SECURING OF THE SAFETY AND ECONOMY OF ACROBATIC AIRPLANE SERVICE

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Keywords: *Acrobatic flying development, Acrobatic airplanes development, Acrobatic categories, Acrobatic losd spectra, Fatigue life of sports aeroplanes*

Abstract

In this paper there are summarized results of the load spectra measurement, which were done since 60ties till 1999. It was shown that two different kinds of "acrobatic operation" should be considered. First, the contest acrobatics and second, the training acrobatics. Both are here expressed by load spectra. It is shown that school and training airplanes are able to fly the same "hard" acrobatics as the special airplanes. On the other hand the school and training airplanes are used to NORMAL flying and so their technical life are mostly not used economical. Therefore it is recommended to record the load history by means of modern electronic fatigue-meter (especially on school and training airplanes) and fly till the limit state that will be allowed by manufacturer.

1 DEVELOPMENT OF THE ACROBATIC FLYING AND ITS INFLUENCE ON ACROBATIC AIRPLANES

"Acrobatics" has attracted pilots since the very beginning of aviation. After experience in both World Wars the sportive acrobatics started to grow all over the world in countries with developed general aviation. After the period of prevailing airshow displays the first international acrobatic competitions started in 50ties. Let us remember e.g. the famous "Lockheed Trophy" in England, where the "modern" acrobatics had appeared in international contests.

The first World Championships in acrobatics took place in 1960 at Bratislava, former CSR, and now Slovak Republic. Since that time the World Championships have been organized in the interval of two years, completed with European Championships in odd years.

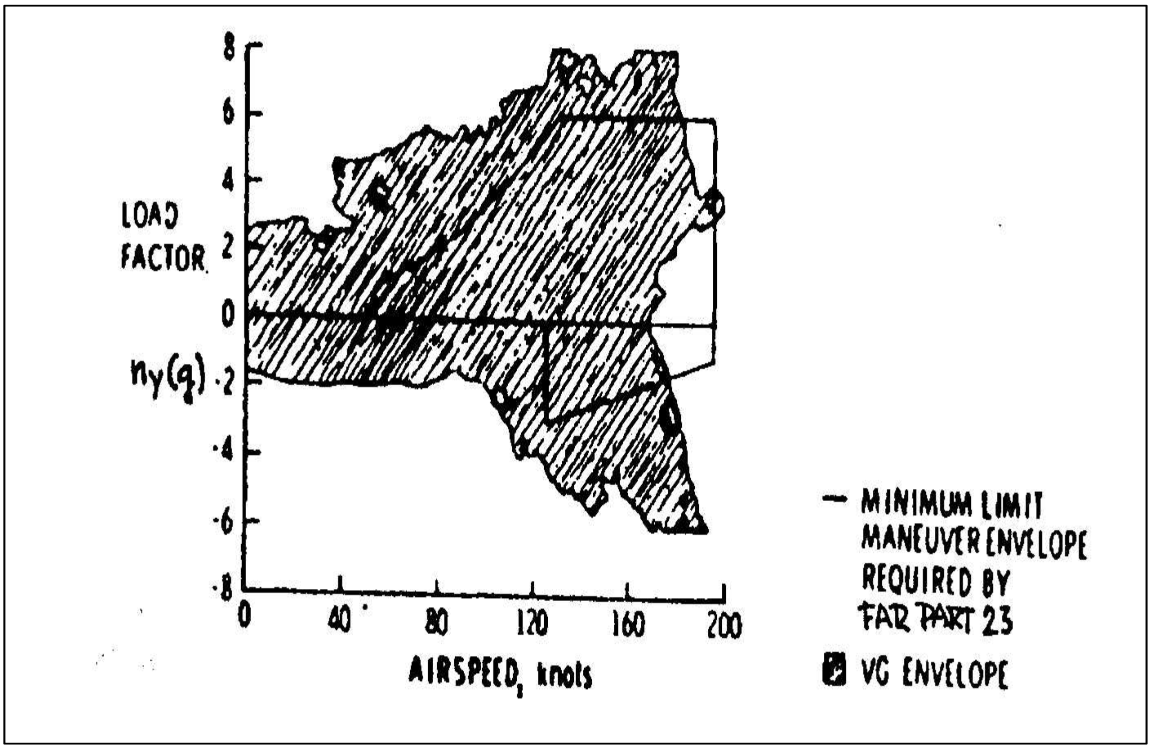
The acrobatics belongs to the "pointed" contest sports and at the very beginning the elegance and smooth transition and combination of individual maneuvers was mostly appreciated. Individual performances /arrangements consisted of the "classic" maneuvers and their combinations (loops, rolls, half-loops and rolls, chandelles, lazy eights, stalls and spins). Inverted maneuvers had appeared scarcely, taking about 10% of the whole arrangement. The minimum range of positive/negative load factors (+6, -3 g), required by the standard, was sufficient enough for such performance.

