb angle will be $\theta_{desc} = -6.5...-7^o$ and the sink rate $V_{y\,desc} = -8...-9$ m/sec. The height loss on turn spiral will be H_{sp} = 700 m and the bank angle during 180º turn will be 2000 m. Accordingly, the minimum height for multiple engine failure landing of MS-21 will be $H_{min} \approx 1200$ m. Having made a spiral turn from $H_{min,}$ the aircraft will be over the outer marker at approximately 500 m, which is good enough for a successful landing. The projection of the spiral path on the vertical and horizontal planes is shown in Figures 3 and 4.

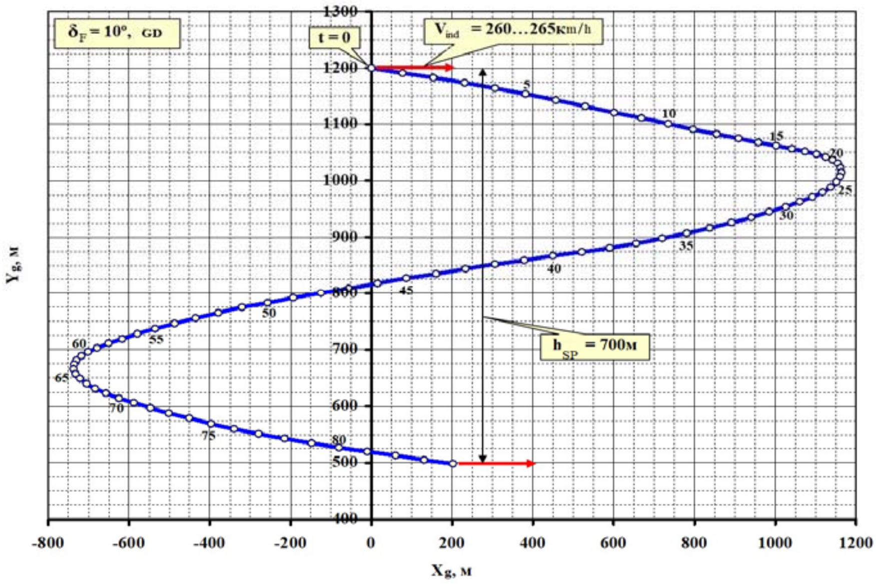

Fig. 3. The projection of the spiral path on the vertical plane Y_gOX_g

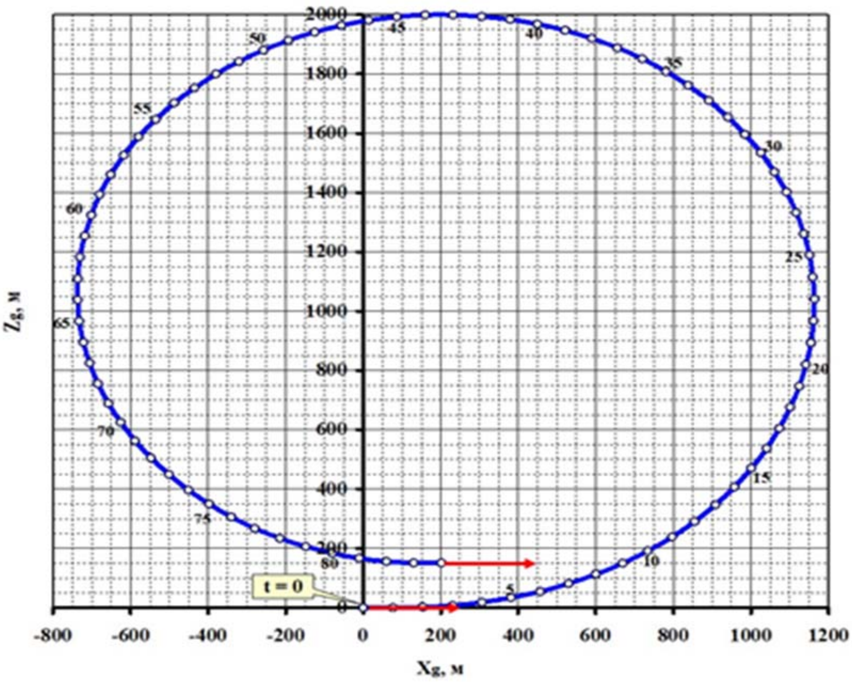

Fig. 4. The projection of the spiral trajectory on the horizontal plane Z_gOX_g

Thus, the parameters to be controlled during the multiple engine failure landing for MS-21 within the landing configuration ($\delta_f = 10^o$, GD) are as follows:

