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# Evaluating the Dynamics of Aircraft Crew Skill Development by Using the Results of Discrete Exercise Marking

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***Abstract* – Aircraft crew training corresponds to the interactive learning models of sensorimotor skill acquisition, and the dynamics of skill acquirement can be approximated by the exponential trend. A model of 5-grade assessment of separate exercises is offered. It helps to calculate a resulting evaluation, in accordance with which the progress level of a discrete exercise is evaluated. Such an evaluation forms one of the points for the analytical construction of a learning curve using the Gaussian method. Possible applications of the learning curve are covered.**

***Keywords* – Flight evaluation, learning curve, progress evaluation.**

## I. Introduction

It is recognized that operator performance skills develop from the initial level to the required level as a result of interactive learning and exercises.

The dynamics of skill acquisition by a particular aircraft crew is influenced by many factors and a possible precise identification of this correlation creates a chance to optimize and individualize the learning process.

In order to obtain skill acquisition parameters, several consecutive measurements of successful exercise fulfillment are necessary. These measurements cannot be reliably acquired by means of assessing a single exercise since the assessment is usually formed by a low-resolution grading system and deals with an absolute security level rather than with skill acquisition progress.

Since basically all known techniques, for example [9], produce the resulting assessment from the partial assessments of individual parameters and actions, it is necessary to develop a criterion which, in using these assessments, would be maximally sensitive to the target reaching progress of an exercise.

In order to correctly identify the characteristics and parameters of skill acquisition dynamics, it is necessary to ascertain how sensorimotor skills and knowledge are created and preserved in the memory of the operator.

It also has to be taken into consideration that exercise details change during the learning process, which creates new situations that consequently produce the dispersion of exercise assessments around the theoretical curve of the learning progress.

## II. Memory, Sensorimotor Skill Acquisition Process and Models

Psychology claims that humans have at least three types of memory: sensory, short-term memory and long-term memory [2], [5], [14], [21]. The information that comes through the five senses is kept in full amount in the sensory memory (sensory register) only for a few seconds or even fractions of a second, and if it is not acknowledged, it is forgotten (Fig. 1).

Acknowledged information is stored in the short-term (working) memory for about 30 seconds and then either gets coded for storage in the long-term memory or is forgotten. The capacity of the short-term memory is not large – approximately 7 ± 2 bits (meaningful units of information). The rehearsal buffer promotes the steady production of information codes for long-term information storage in the long-term memory.

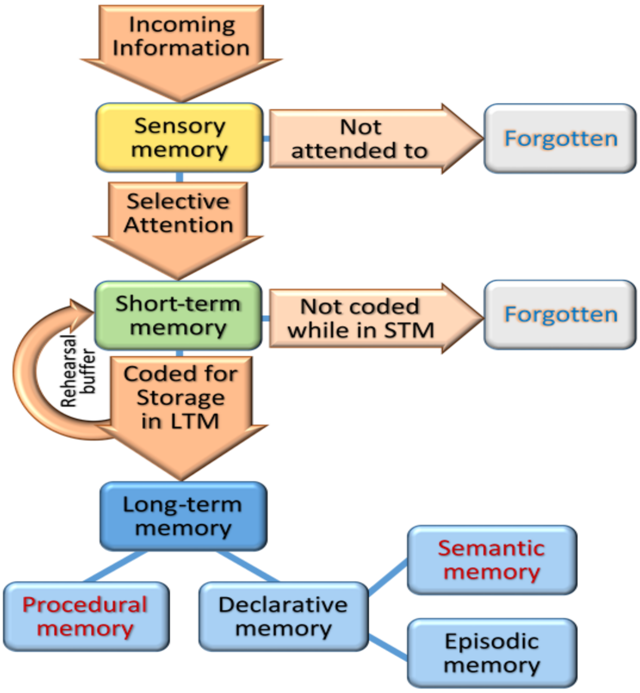


Fig. 1. Success in accordance with the linguistic meaning of marking.