The matter has dramatically changed after introduction of the "Aresti Pointing System" in the acrobatic contest - performance evaluation. Mr. Aresti divided the arrangement into individual maneuvers, these further on the "enter" and "exit" parts and the maneuver itself, appreciated according to the degree of its difficulty (the figures are tabled for the objective judgement). The measure of appreciating the enter (or exit) is based on the degree of maintaining the in advance announced direction and slope. The judge appreciates the degree of maintaining the "trajectory", the quality of performance of individual maneuvers, their degree of difficulty, general impression and maintaining the limited airspace.

The introduction of the Aresti System had increased the objectivity of acrobatic arrangement evaluation, but it resulted in "hardening" of the operational load spectra of the airplanes, too. The contest spectra of the airplanes, too. The contest pilots started to apply the "highly - pointed" maneuvers with inverted figures, the portion of which has increased to 50%. The entry speeds increased to allow maintaining the limited airspace, the maneuvers were controlled in a sharp manner. The pilots became trained for relatively high positive and negative load factors, the obsolete load envelopes were not sufficient enough (see GRAPH 1).

Till the late 60ties two- seaters prevailed in acrobatic contests (the airplanes with higher seat capacity has never been used!). I can say, I am a little bit proud to remember, that it were different models and modifications of Czechoslovak ZLIN TRENERs , that had appeared on the top positions of international acrobatic contests, accompanied with the famous American PITTS SPECIALs, Russian JAK 18s, and later French CAPs.

Above mentioned development of acrobatic flying and "harder" loads (resulting in failures) had called for the modifications of the structure and arrangement of the airplanes (originally built for elementary and advanced training of general aviation pilots): rebuilding on single – seaters, increasing maneuverability by reduction of span, installation of higher engine power etc.

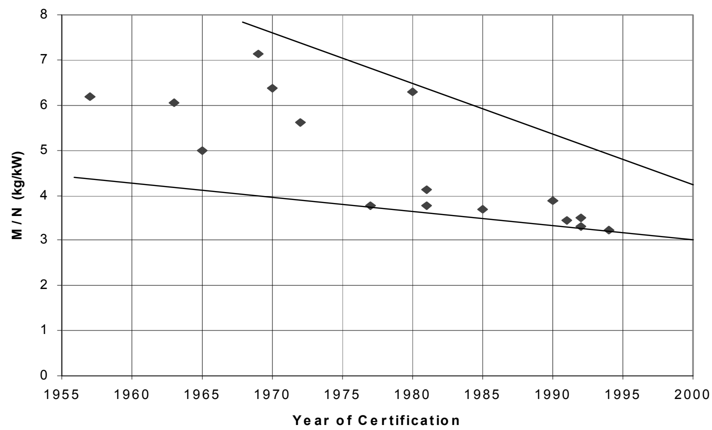


GRAPH 1-Theoretical and measured loads factor – Airspeed Diagram [1] (the winner of the U.S. National Acrobatics Contest)

The "n – V" diagram is a record, reprinted from [ref. 1]. The records confirm that minimum required load envelopes are exceeded, especially in the higher airspeed and negative load parts.