– Optimum spiral turn speed $V_{ind} = 260…265$ km/h;
– Height loss during 180º turn $0.5{\cdot}H_{sp} \approx 350$ m
– Minimum height $H_{min} = H_{outer} + 700$ m;
– Maximum height $H_{max} = H_{min} + 700$ m.

It is necessary to notice, that in order to compensate the possible errors and the head wind component the minimum height may be increased by 100…200 m.

For the tail wind component or in case the height is exceeded, the trajectory may be amended by means of increasing the flap angle.

The Figures 5, 6 and 7 below show the aircraft travel parameters during the final stage of flight from passing the outer marker to touchdown at three HLD (flap) angle configurations $\delta_f = 10^o$; $\delta_f = 18^o$; $\delta_f = 27^o$.

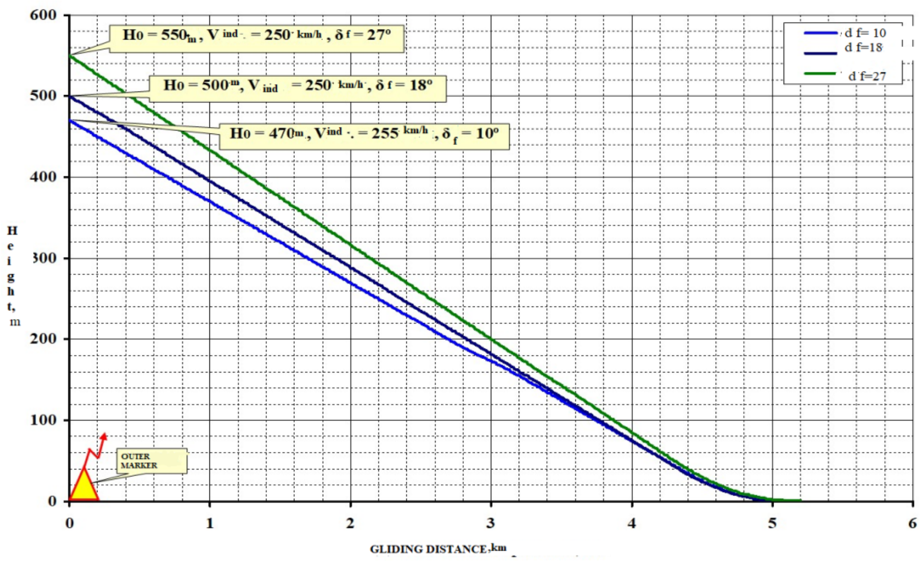

Fig. 5. The change in the height of the pre-landing reduction in distance from the outer marker

