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“*G_Sim*” SOFTWARE PROVIDING SIMULATIONS OF HUMAN PHYSIOLOGICAL RESPONSES TO ±Gz ACCELERATIONS

Specialized software “*G_Sim*”, providing simulations of human physiological responses to dynamic Gz accelerations, is created and tested. “*G_Sim*” is based on a previously developed and published quantitative mathematical model (QMM) that describes human hemodynamics under given Gz profiles without or with special protective tools and algorithms. “*G_Sim*” is a modern information technology realized as an autonomic executive module in the Delphi Pascal environment. By default, the biological parameters of QMM are tuned for the mean man, who is 175 cm in height and has a 70 kg mass. “*G_Sim*” has an intuitive user interface (UI) that provides the user with procedures necessary to actualize characteristics of QMM, realize a computer experiment (simulation), visualize its results in graph forms for analysis, and save the chosen data for further analysis. The actualization concerns biological data associated with human sex, anthropometrics, age, and non-biological characteristics including acceleration profiles, characteristics of the anti-G suit, breathing techniques, and muscle stressing mode. UI's special windows provide additional tunings of the basic QMM. “*G_Sim*” upgrades the traditional training techniques on centrifuges and test flights. The novel beneficial effect of “*G_Sim*” provides the future fighter pilot with realistic-like visual knowledge concerning the dynamics of physiological and protective events. Therefore, simulations will clearly show ways to optimize the combination of artificial protections to prevent negative effects (loss of vision or consciousness). Such knowledge will shorten training and minimize the anthropogenic risk of serious injuries or catastrophes during the training. Test simulations presented in the paper mainly illustrate the potential of “*G_Sim*” as an assistant informational technology.

Keywords: fighter pilot, training, risk, catastrophe, information technology.

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ПРОГРАМНЕ ЗАБЕЗПЕЧЕННЯ «*G_Sim*» ДЛЯ СИМУЛЯЦІЇ ФІЗІОЛОГІЧНИХ РЕАКЦІЙ ЛЮДИНИ НА ±Gz ПРИСКОРЕННЯ

Створено та протестовано спеціалізоване програмне забезпечення «*G_Sim*», що забезпечує моделювання фізіологічних реакцій людини на динамічні прискорення Gz. «*G_Sim*» базується на раніше розроблені та опубліковані кількісні математичні моделі (КММ), яки описують гемодинаміку людини за заданими профілями Gz без або з використанням спеціальних захисних інструментів і алгоритмів. «*G_Sim*» — сучасна інформаційна технологія, реалізована у вигляді автономного виконавчого модуля в середовищі Delphi Pascal. За замовчуванням біологічні параметри QMM налаштовані на середнього чоловіка, який має зріст 175 см і вагу 70 кг. «*G_Sim*» має інтуїтивно зрозумілий інтерфейс користувача (ІК), який надає користувачеві процедури, необхідні для актуалізації характеристик КММ, реалізації комп’ютерного експерименту (симуляції), візуалізації його результатів у вигляді графіків для аналізу та збереження вибраних даних для подальшого аналізу. Актуалізація стосується біологічних даних, пов’язаних зі статтю людини, антропометричними показниками, віком і небіологічними характеристиками, включаючи профілі прискорення, характеристики анти-G костюма, техніки дихання та режим навантаження на м’язи. Спеціальні вікна ІК забезпечують додаткові налаштування основного КММ. «*G_Sim*» вдосконалює традиційні методи навчання на центрифугах і тестових польотах. Новий корисний ефект «*G_Sim*» є в тому, що симуляції надають майбутньому пілоту винищувача реалістичні візуальні уяви щодо динаміки фізіологічних і захисних подій. Таким чином, симуляції чітко покажуть шляхи оптимізації комбінації штучних засобів захисту для запобігання негативним ефектам (втрата зору чи свідомості). Такі знання скоротять навчання та мінімізують антропогенний ризик серйозних травм або катастроф під час навчання. Тестове моделювання, представлене в статті, в основному ілюструє потенціал «*G_Sim*» в якості допоміжної, інформаційної технології.