The development of the reduction of mass and increasing the installed engine power is clearly defined by the "Specific Power Load"

parameter (Take-off Mass / Maximum Engine Power, M/N, [kg/kW]). The time – history of this parameter (including appearance of new models in operation) is shown on Graph 2.
Initial information see TAB 1.



GRAPH 2- Specific Power Load (Airplanes tabeled in TAB 1) [2]

The modifications mentioned above had increased e.g. the load envelope of TRENERs from +6 / -3 g to +7 /-4,5 g , both the PITTS and JAK 18 had got the higher engine power and necessary structural modifications. Despite of it, the safe – life of the latter was only few tens of hours!

In the second half of 70ties the new Czechoslovak "SPECIAL Acrobat", single seater ZLIN Z 50 L has appeared on the acrobatic scene. With relatively low M/N = 3.77 kg/kW (Lycoming 191 kW) and +9/-6 "g's" envelope it has started the era of SPECIALS, followed in 80ties by the French CAP 21, later CAP 231, German EXTRA (+/-10 g) and Russian Su 26 (M) (+/- 12 g).

The mentioned development is reflected also in the classification of both the pilots and the airplanes in "Sporting Code" of FAI – CIVA (International Committee for Acrobatics). We find here three categories for the lower (national) level contests - BASIC, SPORTSMEN and INTERMEDIATE and two - ADVANCED and UNLIMITED for international (World) championships. There are not any exact criteria or figures for the latter classification. It is the matter of CIVA decision and only as the example of the UNLIMITED we mention here the EXTRA 300 (M/N= 3,87 kg/kW), Su 26 M (3,7) Su 31 T (3,3) and Z 50 LE (3,45).

NOTE: The author feels, that the M/N= 5 may be considered now as the approximate boundary between SPECIALS and universal ELEMENTARY SCHOOL and TRAINING/ACROBATIC =

SCOOL AND TRAINING airplanes, used for the wide comprehensive purposes, characterized by the name.

School and training airplanes (S-school airplanes) are used in service in different way. They are mostly used to elementary and advanced training, to cross-country flying, to towing and other flying activities. Most of them does not over-cross load factor in the range from +4 to –1 g see e.g.TOWS on GRAPH 3 and 4, but they are able to carry out the same acrobatics maneuvers as the SPECIALS airplanes (C-competition airplanes) . Compare load spectra of different representative school and special models in GRAPH 3. Due to the relation between NORMAL and ACROBATIC flying the safe life of an individual airplane may considerably changed. It may be 1:10 but even more.

From the point of view of safety and economy it seems to be reasonable to define two acrobatic categories: school and training category and special acrobatics category. It will be discussed in more detail further.

Airplane Model		Max.T.O. Mass (A categ.) (kg)	Wing area (m^2)	Engine Power (kW)	Spec. Power Load (kg/kW)	Max. Operational Load Factor + „g“	- „g“	Year of certification
Z 226 T (2 (A)	S	730 (715)	14,9	118	6,18 (6,05)	6,0	3,0	1957 (1963)
Z 526 F (2 (AFS)	S	940 (740)	15,4 (13,8)	132	7,12 (5,61)	6,0 (7,0)	3,0 (4,5)	1969 (1972)
Z 42 (2	S	840	13,15	132	6,36	6,0	3,5	1970
Z 142 (2	S	970	13,15	154	6,30	6,0	3,5	1980
GROB G 115T (2		?	13,28	195	?	6,0	4,0	1996
EXTRA 300 (2 (S)	C	870	10,7	225	3,87 (2 (1 (3,5?)	10,0	10,0	1990 (1992)
PITTS S-2B SPECIAL (2	C	737	11,6	195	3,78 (2	?	?	1985
JAK 18 PM(S)	C	1100 (?)	16,5	220	5,0 (<5)	9,0	6,0	1965 (1969)
Z 50 L,LA	C	720	12,5	191	3,77	9,0	6,0	1977,1980
Z 50 LE	C	760	11,21	220	3,45	8,0	6,0	1991
Su 26 M	C	1000	11,8	270	3,70	12,0	12,0	1985
Su 31 T	C	968	11,8	294	3,29	12,0	12,0	1992
CAP 21		620	9,2	150	4,13	?	?	1981
CAP 231		730	9,86	225	3,24	?	?	1994