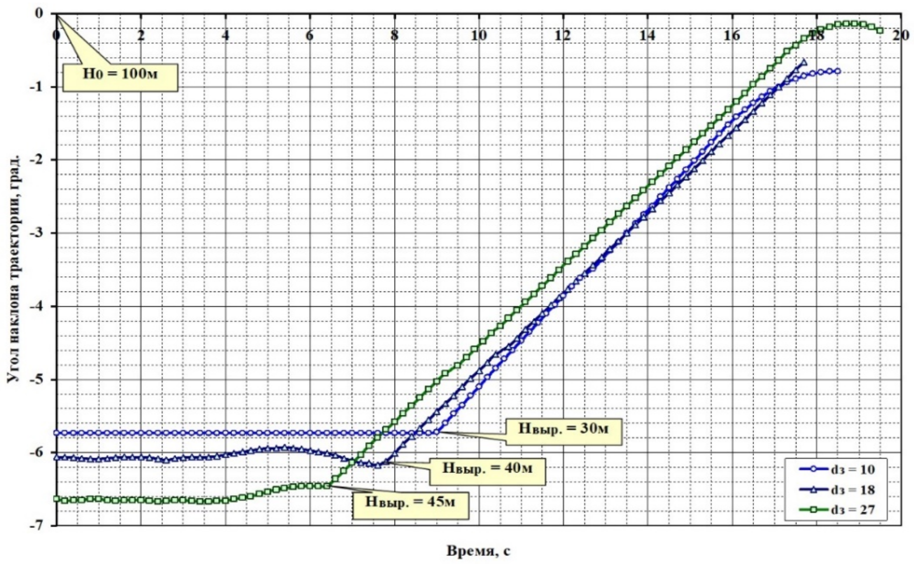

Fig. 6. Climbing angle at the pre-landing descent stage

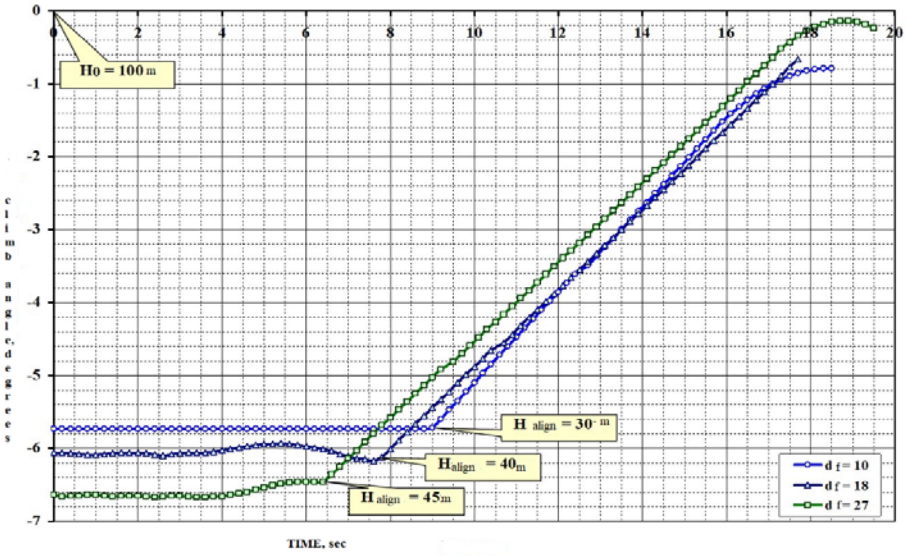

Fig. 7. Descent rate at the pre-landing descent stage

As the results show, the aircraft must have the following parameters of height and equivalent speed to make a safe landing:

– at $\delta_f = 10^o$ – $H_0 = 470$ m, $V_0 = 255$ km/h;
– at $\delta_f = 18^o$ – $H_0 = 500$ m, $V_0 = 250$ km/h;
– at $\delta_f = 27^o$ – $H_0 = 550$ m, $V_0 = 250$ km/h.

The given parameters allow to make a final of 5 km and to start alignment at the height H_{align} = 30…45 m which later result in the following touchdown parameters:

– at $\delta_f = 10^o$ – $\alpha_{touch.} = 11{,}0^o$, $V_{touch.} = 239$ km/h;
– at $\delta_f = 18^o$ – $\alpha_{touch.} = 10{,}8^o$, $V_{touch.} = 233$ km/h;
– at $\delta_f = 27^o$ – $\alpha_{touch} = 10{,}0^o$, $V_{touch} = 218$ km/h.

Normal acceleration is maintained during the alignment procedure $n_{y\ align}$ = 1,06…1,08.

The estimate of MS-21 parameters at engines inoperative was executed using mathematical modeling of aircraft flight dynamics [9].

To check the mathematical model adequacy, the results of spiral turns modeling were compared to the actual flight data. Table 1 shows the comparison results of spiral turns within the cruising configuration at initial altitude of 10 km.

Modes 1 and 2 show the steady-state spirals at "engines at idle" mode. Mode 3 imitates the flight with the engines shut down. Wind milling (autorotation) regime imitation is obtained by means of "engines at idle" mode together with ¼ spoiler extension at travel. Flight mode 3 is compared with spiral turns modeling at engines inoperative. The results of modeling provide a slightly bigger height loss. At the same time, the error rate is within 6%.

