Journal of KONES Powertrain and Transport, Vol. 23, No. 3 2016

ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1216617

THE METHOD TO INCREASE MANEUVERABILITY OF PILOT-TRAINING JET AIRCRAFT

Witold Wiśniowski

Institute of Aviation

Al. Krakowska 110/114, 02-256 Warsaw, Poland
tel.: +48 228460993, fax: +48 228464432
e-mail: witold.wisniowski@ilot.edu.pl

Włodzimierz Gnarowski

Institute of Aviation
Al. Krakowska 110/114, 02-256 Warsaw, Poland
tel.: +48 228460011, ext. 791, fax: +48 228464432
e-mail: wlodzimierz.gnarowski@ilot.edu.pl

Abstract

The article presents the positive results of the works performed at the Institute of Aviation in Warsaw, associated with modernization of a highly manoeuvrable training jet aircraft to make it reach the standards of increased manoeuvrability. It is shown how the maximum increase of a standard training aircraft manoeuvrability was achieved, which was the result of a small modification of the structure, along with the minimal costs of modernization and qualification tests. The paper also presents the basic process of modernization related to the development of iterative methodology, which includes numerical selection of mechanization elements, that is, strakes, slots and flaps. The parameters of the performed aerodynamic model are demonstrated as well as the results of the tests of its properties with the selected types of strakes conducted in a low-cost aerodynamic tunnel of 1.5 m diameter with the use of a six-element aerodynamic weight. Parameters of the selected type of strake model with Fowler flap and slots are shown, as well as the results of the tests performed on it in the aerodynamic tunnel of 5 m diameter, and also the results of the buffeting resistance tests conducted in a transonic tunnel. The paper also presents the parameters of the designed optimized strakes, flaps and slots in 1:1 scale, which were mounted onto the aircraft prototype. Finally, the article presents the results of the full cycle of in-flight tests, which confirmed the anticipated project objectives and obtaining of a significant increase in the aircraft manoeuvrability by 48%.

Keywords: *jet aircraft, aircraft manoeuvrability, Fowler flap, aerodynamic slots*

1. Introduction

Thousands of classic conventional jet aircrafts fly in schools of aviation and other training centres [17].

Such aircrafts are currently subject to different requirements, which are necessary for training pilots to fly with increased manoeuvrability, close to standards for combat aircraft [8, 9].

In the Institute of Aviation, a new method has been developed, owing to which the effective modernization of training jet aircraft was performed, while assembly instruments were not changed, there was a minimal number of trail evidence and costs of the whole project were minimal.

Formulated demands, regarding short time and low costs of the modernization excluded the possibility of making any corrections to the flying demonstrator.

Therefore, the developed method has a multidimensional structure and focuses on finding the most optimal solutions at the possibly earliest stage of preparations for modernization.

2. Method to modernize the pilot-training jet aircraft

The algorithm of modernization of the training jet aircraft has been presented in Fig. 1.

The developed method of design and testing of the aircraft aerodynamics was divided into 5 stages:

1. Analysis of requirements, shape and aerodynamics of aircraft concluded with the choice of several variants of strakes.
2. Aerodynamic testing of the aircraft model in ∅ 1.5 m tunnel in order to find the optimal variant of strakes.
3. Aerodynamic testing of the aircraft model in ∅ 5 m tunnel with the selected strake variant and full mechanization of wings in form of slats and flaps.
4. Observation if the buffeting occurs through testing of the aircraft model in the transonic tunnel.
   The cycle of the tests in accordance with stages 1 ÷ 4 can be repeated multiple times until satisfactory results are obtained.
5. Preparation of design documentation, performance of the prototype modernization and in-flight testing.