Ключові слова: пілот-винищувач, навчання, ризик, катастрофа, інформаційні технології.

Introduction

Modern high maneuverable fighter aircraft is a source of rapid altering and often highly sustained extreme accelerations [1-3]. Both physiological [4-9] and biotechnical [10-12] problems that arose in parallel with an increase in military aircraft's maneuverability have been properly investigated [4-18].

Human physiology evolutionarily adapted to the one g Earth environment, cannot provide adequate functioning of the brain and eyes of a sitting person. These organs, very sensitive to oxygen and glucose supply, suffer in parallel with the decreasing of their input blood pressure. Under accelerations, the hydrostatic pressure increases proportionally to the acceleration value. This additional factor creates opposite effects in vessels located upper or lower the heart: in upper arteries blood inflows become difficult while the flow toward body lower regions becomes easier. In veins, alterations are opposite directions. The altered pressure gradients redistribute blood volumes worsening the circulation at the cardiovascular scale. Accelerations also alter the ventilation-perfusion ratio in lungs [13,14].

Most critical are extreme value positive (+Gz) accelerations acting in the direction of head-legs, or negative (-Gz) accelerations acting in the opposite direction [4-6]. In terminal zones (brain, eyes), the lowered circulation causes oxygen lack and worsens the pilot's vision and consciousness [9,12]. Under -Gz, the elevated local blood pressure in the eyes and brain causes rupture of microscopic vessels and hemorrhages. Both the value of Gz and the gradient of acceleration change play an essential role in these events.

Under relatively slow (0.1-0.4 g/sec) linearly increasing +Gz accelerations, a mean healthy person not using artificial protections is operable for approximately +4Gz accelerations [11]. Further elevation of the G-load causes the G-lock phenomenon usually disappearing after a break [2,6,8]. Modern fighter aircrafts can provide acceleration gradients exceeding 2 g/sec. This requires special protection algorithms and devices. Currently, typical protection algorithms include the use of special pneumatic or water-augmented anti-G suits, muscle stress, as well as breathing with a positive pressure air [1,11,17]. The adaptive protection algorithms combining multiple methods depending on the dynamics of accelerations are the most effective. So, technologies helping to optimize the use of protective methods and tools are encouraged.

Traditionally, empiric research on centrifuges is the main way for inventing more effective protections [1,5,6-8]. Mathematical models realized as special software [18-20] showed additional ways for maximizing the individual resistance of a pilot to the negative effects of accelerations. The experience in the last area was taken into account during the development of an advanced version of basic models [21-23] necessary to create our current version of "***G_Sim***" software which is autonomic executive software oriented to PC.

The goal of this article is to inform potential users of our simulator about its purpose and possibilities.

The user interface of "*G_Sim*"

Every interaction with "***G_Sim***" is provided by the user interface (UI). Its general view presented in Fig.1. indicates that "***G_Sim***" is oriented to problems associated with dynamic accelerations that appear either when employing a professional centrifuge or during the piloting of military fighter aircraft.

The mathematical model of cardiovascular physiology of a healthy and physically well-trained human sitting in a standard aviation chair is the basis of our simulator [22,23]. Fig.1. also shows that standard protection tools are also modeling subjects.

In the upper left sector of Fig.1., one can see eight special icons that provide the user with all the procedures necessary to prepare and execute a single computer experiment (simulation).

The icon containing a picture of a sited human and the abbreviation "SETS" is the main one clicking which the user opens a window shown in Fig.2.