Table 1

Parameters of steady-state spirals

№ mode	γ, degrees.	G, thrust specific fuel consumption	$H_{init.}$, ft	$V_{пр.}$, kt	$H_{sp\ flight}$, ft	$H_{sp\ model}$, ft	$\Delta h_{sp.}$, ft	$\Delta h_{sp.}$, m	$\Delta h_{sp.}$, %
1	20	56123	33043	212	9543	9843	+300	+91	3,1
2	30	53893	33022	199	6082	6430	+348	+106	5,7
3	30	53543	32894	205	7193	7536	+343	+104	4,8

Here $h_{sp\ flight}$ – spiral turn height obtained in flight;
$h_{sp\ model}$ – spiral turn height obtained from modeling;
$\Delta h_{sp} = h_{sp\ model} - h_{sp\ flight}$.

The modelling results prove the high degree of wind milling imitation precision by means of combining the "engines at idle" mode together with ¼ spoiler extension at travel. The spiral turn height increase at spoiler extension was 1111 ft (the comparison of flight modes 2 and 3), the increase in spiral turn height at shut down engines was 1106 ft according to the modelling results.

The table shows that the decrease of the bank angle from 30 to 20º increases the radius and the spiral turn height more than 1.5 times. Accordingly, it is recommended to have a bank angle of $\gamma = 30º$ when reckoning a multiple engine failure landing procedure.

THE RESULTS EVALUATION AND CONCLUSION

As the obtained results show, the technique evaluated in the paper allows a simple algorithm of the flight deck crew actions in case of a multiple engine failure that leads to a safe landing at any airfield equipped with an outer marker localizer with no need in explicitly stated visible landmarks. The minimum information required for the calculation of the landing approach is limited to three parameters: the minimum drag airspeed in the landing configuration, the height of the flight over an outer marker before the landing and the height loss on turn spiral on the pre-landing maneuver.

The present-day level of control systems automation [10, 11] allows to delegate the task of reference height method calculation within the automatic or directory flight control modes.

REFERENCES

1. **Kiselevich, V.G., Petrov, Yu.V. and Tsipenko, V.G.** (2015). *Analiz osobennostey letnoy ekspluatatsii samoleta IL-96T na vzlete pri otkaze dvigatelya po rezultatam vychislitelnykh eksperimentov* [Analysis of the characteristics of the flight operation of the Il-96T at take-off in case of an engine failure based on the results of computational experiments]. *XXVI nauchno-tekhnicheskaya konferentsiya po aerodinamike, g. Zhukovskiy, 26–27 fevralya 2015 g.: sb. trudov* [XXVI Scientific and Technical Conference on Aerodynamics], pp. 133–134. (in Russian)

2. **Kiselevich, V.G., Kublanov, M.S., Tsipenko, V.G. and Chernigin, K.O.** (2014). *Razrabotka rekomendatsiy po letnoy ekspluatatsii samoleta IL-96T pri otkaze dvigateley na vzlete* [Development of flight operation recommendations of IL-96T aircraft with engine failure on takeoff]. *Nauchnyy vestnik UVAU GA(I)* [The Scientific Bulletin of the Ulyanovsk Civil Aviation Institute], vol. 6, pp. 17–23. (in Russian)

3. **Kiselevich, V.G., Kublanov, M.S. and Tsipenko, V.G.** (2013). *Modelirovaniye zakhoda na posadku i posadki samoleta IL-76 s razlichnymi posadochnymi massami i pri otkaze dvigateley* [Simulation of landing approach and landing of an IL-76 aircraft with various landing masses and in the case of an engine failure]. The Scientific Bulletin of the Moscow State Technical University of Civil Aviation, no. 188, pp. 7–9. (in Russian)

4. **Kiselevich, V.G.** (2015). The development of flight operation recommendations for IL-96T at interrupted take-off. The Scientific Bulletin of the Moscow State Technical University of Civil Aviation, no. 211, pp. 79–84. (in Russian)