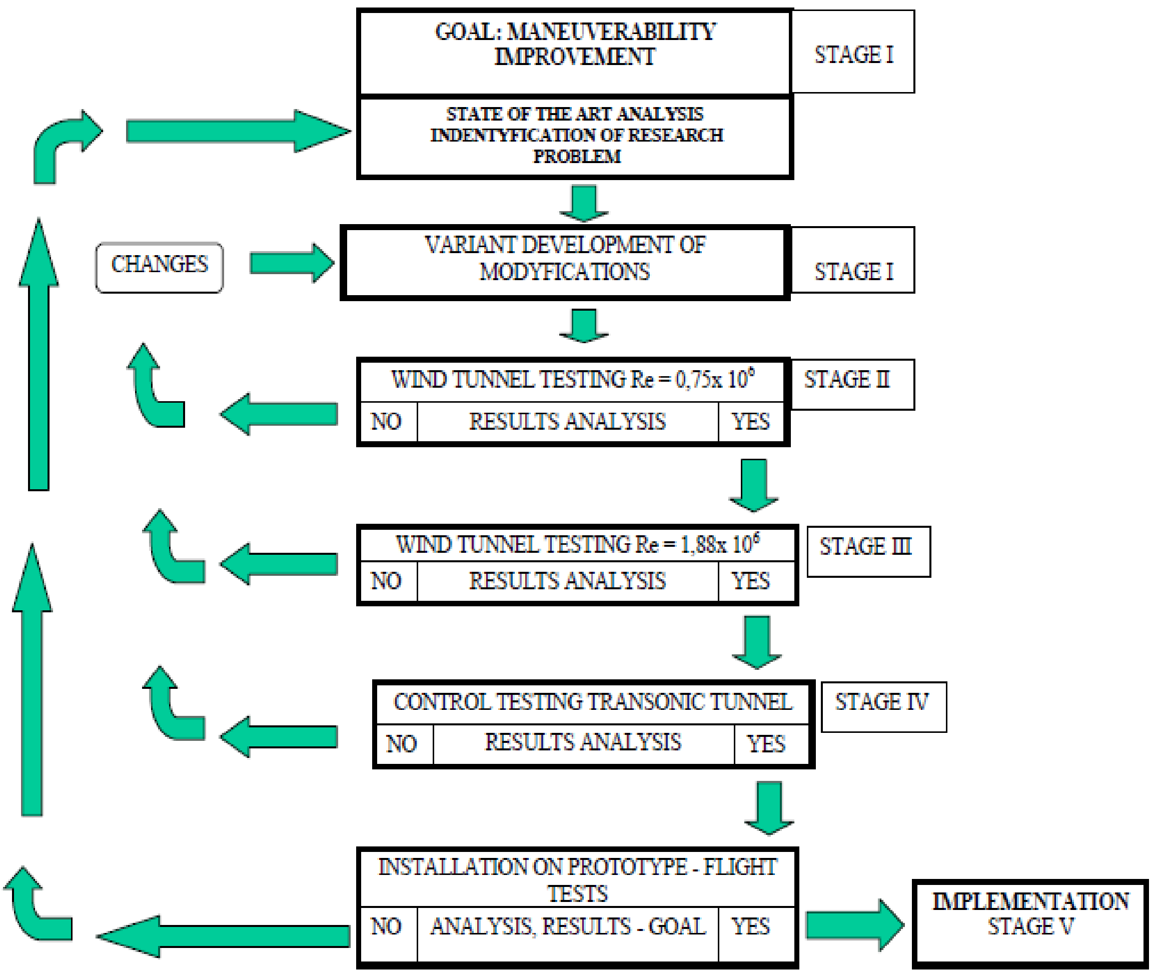

Fig. 1. Design and testing method algorithm [3]

3. Test results of the aircraft model – stage 2 and 3

Figures 2 and 3 present the examples of the results obtained during testing of the aircraft model in ∅ 1.5 m tunnel (R_e= 0.75 x 10^6) within the realization of stage 2.

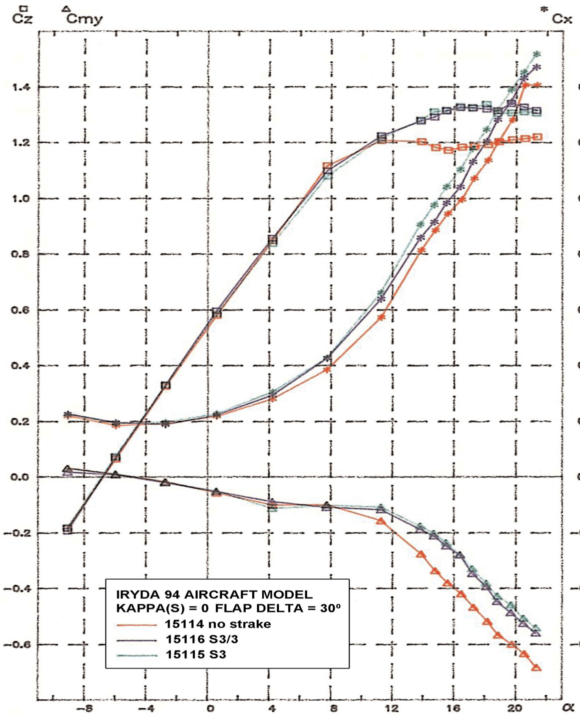

Fig. 2. Aerodynamic characteristics of aircraft model Cz(α), Cx(α) and Cmy(α) with and without strake in various variants (slotted flap δ_K = 30°) [6]