TAB 1 - Technical data of dicussed airplanes [2,3]

NOTES: (1 Estimated for „solo“ operation
(2 Two-seater Model
A airplane designed as school and trainer airoplane
C airplane designed for acrobatic flying

2 AVAILABLE SET OF ACROBATIC LOAD SPECTRA

2.1 Introductory notes

The load spectra of different acrobatic airplanes, measured with different instrumentation and during different flight time, on models with different envelopes of operational loads, in the period of approximately 1962 to 1999 are presented in this section. But basically there are two groups – load spectra of the purely competition acrobatic operation and load spectra measured by the air-school, specialized on elementary acrobatics and advanced training but carrying out the standard elementary training , too.

2.2 Normalization of individual spectra

For comparative purposes of this paper the real spectra of different models with different operational load envelopes are "normalized". This is done by recalculation of real load factor values on the normalized ones, corresponding to the minimum range of positive/negative load factors required by airworthiness standards i.e. +6 / -3 "g". The positive load factor levels are reduced by the multiplication by +6 / n +.real, the negative ones by –3 / n – real, where n +/- real are the real operational limits of load factor of the given airplane. The relevant technical data of evaluated airplanes are plotted in the upper part of the table on TAB 1.

2.3 Contest acrobatic load spectra

Five spectra of different airplanes are plotted on GRAPH 3. Four of them were measured on Czech school and training airplanes - SCHOOL, the one on the acrobatic SPECIAL German EXTRA 300. The current practical experience shows, that such a load spectrum is applied in case of SPECIALs for the 50% (two-seater version) to 70% (single – seater) of the technical life period (the rest is spent at the type qualification training and cross-country flights).

The portion of this load spectrum in school and training airplanes technical life is quite unpredictable and depends on a lot of variable circumstances and ways of the real operational usage of the individual airplane. The set of these Contest Load Spectra is provided with proposed upper and lower limit envelope curves for better comparison.

2.4 Discussion on the GRAPH 3 – Contest Acrobatic Spectra

The set of Contest Acrobatic Spectra creates the bandwidth, expressed in term of cumulative frequency, of the 0,5 to 1,0 orders. It confirms, that on the school and training airplanes the similar "hard" acrobatics may be flown as on the acrobatic SPECIAL . Of course, the differences, resulting from the SPECIAL design, may be observed in the frequency.

The GRAPH also shows, that there was not any significant difference in flying "hard" acrobatics in 1962 compared to 1999! The author expects that the Contest Acrobatics in near future would copy the presented band or his upper envelope respectively.