5. **Kiselevich, V.G.** (2015). Reculiarities of IL-96T flight operation at prolonged take-off. The Scientific Bulletin of the Moscow State Technical University of Civil Aviation, no. 211, pp. 128–131. (in Russian)

6. **Tikhonov, D.V. and Tikhonov, V.N.** (2015). Forecast of flight severity situation with an engine failure on the ascending maneuvers based on computational-experimental data and expert

judgment. The Scientific Bulletin of the Moscow State Technical University of Civil Aviation, no. 212, pp. 90–97. (in Russian)

7. Kotel'nikov, G.N., Lysenko, N.M. and Radchenko, M.I. (1989). *Dinamika i bezopasnost poletov* [Dynamics and safety of flights]. Kiev: Vyshcha shkola, 332 p. (in Russian)

8. *Aerodinamika i dinamika poleta manevrennykh samoletov* [Aerodynamics and flight dynamics of a maneuverable aircraft]. (1984). Ed. N.M. Lysenko. Moscow: Voyenizdat, 541 p. (in Russian)

9. Levitskiy, S.V. and Sviridov, N.A. (2008). *Dinamika poleta* [Flight dynamics]. Moscow: VVIA im. prof. N.Ye. Zhukovskogo, 527 p. (in Russian)

10. Aloshin, B.S., Bazhenov, S.G., Didenko, Yu.I. and Shelyukhin, Yu.F. (2013). *Sistemy distantsionnogo upravleniya magistralnykh samoletov* [Remote control systems for long-haul aircraft]. Moscow: Nauka, 292 p. (in Russian)

11. Kiselev, M.A. (2007). *An algorithm of an aircraft turn executed with maximum angular velocity*. Journal of Computer and Systems Sciences International, vol. 46, no. 5, pp. 815–825.

INFORMATION ABOUT THE AUTHORS

Mikhail A. Kiselev, Doctor of Technical Sciences, Professor, Head of the Aerodynamics, Design and Strength of Aircraft Chair, Moscow State Technical University of Civil Aviation, m.kiselev@mstuca.aero.

Sergey V. Levitsky, Doctor of Technical Sciences, Professor, Lead Design Engineer, JSC Irkut Corporation, flamento@yandex.ru.

Vladimir A. Podobebov, Doctor of Technical Sciences, Professor, Deputy Chief Designer – Head of Aerodynamics, JSC Irkut Corporation, Vladimir.Podobedov@irkut.com.

МЕТОДИКА РАСЧЕТА ЗАХОДА НА ПОСАДКУ ПАССАЖИРСКОГО САМОЛЕТА ПРИ ОТКАЗЕ ВСЕХ МАРШЕВЫХ ДВИГАТЕЛЕЙ

М.А. Киселев[1], С.В. Левицкий[2], В.А. Подобедов[2]
[1]*Московский государственный технический университет гражданской авиации, г. Москва, Россия*
[2] *Публичное акционерное общество «Научно-производственная корпорация "Иркут"», г. Москва, Россия*

Случаи отказа (выключения) всех маршевых двигателей многодвигательной силовой установки в полете, к сожалению, происходят как в России, так и за ее пределами. Причиной таких ситуаций может быть, например, попадание в облако вулканического пепла, как в случае с инцидентом с Boeing 747 над островом Ява в 1982 году, или прекращение подачи топлива, как в случаях аварийной посадки Boeing 767-233 в 1983 году на неиспользуемый военный аэродром Гимлии и аварийной посадки Ту-204 на аэродром в Омске в 2002 году. В то же время в руководящей документации действия экипажа для этого случая или не прописаны вовсе, или прописаны настолько сжато, что не предполагают конкретного перечня действий, или, другими словами, требуют от экипажа в условиях дефицита времени и повышенной психофизиологической нагрузки самостоятельного поиска необходимых действий в части управления воздушным судном (ВС). В предлагаемой статье раскрывается содержание методики, обеспечивающей вывод самолета с неработающей силовой установкой в безопасные условия посадки на любой аэродром с дальним приводным радиомаяком (ДПРМ). Отличительная особенность рассматриваемого подхода заключается в отсутствии необходимости привязки параметров движения ВС к заранее заданным наземным ориентирам. Кроме того, указанный подход прост в реализации и на современном этапе развития систем автоматического управления вполне может быть реализован на борту ВС в автоматическом или директорном режимах. Минимальная информация, необходимая для осуществления расчета захода на посадку, ограничивается тремя параметрами: наивыгоднейшей скоростью полета в посадочной конфигурации, высотой пролета ДПРМ перед посадкой и шагом спирали на высоте предпосадочного маневрирования.