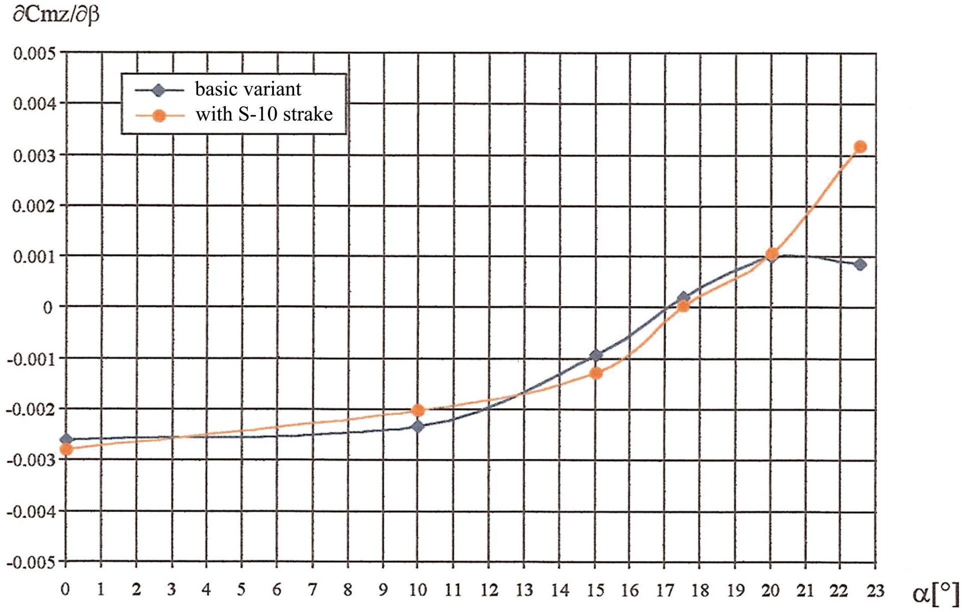

Fig. 3. Relation of δCmz/δβ in the function of angle of attack of the aircraft model with and without strake [18]

Figures 4 and 5 present the results of tests on the aircraft model performed in 5 m diameter tunnel (R_e = 1.88 x 10^6).

Within the frame of the tests performed on the 3rd model of aircraft in the 5 m diameter tunnel, it has been stated that the use of a strake results in an increased lift of the aircraft model in smooth configuration by Δ*Czmax* = 0.20 and the increase of the critical angle of attack by $\Delta\alpha_{kr}$ = 6°. Moreover, the use of strake with swivelled flap in the manoeuvring position resulted in an increase of aircraft model lift by o Δ*Czmax* = 0.85 and an increase of the critical angle by $\Delta\alpha_{kr}$ = 13.5°. In case of smooth configuration with strake, zero value of *Cmz*/δβ derivative for angle of attack α = 23.5° was obtained, and in case of strake configuration and manoeuvring configuration , zero value of δ*Cmz*/δβ derivative for angle of attack α = 29° was obtained.