The long-term memory consists of a declarative memory, where direct knowledge acquired by direct memorization of information is stored, and a non-declarative memory, which is related to specific reflexes to incoming stimuli. The procedural memory storing sensorimotor skills (for the pilot – the piloting skills) is the most important part of the non-declarative memory.

A semantic memory, a part of the declarative memory, is equally important since the knowledge of necessary actions in specific flight situations acquired from instructions or theoretical lessons is kept there. However, a lot of this knowledge has to be turned into sensorimotor skills during exercises. Then it has to be secured and periodically refreshed since there is a possibility that in course of time knowledge and skills can be partially or completely lost.

Frequently, a three phase or stage model [10], [11] is used in describing sensorimotor skill acquisition. In 1967, Fitts and Posner proposed the most used labels of the three stages (or phases) of learning: the cognitive, associative and autonomous stages. Rasmussen's [23] sensorimotor action model (Fig. 2) is also widely used and there the stages are classified as Knowledge-based, Rule-based and Skill-based control.

According to this model, new sensorimotor skills (cognitive stage) are created by sensory information producing particular time-space variables – symbols indicating the necessity to take action. Based on previous experience, semantic knowledge and action goals, planning and attempts to implement the necessary automatic actions take place. In the event of successful implementation, they are gradually secured into the procedural memory as particular action scripts.

During the associative stage, cues corresponding to particular action scripts are identified within sensory information, and an attempt to implement them through the respective procedures is made.

During the autonomous stage, changes and signals in sensory information create automatic sensorimotor reaction and its pattern is stored in the procedural memory of the operator.

During the real life operator performance, all the three stages overleap and function simultaneously in accordance with the recognition of the existing situation and the solidity of the developed reflexes.

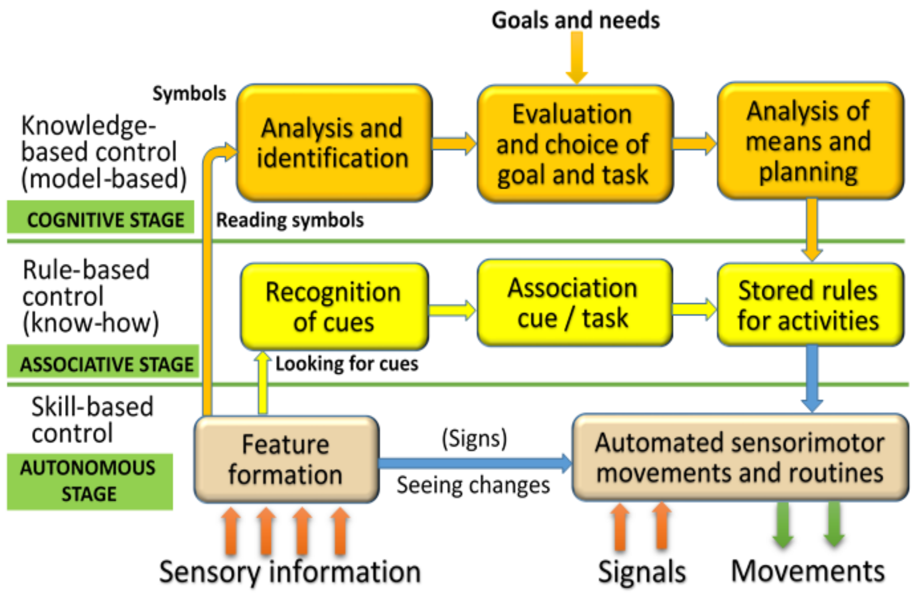


Fig. 2. Three levels of performance by skilled human operators. (Redrawn from [23]).

Among others, the Gentile [15], [16] two-stage model is also popular. It consists of an Initial Stage (getting the idea of movement) and a Later Stage (fixation/diversification stage) which basically combines the associative and autonomous stages.

