Could stoppage of fuel supply from one wing tank andanger stability and control of aircraft?

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The paper deals with the consequences of stoppage of fuel supply from one wing tank for stability and control of aircraft. It is shown that the counterbalancing of the weight of the blocked fuel causes the development of the additional moment about the transverse axis of the aircraft, which changes the load index at landing. It is pointed out that the intersection of the changed loaded index at landing and actual landing weight could be displaced out of the operating limits of the aircraft in the balance graph. The question is raised whether the manufacturers have considered the described stoppage in fuel supply when laying down the operating limits, i.e., has the adequate safety reserve been provided.

Key words: stability of aircraft, control of aircraft

2 Counterbalancing of the blocked fuel

The weight $\Delta F_y$ of the blocked fuel produces the moment about the longitudinal axis of the aircraft which has to be counterbalanced. The moment of the equal magnitude, but acting in the opposite direction about the longitudinal axis is produced by turning downward the aileron on the wing with blocked fuel and by turning upward the aileron on the wing on the other side. The increase of the lift $\Delta F_{1,\text{a}}$ acting on the down - moved aileron and the decrease of the lift $\Delta F_{2,\text{a}}$ acting on the up - moved aileron produce the mentioned counterbalancing moment about the longitudinal axis.

The turning of the ailerons besides the changes of the lifts acting on the wings cause the changes of the wing drags. If the ailerons are appropriately designed and if the angles of downward turned aileron and of upward turned aileron are properly correlated, the change of the drags on the wings will be of equal magnitude with the sense of increase, i.e., directed aft. (Otherwise, the different changes of the wing drags would cause the development of the moment acting about the vertical axis). The sum of the increases of the left wing drag and of the right wing drag, $\Delta F_y = \Delta F_{1,\text{a}} + \Delta F_{2,\text{a}}$ has to be covered by the increase of the thrust $\Delta F_T$ produced by the engines. As $\Delta F_T$ and $\Delta F_y$ are the forces of equal magnitude acting in opposite directions along two parallel lines, they form a couple. If the engines are positioned under the wings (Fig. 2, a), the couple $\Delta M_{1,\text{a}}$, $\Delta F_T$ produces a positive moment $\Delta M_{1,\text{a}}$ about the transverse axis, and if the engines are positioned over the wings (Fig. 2, b), the couple $\Delta M_{2,\text{a}}$, $\Delta F_T$ produces a negative moment $\Delta M_{2,\text{a}}$ about the transverse axis. Thus, the consequence of counterbalancing of the weight of the blocked fuel is the development of additional moments about the transverse axis of the aircraft - either the positive $\Delta M_y$ or the negative $\Delta M_y$, depending on the position of the engines with respect to the wings.
3 Change of the loaded index at landing

The loaded index LI is determined by

$$LI = \frac{\sum F_i (x_{STA} - x_{REF, STA})}{C} + K$$

where $F_i$ is the weight of the particular load, $x_{STA}$ is the horizontal distance from the manufacturer's station zero (referent vertical line near the nose of the aircraft) to a particular point at which $F_i$ is acting, $x_{REF, STA}$ is the horizontal distance from the station zero to the reference axis from where distances are measured for balance purposes, $C$ is the constant by which moments are transformed into suitable index units and $K$ is the constant providing the positive value of the loaded index.

As the loaded index is determined by the sum of the moments of the weights of the particular loads about the transverse axis placed on the location of the reference axis, the additional moments $\Delta M_{p,x}$ and $\Delta M_{p,y}$, changing the value of the total moment about the transverse axis, have to be taken into account in determining the loaded index. The according changes of the loaded index caused by $\Delta M_{p,x}$ and $\Delta M_{p,y}$ are

$$\Delta I_x = \frac{\Delta M_{p,x}}{C} \quad \text{and} \quad \Delta I_y = -\frac{\Delta M_{p,y}}{C}$$

If the differences between the arms of the weights of the unconsumed fuel in the particular tanks for the case of the regular fuel supply and for the case of the stoppage of fuel supply from one wing tank are neglected, the loaded index will be changed only due to $\Delta I_x$ or $\Delta I_y$. Thus the intersection $A$ of the calculated loaded index at landing and the actual landing weight is displaced aft due to $\Delta I_x$, and the intersection $B$ is displaced forward due to $\Delta I_y$, as shown in schematized balance graph (Fig. 3.).

3 Crossing the landing limits

At last, let the following occurrences be considered. The intersection $A_0$ of the loaded index at zero fuel weight (LIZFW) and the zero weight (ZFW) is positioned forward of the aft landing limit, but very close to it (Fig. 4.). It is a regular position of this intersection. The actual landing weight LDW is bigger than ZFW for the weight of the unconsumed take-off fuel. The loaded index at landing LILDW is moved somewhat forward of LIZFW, and the intersection $A$ of the LILDW and LDW is positioned forward of the aft landing limit. The occurrence of the stoppage of fuel supply from one wing tank producing $\Delta I_y$ causes the displacement of $A$ into position $A_1$, across the aft landing limit. This is an irregular position.

The similar situation can be imagined close by the forward landing limit. The intersection $B_0$ (Fig. 4.) is in a regular position. The intersection $B$ of LILDW and LDW is aft of the forward landing limit, but the occurrence of the stoppage of fuel supply from one wing tank producing $\Delta I_y$ causes the displacement of $B$ into position $B_1$, across the forward landing limit. This is also an irregular position.
4 Concluding question

Finally the question arises: have the manufacturers taken into consideration the consequences of the stoppage in fuel supply from one wing tank for stability and control of their aircrafts? Is the magnitude of the $\Delta I$ of the possible change of $LILDW$ analyzed and based on that analysis is it ensured that the landing limits in the balance graphs are laid down with an adequate safety reserve, i.e. is it ensured that the intersection of $LDW$ and the actual (changed) $LILDW$ in the most auspicious case will not be positioned out of the actually safe area?

**General references**