Содержание метода в статье иллюстрируется результатами расчета захода на посадку перспективного отечественного ближне-среднемагистрального ВС МС-21 при отказе обоих двигателей.

Ключевые слова: динамика полета, отказ двигателя самолета, моделирование, пилотирование, особый случай в полете.

СПИСОК ЛИТЕРАТУРЫ

1. **Киселевич В.Г., Петров Ю.В., Ципенко В.Г.** Анализ особенностей летной эксплуатации самолета Ил-96т на взлете при отказе двигателя по результатам вычислительных экспериментов // XXVI научно-техническая конференция по аэродинамике, г. Жуковский, 26–27 февраля 2015 г.: сб. трудов. 2015. С. 133–134.
2. **Киселевич В.Г.** Разработка рекомендаций по летной эксплуатации самолета Ил-96т при отказе двигателей на взлете / М.С. Кубланов, В.Г. Ципенко, К.О. Чернигин // Научный вестник УВАУ ГА(И). 2014. Т. 6. С. 17–23.
3. **Киселевич В.Г., Кубланов М.С., Ципенко В.Г.** Моделирование захода на посадку и посадки самолета Ил-76 с различными посадочными массами и при отказе двигателей // Научный Вестник МГТУ ГА. 2013. № 188. С. 7–9.
4. **Киселевич В.Г.** Разработка рекомендаций по летной эксплуатации самолета Ил-96Т при прерванном взлете // Научный Вестник МГТУ ГА. 2015. № 211. С. 79–84.
5. **Киселевич В.Г.** Особенности летной эксплуатации самолета Ил-96Т при продолженном взлете // Научный Вестник МГТУ ГА. 2015. № 211. С. 128–131.
6. **Тихонов Д.В., Тихонов В.Н.** Прогноз степени опасности полетной ситуации при отказе двигателя на восходящих маневрах на основе расчетно-экспериментальных данных и экспертной оценки // Научный Вестник МГТУ ГА. 2015. № 212. С. 90–97.
7. **Котельников Г.Н., Лысенко Н.М., Радченко М.И.** Динамика и безопасность полетов. Киев: Выща школа, 1989. 332 с.
8. Аэродинамика и динамика полета маневренных самолетов: учебник / под ред. Н.М. Лысенко. М.: Воениздат, 1984. 541 с.
9. **Левицкий С.В., Свиридов Н.А.** Динамика полета. М.: ВВИА им. проф. Н.Е. Жуковского, 2008. 527 с.
10. **Алешин Б.С.** Системы дистанционного управления магистральных самолетов / С.Г. Баженов, Ю.И. Диденко, Ю.Ф. Шелюхин. М.: Наука, 2013. 292 с.
11. **Киселев М.А.** Алгоритм автоматизации разворота самолета, выполняемого с максимальной угловой скоростью // Известия РАН. Теория и системы управления. 2007. № 5. С. 150–160.

СВЕДЕНИЯ ОБ АВТОРАХ

Киселев Михаил Анатольевич, доктор технических наук, профессор, заведующий кафедрой аэродинамики, конструкции и прочности летательных аппаратов МГТУ ГА, m.kiselev@mstuca.aero.

Левицкий Сергей Владимирович, доктор технических наук, профессор, ведущий инженер-конструктор ПАО «Корпорация "Иркут"», flamento@yandex.ru.

Подобедов Владимир Александрович, доктор технических наук, профессор, заместитель главного конструктора – начальник отделения аэродинамики ПАО «Корпорация "Иркут"», Vladimir.Podobedov@irkut.com.

Поступила в редакцию	26.04.2019	Received	26.04.2019
Принята в печать	23.07.2019	Accepted for publication	23.07.2019