Studying the development of the learning curve, Ritter and Schooler [24] consider the opposite process – forgetting to be equally important for skill acquisition and retention (Fig. 3)

The first stage of learning is dominated by the declarative memory and preserved information can be forgotten completely. Thus, after 1 hour only about 50 % of memorized information are kept within the declarative memory and after six days only 25 % of information. The autonomous stage is dominated by the procedural memory and skills acquired during this stage usually do not get lost, however they can decrease to an unacceptable level and therefore some practice for skill renewal is necessary. It was also established that the pace of various skill acquisition and forgetting processes can differ considerably.

Consequently, the operators' actual sensorimotor skill level constantly changes in time and as a result of practice. It is important to clarify how to measure it and identify by which mathematical coherence actual skill level results can be approximated.

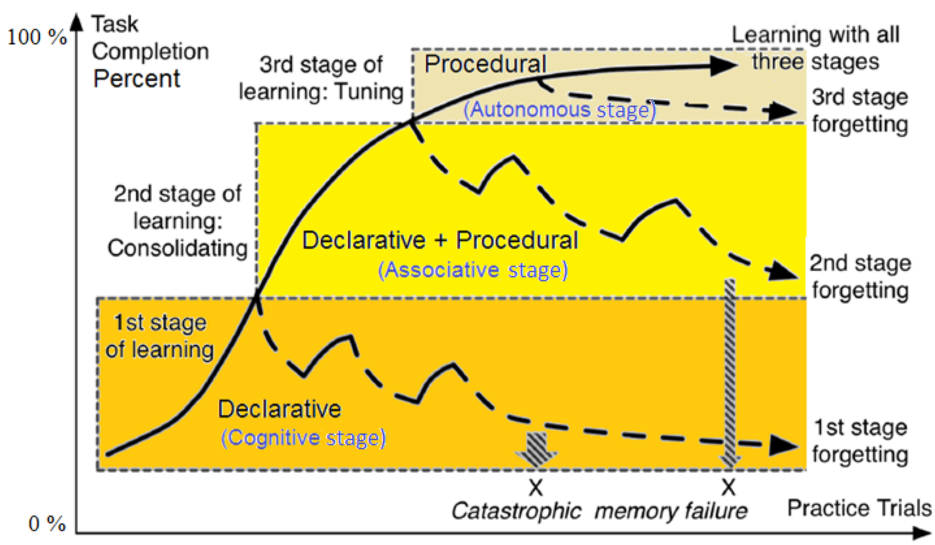


Fig. 3. Sensorimotor skill acquisition and loss during different learning stages. (Redrawn from [24]).

### III. Learning Curve

Processing the results of many simple frequentative exercise series, it was established that by putting aside the results depending on exercise quantity within logarithmic coordinates they position approximately in the linear order (except the initial learning stage). It allows to conclude that the progress (decrease in mistake quantity or exercise performance time) resulting from exercises complies either with an exponential function $E(n) = Bn^{-\beta}$ or with an exponential correlation $E(n) = Be^{-\alpha n}$, where $E$ is an evaluation of the progress after $n$ exercises, $B$ is a range of progress changes, while $\alpha$ and $\beta$ are coefficients of the speed of progress changes.

The approximation of the exponential function (Power Law) [18] is popular in psychology and used in several theories of expanded cognition such as ACT-R [3], [4] and SOAR [19]. However, the statistic processing of large quantity exercise series [17] performed later on reveals that in about 80 % of cases approximation with exponential correlation is more precise, particularly if this is a minor series performed by a particular operator.

Looking at a possible frequentative learning theoretical basis from five different vantage points and analysing 28 different possible models, Novikov [20] concludes that none of those is in conflict with the exponential character of progress changes. By using exponential correlation, it is possible to approximate the increase of exercise performance progress (Fig. 4a) and the decrease in amount of mistakes (Fig. 4b), as well as *S-type* correlation (Fig. 4c) that is specific to the start of learning from the theoretical basis without any corresponding preliminary sensorimotor skills.