2.5 Elementary and Advanced (Acrobatic) Training spectra – GRAPH 4

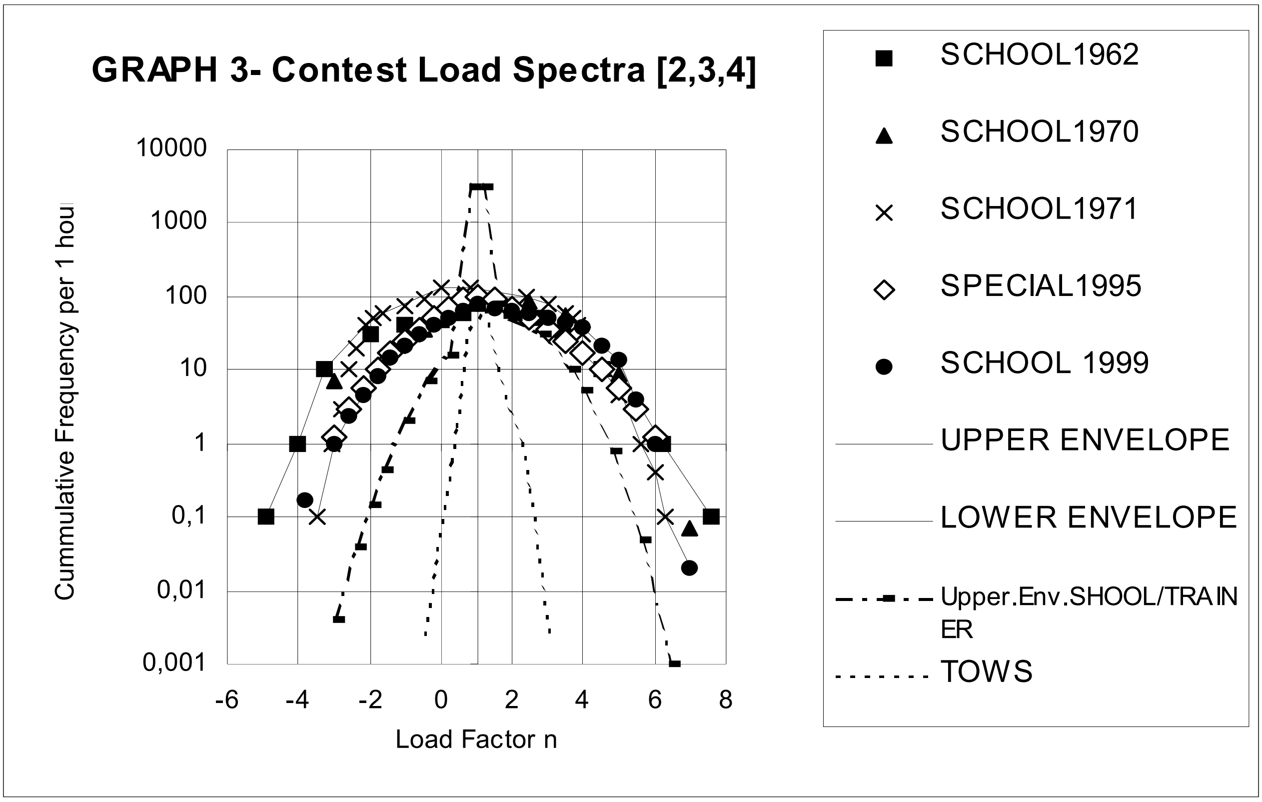
As we have emphasized in preceding sections, the "training" operation spectra of school and training airplane may vary very considerably. The operation may cover elementary training, including elementary acrobatics, cross-country flights for training the navigation (see TOWS on GRAPH 3 and 4), advanced acrobatics training including the lower (National level) acrobatics contests – see SCHOOL1999 on GRAPH 3.

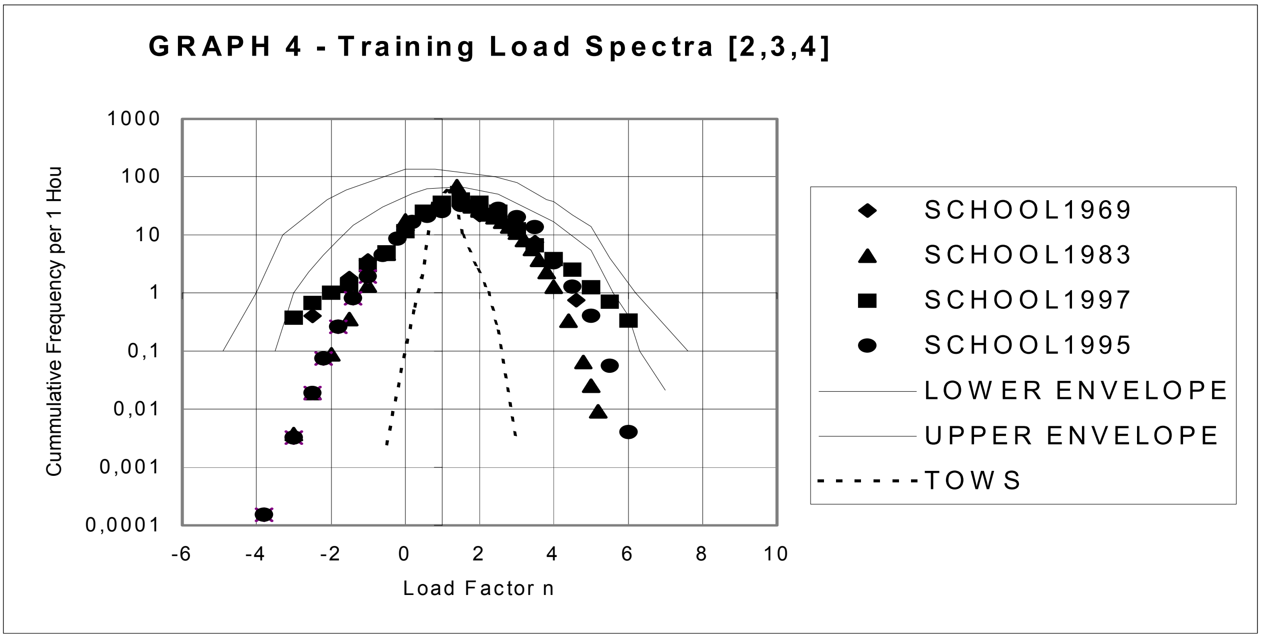
On the GRAPH 4 four spectra of load factors, measured on different school and training airplanes, are plotted. For illustration and better comparison of the differences among "training" and "normal" operations the load spectrum describing glider towing is shown on this graph. The upper and lower envelopes show the contest load band.