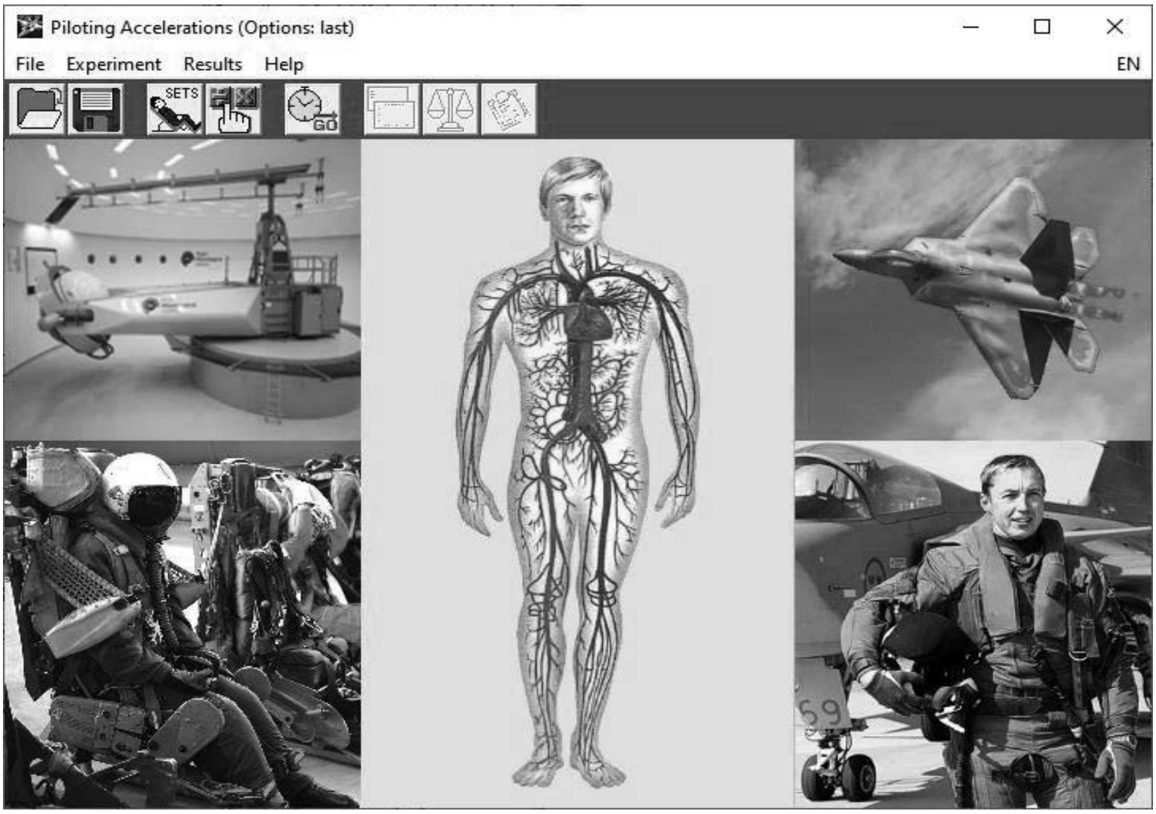


Fig. 1. General view of the user interface of ***"G_Sim"***.