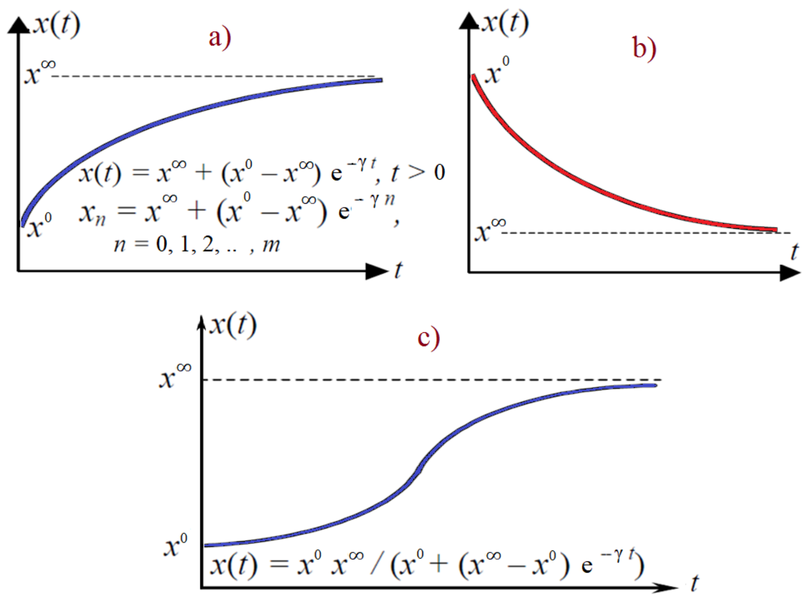


Fig. 4. The approximation of the dynamics of frequentative learning with exponential correlation.

As it is often necessary to evaluate the progress dynamics of a particular crew during each series of exercises when the initial learning of the pilot (cognitive stage) is not examined, the progress can be best approximated using the Fig. 4a type correlation:

$$Progr(n_{fl}) = 100 - (100 - Progr_0)\,e^{-Lsp \cdot n_{fl}}\,. \qquad (1)$$

where

- $Progr_0$ initial level of progress (learning);
- $Lsp$ learning speed constant (individual for the crew);
- $n_{fl}$ exercise serial number (usually flight in circle).

The parameters $Lsp$ and $Progr_0$ are obtained by processing exercise result marks using the Gauss method.

The possible nature of exercise progress dynamics according to (3) is represented in Fig. 5:

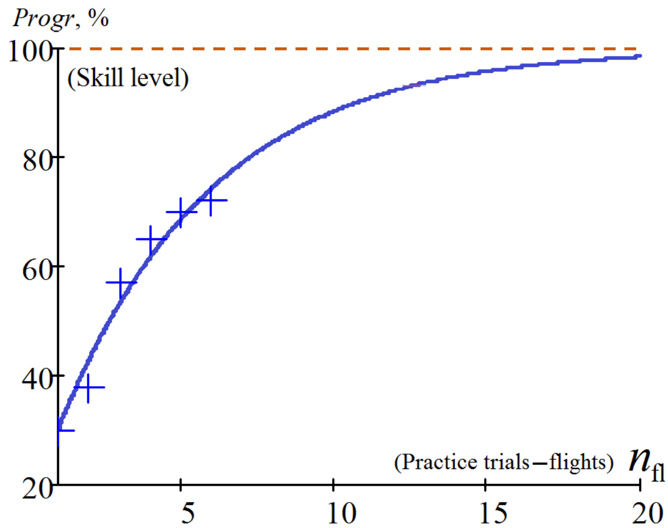


Fig. 5. The possible arc of learning curve using the approximation of exponential exercise progress evaluation.

To make the results maximally precise, it is important to evaluate each exercise accurately and in detail. The situation is made complicated by the fact that the conditions of exercises are changed from one exercise to another to make the crew experience as many probable flight situations as possible. This kind of learning does not correspond to the standard frequentative exercise scheme and the evaluation of a particular exercise can differ considerably from the actual progress level.