Training load spectra represent the typical spectra of “Mixed Training Operation” in which the portion of acrobatics does not exceed 50% of total technical life.

2.6 Comparison of the both sets of load spectra

The graph 3 and 4 confirms, that “two different kinds of acrobatics” should be





considered. The “Contest acrobatics” may be described by the upper and lower envelope with the bandwidth of 0,5 to 1,0 orders of cumulative frequency at the levels, approaching the limit loads. According to recent experience we can assume, that such load spectrum should be applied in the interval of 50 to 70 % of the total life.

The "Elementary and Advanced (Acrobatic) Training" spectra are typical for training flying. They are remarkably separated from the "lower" contest spectra envelope. Their bandwidth increases to more than 1 order in the part approaching the both positive and negative limit load factors. Their " points" shows the spectrum of a school and training airplane, on which the acrobatic training operation covers approximately the 50 % portion of the total technical life. The author believes, that such an bandwidth may be considered as the adequately conservative source at design of the future school and training airplanes, certified in category A.

In case, the school airplane will not fly advanced training, its load spectrum will be near to "TOW" spectrum and then the technical life of this individual airplane may be very high – almost unlimited.

3 Securing of the safe life and economy of service

The load spectrum of the acrobatic SPECIAL should be relatively steady and homogenous for each operated airplane. So, it is possible to ensure safety and economy of service by common means.

The service life of school and training airplanes may change dramatically, one airplane to another, depending on the real operational program. The scatter 1:10 may be expected. If the service life is established on the basis of single, relatively "hard" spectrum (e.g. see GRAPH 4) the economical impact on the "non-acrobatic user" would be unacceptable.

Safety should be in this case secured by application of different approach – e.g. by the approved system of "structural inspections" or by individual monitoring of applied loads on each individual aircraft. Only such or similar method can provide both the necessary level of safety and the economy of operation of school and training models.

Nowadays there exist relatively lightweight, cheap and reliable fatigue-meters on the current market and their application, as the standard equipment of sportive airplanes, should encourage the manufacturers, Aviation Authorities and users, too. It is necessary the producer to establish the limit value of decisive levels. Then each individual airplane can fly till this limit state. This system can help to follow service of special airplanes, too.

4 Acknowledgement

I would like to thank to Mr.Petr Kousal (his last employment: the technician of the Czech CAA) who helped me with gaining some spectra and information on classification of both the pilots and the acrobatic airplanes.

References

[1] Hall, A.W.: Loading Conditions Measured During Acrobatic Manoeuvres, Langley Research Center, NASA T.R. 700222

[2] Maler, Z.: Private file of records and notes prepared during the work on fatigue life proofs of the ZLIN aircraft of different types

[3] Kousal,P.: Private file of records and notes

[4] Data provided to author by the Czech CAA