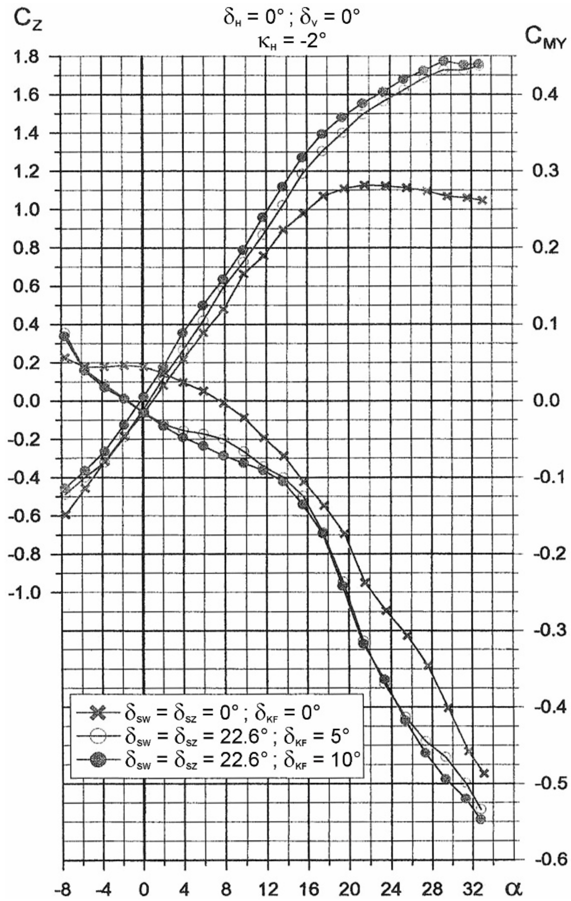

Fig. 4. Aerodynamic characteristics of the aircraft model Cx(α), Cz(α) and Cmy(α) with the selected variant of strake with Fowler flap and hidden slot as well flap and slot in a manoeuvring position angled by o δ_{KF} = 5° and δ_{KF} = 10° [7]

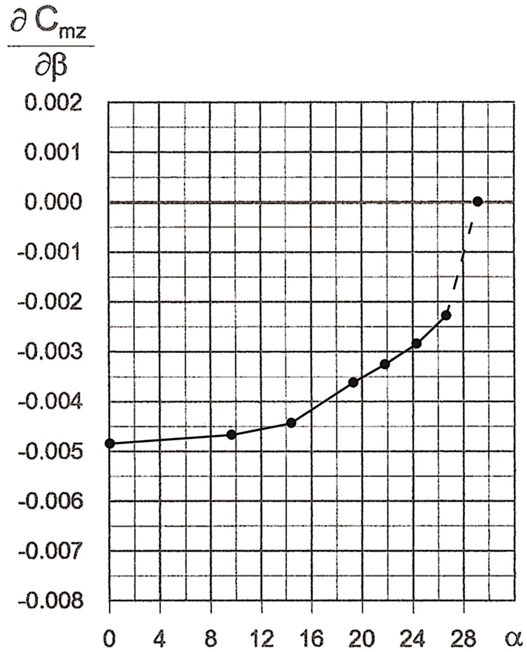

Fig. 5. Dependence of δCmz/δβ on the wing angle of attack for the tested configurations of the model of aircraft with a band and a swivelled wing flap in the manoeuvring position [7]

Furthermore, the tests proved high efficiency of the manoeuvring configuration of wing mechanization, and the use of strake resulted in a decrease of maximum level of vibrations of horizontal tail-plane occurring after the critical angle of approximately 17% for the smooth version of the aircraft model is achieved. The decrease of maximum level of vibrations of horizontal tail-plane, which occurs after the critical angle of approximately 33%, for variant of wing mechanization in landing configuration is achieved, was also observed. In case of the modified wing mechanization with mounted Leading Edge Root eXtension (LERX) in relation to the starting configuration (without strake, with slotted flap deflected by $\delta_K = 25°$ angle), a 31% lower level of vibrations were registered at horizontal tail-plane for high angles of attack.

4. Aircraft model test results for stage 4

In the tested range of angles of attack, the characteristics of the model with mounted LERX did not show any irregularities, and the limited measuring feasibility of the tunnel allowed for the conduct of tests for high Mach numbers M = 0.7 and the angle of attack $\alpha = 8.5°$. It was stated that the wing LERX caused the increase of minimum value of the resistance factor by approximately $\Delta C_{xmin} = 0.0025$, and the rising of the vertical tail led to an increase of minimum value of resistance factor by approximately $\Delta C_{xmin} = 0{,}001$. Performed tests of the flow visualization allowed for quality assessment of the impact of mounted LERX on the central part of the wing and the lower surface of horizontal tail-plane of the aircraft model. There were no irregularities found in the limited range of angle of attack (without registration of the wing drag condition) which was tested.

In case of in-flight testing of the modernized aircraft (Fig. 6) in the range of small speeds, it was observed that the introduction of the strake led to a decrease of stall speed (V_S) of aircraft by 10.7% and an increase of the critical angle of attack (α_{Kr}) by 60% in relation to aircraft configuration without LERX. In turn, the introduction of a strake, slot and Fowler flap in the manoeuvring position led to a decrease of the dragging speed (V_S) of aircraft by 28.5% and an increase of the critical angle of attack (α_{Kr}) by 65.7% with the simultaneous increase of the lift factor C_Z by 93.5% in relation to unmodified aircraft configuration [11, 14-16].