## IV. Evaluating the Progress of a Discrete Exercise

For the evaluation of a discrete exercise to be used in the assessment of skill dynamics, the produced evaluation has to be maximally sensitive even to the smallest progress changes. The evaluation has to include all the crucial aspects of the action at the same time focusing the attention on the crucial – the parts which directly influence the progress of the whole exercise.

The existing official evaluation techniques [1], [6] are mainly focused on a 2-grade evaluation (acceptable, unacceptable), and actually there are formulated end results to be achieved. Only the piloting technique is evaluated in quantitative figures, while the decision-making and discrete actions are not assessed at all or are assessed only through qualitative evaluation.

Many pilot instruction and training centres use their own evaluation systems with 3 to 5 grade detailing [8], [9], [13], [22], [25]. These types of assessment in many instances are approved or developed by the respective country’s CAA (Civil Aviation Administration) [12], [13] or military organizations [25]. However, for the main part, it is not specifically defined how the resulting evaluation should be formed and which of the partial assessments should be regarded as crucial in producing the resulting evaluation.

It should also be noted that most partial assessments can be obtained by processing flight registration data – from actual flights, as well as from training sessions on a full-flight simulator [7], [9]. In practice, by evaluating all flight parameters and actions in this way it can be observed [9] that high-level partial assessments dominate and that it is necessary to develop a specific methodology for producing the resulting evaluation.

The evaluation of a discrete exercise, particularly a test, should be focused on “absolute safety”. Thus, if something crucial does not comply with the requirements, the resulting evaluation should be “unacceptable”. However, progress evaluations should have more detailed assessments that would allow to identify the slightest positive improvements by simultaneously putting the emphasis on the lowest grades.

It is proposed to use a slightly modified 5-grade system with markings from 5 – excellent to 2 – unacceptable with transitional marking 2.5 – bad, but not disastrous (marking 1 will not be used since in school evaluation mark 1 usually means total incompetence and is rarely applied in practice).

Consequently, for the identification of aircraft crew skill dynamics, the following methods are proposed:

– For the evaluation of exercise progress, the partial assessment of the following activities should be used:
  - Keeping the flight parameters within the defined ranges;
  - Systems control (turning on, turning off);
  - Decision making in each exercise step;

– The emphasis should be put on the most important flight steps (summarizing the similar ones), and in each step the parameters should be classified by their importance into 3 groups:
  - Group 1 – the aim of the step is to reach the defined value of the parameter (criterion weight is 4);
  - Group 2 – the parameter directly influences the parameters of the first group (criterion weight is 2);
  - Group 3 – the parameter is evaluated, but it is not included in the first or second group (criterion weight is 1).

  For example, during the landing approach, the flight speed, vertical speed, lateral deviation and altitude should refer to the first group; pitch angle, bank angle and sideslip angle – to the second group, but load factor – to the third group.

– In accordance with the grading linguistic meaning:
  - Partial mark "5" means 'the aim is fully achieved', 'excellent' – therefore, the successes level for the following particular parameter, operation or decision is 100 %.
  - Partial mark "2" means 'the aim is not achieved', 'below acceptable standards' – success 0 %.
  - Partial mark "3" means 'average', 'good enough' – success ≈ 50 %
  - Partial mark „4" means 'good', 'above average', 'normally' – success ≈ 80 %
  - Partial mark "2.5" – 'below average, but not complete failure' – success ≈ 25 % to 30 %.