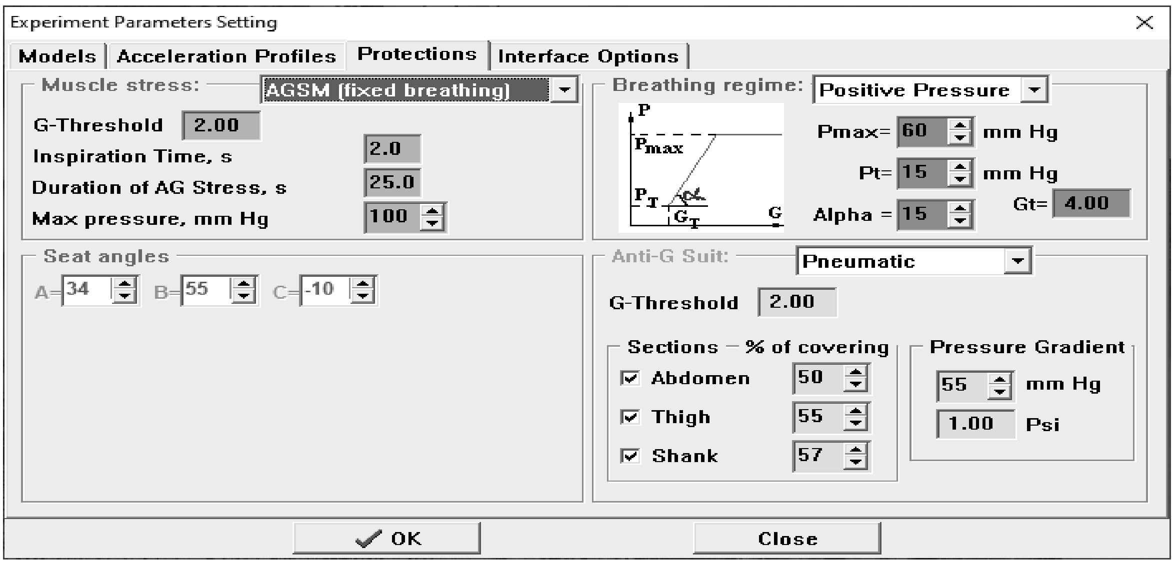


Fig. 2. The main window form to prepare a single simulation. This image shows the expanded content of the operations that can be accessed by clicking on the menu bar "Protections".

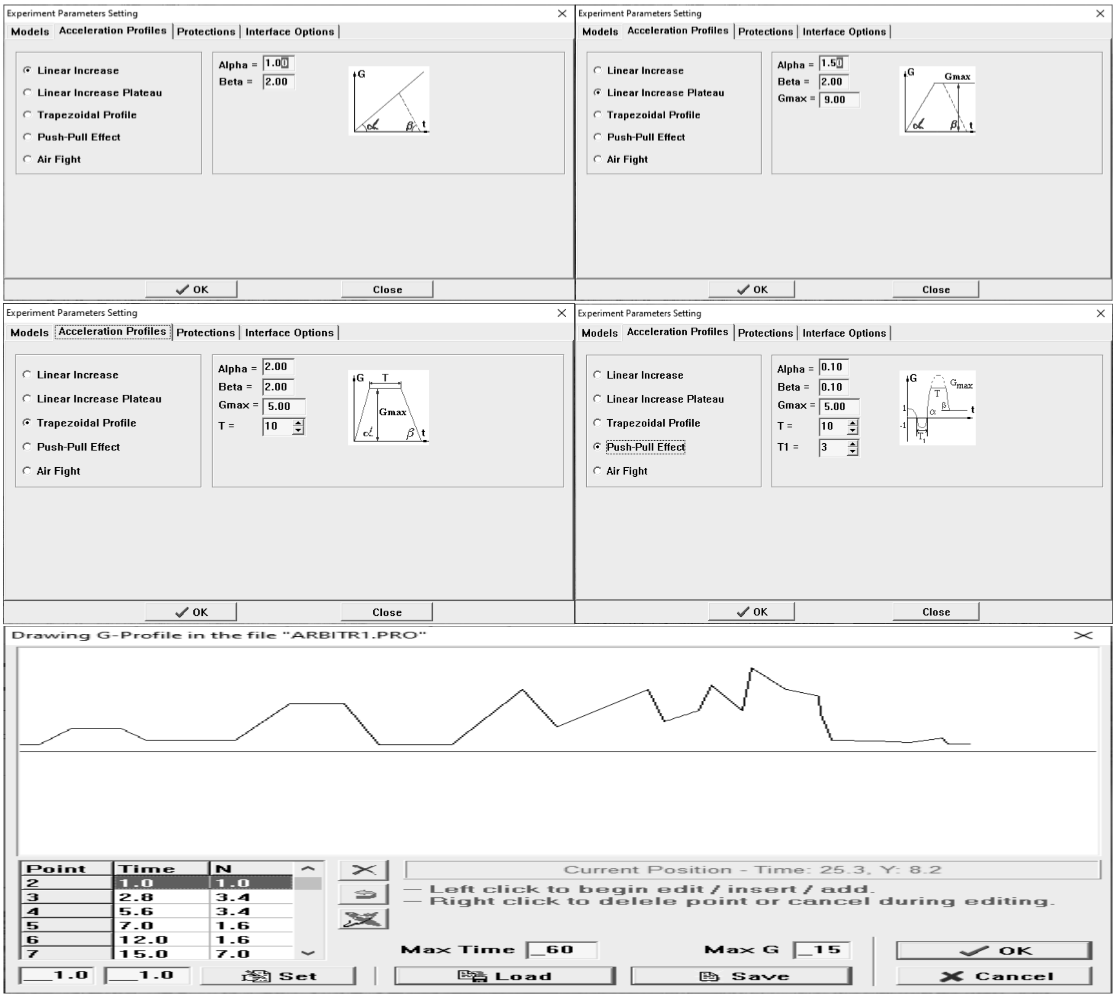
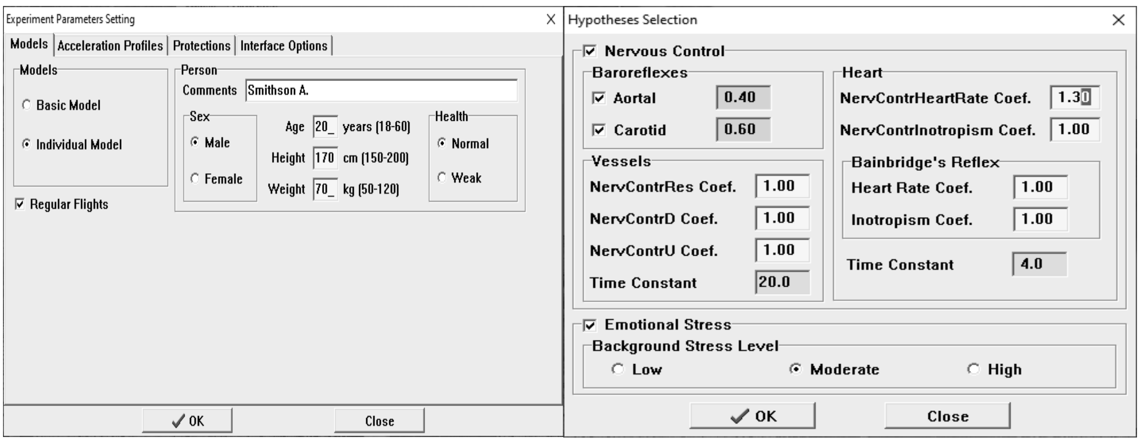