Fig. 6. Modernized aircraft I-22M96

In the manoeuvring configuration, the effect of loss of directional stability within the tested scope, and the static side stability of aircraft with mounted LERX and lifted vertical ballast presented appropriate flight capabilities during the performance of directional slides.

In-flight testing of the modernized aircraft in the range of high speeds, slowed to determine the buffeting limit (Fig. 7), [5, 12, 19]:

1. In design diving speed, with maximum engine thrust and idle thrust;
2. During recovery from diving with limit accelerations (at the beginning of buffeting vibrations) at 90%, 95% and 100% of the maximum Mach number;
3. During recovery from diving with limit accelerations and indirect combinations of speed and Mach Number.

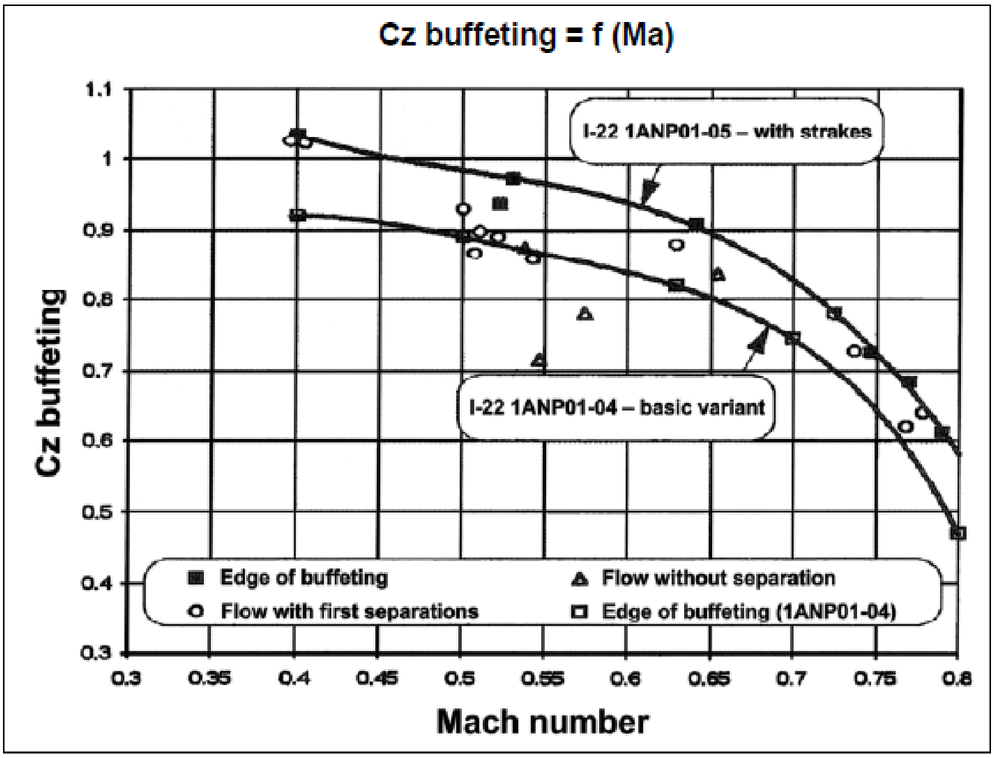

Fig. 7. Comparison of the lift factor at initial buffeting vibrations of aircraft prototype with mounted strake and without mounted strake [5, 12]

Figures 8 and 9 present a comparison of the aircraft manoeuvring characteristics before and after its modernization with mounted LERX and flap in manoeuvring position for steady and unsteady turn.