– The impact of marks on the progress evaluation can be quite precisely described by the approximation (2), (Fig. 6), which shows about 1.5 times larger impact of negative marks;

$$Progr(Mark) = 142.1 - 42.1 \cdot 1.5^{(5-Mark)}. \quad (2)$$

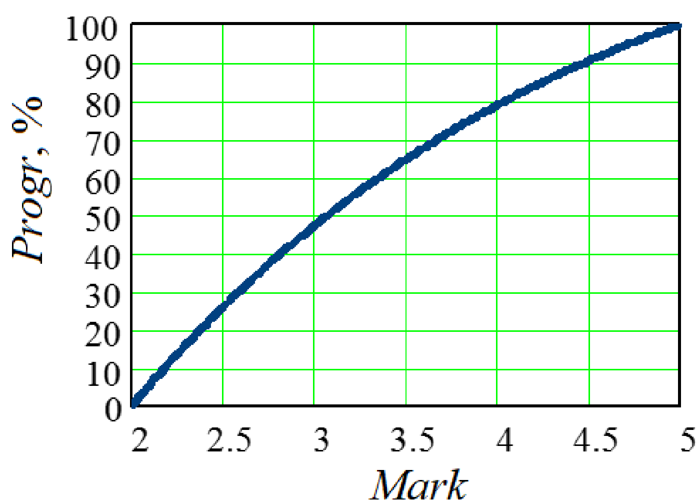


Fig. 6. Success in accordance with the linguistic meaning of marking.

– Evaluation of a particular action '*k*' should be calculated by summing up partial assessments taking into account their weight and 1.5 times larger impact of negative marks (3):

$$Mark_k = \frac{\sum_{i=1}^{n}(Mark_i \cdot 1.5^{(5-Mark_i)} \cdot Mcn_i)}{\sum_{i=1}^{n}(1.5^{(5-Mark_i)} \cdot Mcn_i)}, \quad (3)$$

where

$Mark_i$ particular partial mark;

$n$ number of different grades, marks;

$Mcn_i$ number of the marks of the particular $Mark_i$ grade (for the evaluation of piloting, it should be multiplied by the "weight" of a particular parameter: 4, 2 or 1).

– The relation (3) is used to acquire the resulting mark of piloting quality during each step; after that, the resulting mark of piloting quality for the whole exercise (*n* – number of steps); then the mark of discrete operations and decision making (summarizing all the partial marks); and finally of the whole exercise in total. If the partial marks take only the given fixed values, inserting them into the expression (3) will make it possible to obtain:

$$Mark_{\text{pil}} = \frac{5Mcn_5 + 6Mcn_4 + 6.75Mcn_3 + 6.9Mcn_{2.5} + 6.75Mcn_2}{Mcn_5 + 1.5Mcn_4 + 2.25Mcn_3 + 2.76Mcn_{2.5} + 3.375Mcn_2}. \quad (4)$$

If the partial marks are acquired through the calculation, for example, processing the data of objective control which has decimal values, the total evaluation of piloting will be more precise when $Mark_i$ is used without the approximation. In this case:

$$Mark_{\text{pil}} = \frac{\sum_{i=1}^{n}(Mark_i \cdot 1.5^{(5-Mark_i)} \cdot 2^{(3-gr_i)})}{\sum_{i=1}^{n}(1.5^{(5-Mark_i)} \cdot 2^{(3-gr_i)})}, \quad (4a)$$

where

$gr_i$ is the "weight" of the group according to the evaluation parameter: 4, 2 or 1.

– The quantity of partial marks for decision-making and discrete actions is rather small, therefore it is proposed to merge them and produce a total resulting grade $Mark_{\text{ddc}}$ in accordance with the expression, like in (4). Considering that the quantitative assessment techniques for these actions are still insufficiently developed, initially the level of "weight" for these marks should be attributed equally. If for the evaluation of actions we use uninterrupted timeliness distribution statistic function as, for example, in [9], we can also use the analogous expression (4a) to evaluate discrete actions.

– The resulting grade for the progress evaluation of an exercise consisting of resulting progress marks for piloting and discrete actions/decision making is:

$$Mark_{flight} = \frac{Mark_{pil}1.5^{(5-Mark_{pil})} + Mark_{ddc}1.5^{(5-Marl_{ddc})}}{1.5^{(5-Mark_{pil})} + 1.5^{(5-Mark_{ddc})}} \quad (5)$$

– The percentage evaluation of progress level for a particular exercise for learning curve construction is:

$$Progr_{\text{fl}} = 142.1 - 42.1 \cdot 1.5^{(5-Mark_{\text{flight}})}. \quad (6)$$

## V. Calculation of Learning Curve Parameters

If the learning process, i.e. the learning curve, is approximated with the help of expression (1), the initial level of progress is obtained from the progress assessments of discrete exercises before the exercise series $Progr_0$ and learning speed constant $Lsp$.

Since the progress evaluation of a particular exercise is rather approximate and the progress itself can be perceived as a plateau or even in decline (when the tasks of the exercise get complicated), for the calculation of approximation parameters it is necessary to use the Gauss Least Squares method including all the flights $n_{fl}$ of the exercise series.

In accordance with the Gauss method the learning speed constant is:

$$Lsp = \frac{1}{a}\left( n_{fl}\sum_{i=1}^{n_{fl}}(n_{fl_i} \cdot y_{fl_i}) - \sum_{i=1}^{n_{fl}} n_{fl_i} \sum_{i=1}^{n_{fl}} y_{fl_i} \right), \tag{7}$$

where

$$a = n_{fl}\sum_{i=1}^{n_{fl}} n_{fl_i}^2 - \left(\sum_{i=1}^{n_{fl}} n_{fl_i}\right)^2; \tag{8}$$

$$y_{fl_i} = \ln(100 - Progr_{fl_i}); \tag{9}$$

$n_{fl_i}$ index number of exercise $i$ within the exercise series.

The initial level of progress before the training:

$$Progr_0 = 100 - e^b, \tag{10}$$

where

$$b = \frac{1}{a}\left( \sum_{i=1}^{n_{fl}} n_{fl_i}^2 \sum_{i=1}^{n_{fl}} y_{fl_i} - \sum_{i=1}^{n_{fl}} n_{fl_i} \sum_{i=1}^{n_{fl}} (n_{fl_i} \cdot y_{fl_i}) \right). \tag{11}$$

The graphical interpretation of the initial level of progress before the exercise series $Progr_0$ and the learning speed constant $Lsp$ are represented in Fig. 7.

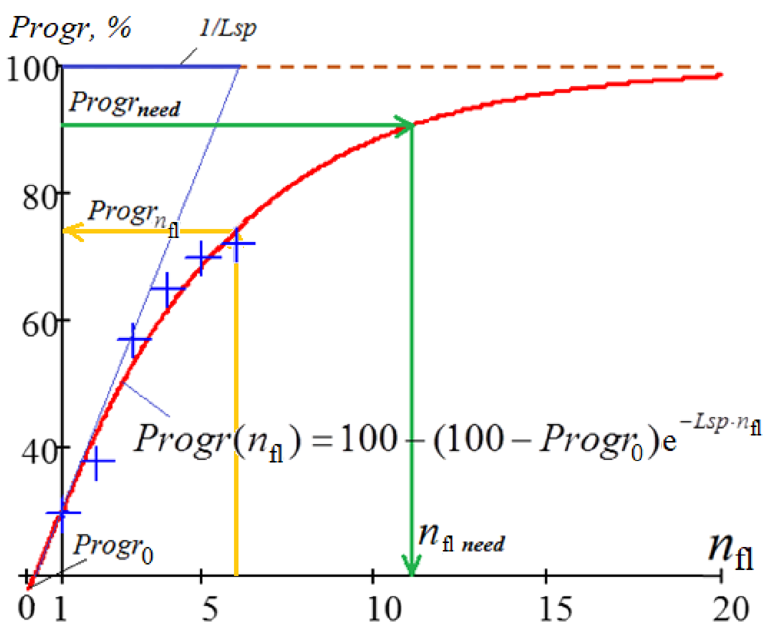


Fig. 7. The approximation of the quantity of exercises necessary for achieving the required progress level.