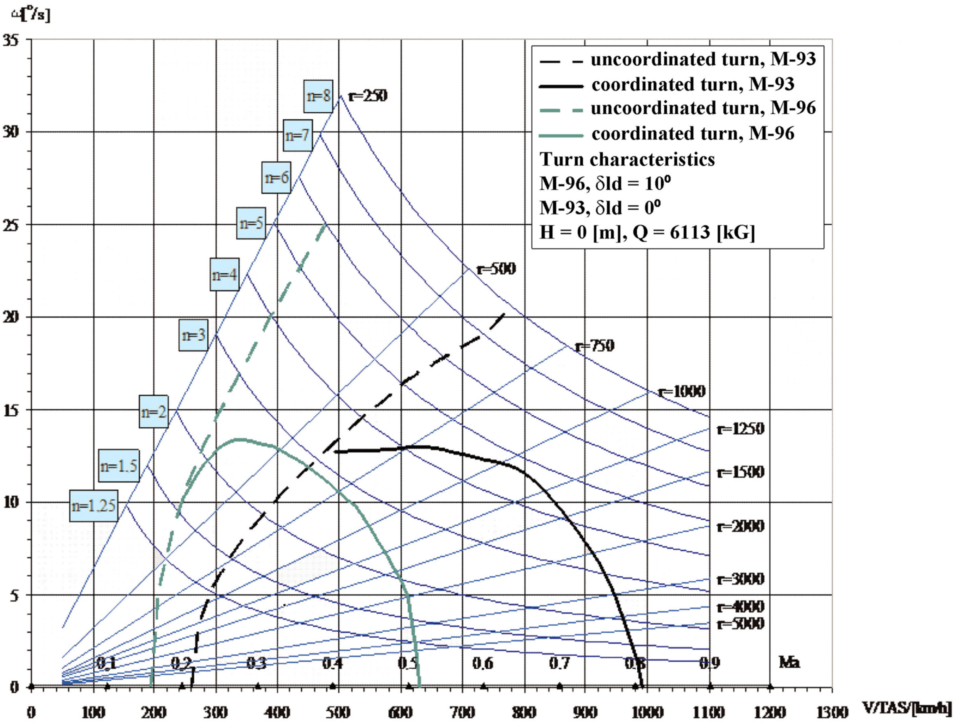

Fig. 8. Characteristics of steady and unsteady turn radius versus speed for I-22 "Iryda" plane before and after its modernization with the flap in a manoeuvring position for height H= 0 m [4, 10]

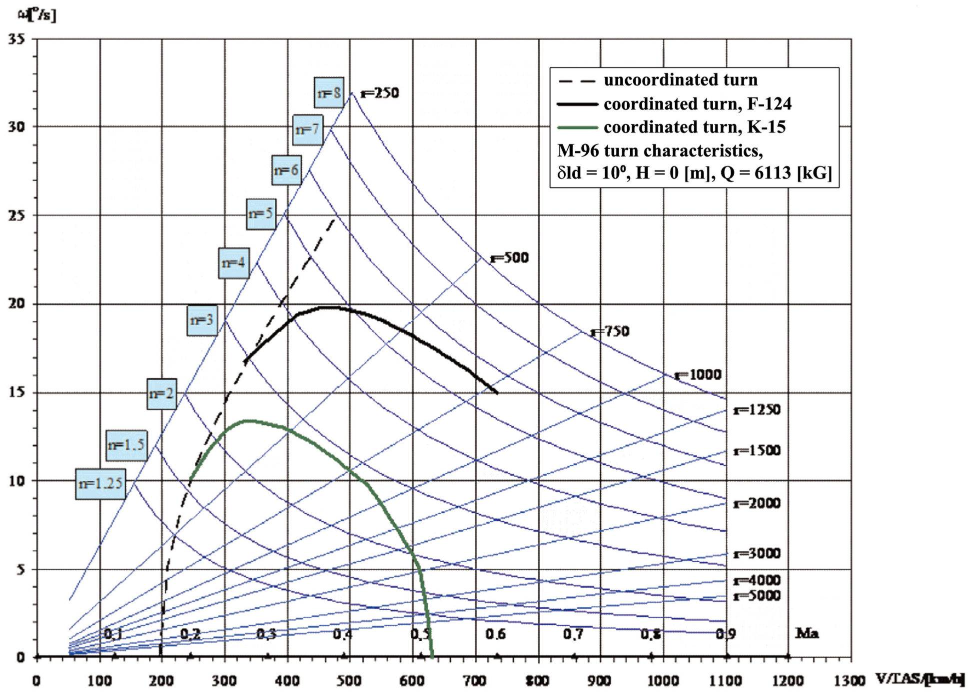

Fig. 9. Characteristics of steady and unsteady turn for aircraft with mounted LERX and the flap in a manoeuvring position with thrust; 2 x 1500 daN and thrust 2 x 2833 daN for height; H= 0 m [4, 10]

5. Conclusions

Based on the performed tests, the following conclusions can be drawn:

1. In-flight tests of the modernized training jet aircraft have proved the efficiency of the presented method. It is possible to improve the manoeuvrability characteristics of pilot-training jet aircraft by the appropriate use of strakes, slats and flaps [1, 2, 13].
2. Four-stage algorithm enabled to minimize the costs of modernization preparation as well as the risk of necessity of further design changes to be done during more advanced stages of the prototype manufacturing.
3. Mounting the strake and introduction of manoeuvring wing mechanization allowed for a decrease of unfixed range radius from R = 620 m to R = 320 m (by 48.4%) and a decrease of minimum speed from V_{min} = 480 km/h to V_{min} = 240 km/h.
4. Further improvements of the aircraft manoeuvring parameters would be possible with increased thrust.

5. References

[1] *Design Requirements for Aeroplanes for the Royal Air Force and Royal Navy. Air Publication 970. Part. 6, Aerodynamic and flight properties,* 1956.

[2] *Design Requirements for Aeroplanes for the Royal Air Force and Royal Navy. Air Publication 970. Part. 9, Flight test – flight properties,* 1956.

[3] Gnarowski, W., *Method for improving the manoeuvrability of a top-wing monoplane.* Doctor Dissertation, Institute of Aviation, Warsaw 2014.

[4] Goraj, Z., *Dynamics and Aerodynamics of manoeuvring aircraft with elements of calculations*, Scientific Library of IoA, Warsaw 2001.

[5] Idzikowski, M., Lenort, F., Sandauer, J., *The report from the handling characteristics tests of aircraft I-22 Serial No 1ANP01-05 at high speeds. Determining buffeting boundary,* No. W300 – BL/836, Warsaw 1997.

[6] Jóźwiak, R., Romicki, M., A*erodynamic research of „Iryda”* a*ircraft I-22 model with strakes,* Report No 181/BA/94/A, Warsaw 1994.
[7] Kania, W., *Aerodynamic characteristics of I-22 „Iryda” M96 aircraft model in wind tunnel tests. Summary elaboration,* Report No 200/BA/96/A”, Warsaw 1996.
[8] Kopp, C., *F/A-18E/F Super Hornet vs. Sukhoi Flanker,* Defence Today, Vol. 6, No. 1, April/May 2007.
[9] Kopp, C., Goon, P., *Assessing the Sukhoi PAK-FA,* February 2010.
[10] Michalak, K., *Turn characteristics. The algorithm and the program*, Report No 90/BP-A/89, Warsaw 1989.
[11] Papierski, Z., Budzeń, B., Stępień, W., *Report No OLL/472/W300/89 from flight test of the prototype aircraft W-300, Serial No 1ANP01-05*, Mielec 1989.
[12] Papierski, Z., Budzeń, B., Kucharski, R., *Report No OLL/534/W300/91 from flight test of aircraft Serial No 1ANPO1-04 at high speed,* Mielec 1991.
[13] *Protocol of the qualification tests of combat trainer aircraft I22 ‚Iryda" basic version*, Air Force Technical Institute*,* Warsaw 1991.
[14] Wojtkowski, M., Papierski, Z., Świerczyński, Z., *Report No LTO-6L/648/W 300/97 from the initial assessment of the impact of the first phase of modernization of the aircraft I-22 M-93K serial number 1ANP01-05 version M-96 on the airplane properties at low speeds,* Mielec 1997.
[15] Wojtkowski, M., Papierski, Z., Świerczyński, Z., *Report No LTO-6L/664/M-96/97 from flight test of aircraft I-22 „Iryda”, serial No ANA 02-04, M-96 version* , Mielec 1997.
[16] Wojtkowski, M., Papierski, Z., Świerczyński, Z., *Report No LTO-6L/665/M-96/97 from flight tests of I-22 „Iryda” aircraft, Serial No ANA 02-04, version M-96 after construction fine-tuning,* Mielec 1997.
[17] www.globalfirepower.com, March 2016.
[18] Wysocki, Z., Jóźwiak, R., Romicki, M., Kania, W., A*erodynamic research of I-22 „Iryda” aircraft model in the 1.5 m wind tunnel. The directional stability of the selected strake variant,* Report No 184/BA/95/A, Warsaw 1995.
[19] Zwierchanowska, B., Krzysiak, A., Kania, W.: *Tests of aerodynamic characteristics and the beginning of buffeting of the model airplane I-22 with strake S3/3 in wind tunnel N-3,* Report No 106/BA/95/D, Warsaw 1995.