## VI. Learning Curve Application

The initial level of progress before the exercise series Progr0 characterizes the initial level of qualifications and depends on the theoretical preparedness, previous flight experience, hiatus in piloting practice, etc.

The learning speed constant *Lsp* describes the speed of skill acquisition and the abilities and teamwork of a particular crew, however if the curve is constructed on the basis of flights by multiple crews, it can be used to judge the efficiency of the training course and learning methodology.

If a definite number of exercises have been completed, the learning curve makes it possible to forecast the required total amount of the exercises $n_{\text{fl need}}$ necessary for achieving the needed learning level $Progr_{\text{need}}$.

The needed exercise quantity $n_{\text{fl need}}$ can be determined either graphically (Fig.7) or by using the following expression:

$$n_{\text{fl need}} = 1 - \frac{1}{Lsp} \ln \frac{100 - Progr_0}{100 - Progr_{\text{need}}}. \quad (12)$$

The dispersion of exercise assessments around the approximated learning curve is also an important feature of the learning process. The dispersion can be calculated in accordance with:

$$D_{Progr} = \frac{1}{n_{\text{fl}}} \sum_{i=1}^{n_{\text{fl}}} Progr_{\text{fl}_i} - Progr(n_{\text{fl}_i}))^2, \quad (13)$$

where $Progr(n_{\text{fl}_i})$ is the point on the learning curve which corresponds to a particular exercise calculated in accordance with (1).

The dispersion characterizes both the stability of skill acquisition by a particular crew and the accuracy of the exercise sequence of the learning program itself when it is calculated for a large quantity of crews. The dispersion is also a criterion by minimizing which it is possible to optimize the calculation algorithm of discrete exercise progress level.

The learning curve can also facilitate the rationalization of the learning process. Thus, by analyzing the progress level dynamics of a particular number of trainees, they can be divided, for example, into 3 groups depending on the achieved progress level by the end of training. A new group of trainees can also be divided, with a large probability, into 3 corresponding groups after the completion of the first 3 to 4 exercises. Then a slightly different further training program can be planned for each group.

It is advisable to form the final evaluation of learning steps not only from the assessment of the final control exercise, but also by taking into consideration the marks of previous exercises. The resulting grade for a series of exercises can be determined as a grade which corresponds to the progress level on the learning curve for the flight quantity $n = n_{fl}$ (Fig. 7):

$$Mark_{n\text{fl}} = \frac{5.767 - \ln(42.1 + (100 - Progr_0)\, e^{-Lsp \cdot n_{\text{fl}}})}{0.405}, \quad (14)$$

where

$n_{\text{fl}}$ is the index number of the last exercise.

## VII. Conclusion

The offered method of learning curve construction has to be verified and specified in practice and the best way to do it is by using an automated equipment of discrete exercise assessment that is based on the instrumental means of objective control in combination with the expert evaluations of instructors.

If the learning curve is not constructed, it is proposed to use the linear assessment of previous exercise weights taking into account from 1 to 5 of the previous assessment results, since the evaluation of exercise series based only on the results produced during the final exercise may have a random nature. The final exercise, of course, has a greater impact. At the same time, the number of included exercises must not be too large so that the total evaluation would not be negatively affected by the previous mistakes which have already been eliminated during the learning process.

The resulting assessments of discrete exercises depending on the quantity of included exercises should be multiplied in accordance with the weight coefficients listed in the following Table I:

TABLE I

WEIGHT COEFFICIENTS FOR ASSESSMENTS DEPENDING ON THE QUANTITY OF INCLUDED FINAL EXERCISES

| QUANTITY OF INCLUDED EXERCISES | EXERCISE INDEX | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 2 | 0.33 | 0.67 | | | |
| 3 | 0.17 | 0.33 | 0.50 | | |
| 4 | 0.10 | 0.20 | 0.30 | 0.40 | |
| 5 | 0.07 | 0.13 | 0.20 | 0.27 | 0.33 |

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