Fig. 3. The window form provides settings of parameters that determine the acceleration profile. Using the bottom-located form the user can construct an arbitrary acceleration profile imitating complex combat maneuvers.

By clicking on the menu bar “Models” or “Interface Options”, the user can actualize the physiological model.



A B

Fig. 4. Special window forms provide settings of parameters that determine actual parameters of QMM: A) basic or personal model including the health level; B) activities of physiological mechanisms controlling the circulation.

The icon "GO" located in the central area of Fig. 1. starts the program's calculation according to the actualized set of parameters. According to the algorithm, the calculation is over if special events (e.g., G-LOC) happen or the time limit is used. Then, "G-Sim" builds graphs presenting the dynamics of model characteristics. They include both physiological and technical data. The physiological data concern blood pressures, flows, and volumes in certain body parts. The technical data concerns specific parameters of protection. Theoretically, the data set could provide advanced experts with additional capabilities for investigating new algorithms for protection optimization.

In this article, we illustrated only a part of the information. The main window to illustrate the most important information contains three sections. Each combines a special sub-set of variables (see Figures 5-9).

Fig.5. represents the basic data concerning a relaxed healthy human sitting in an armchair but without using any protection. The bottom section presents the acceleration dynamics. The middle section presents the dynamics of the pressure PExt provided by a compressor and six specific pressures (in this simulation, pressures in three sections of the pneumatic anti-G suit are not presented but are calculated and can be illustrated using specific activators). PExtThr, PMuscle, and PBrLiq represent pressures in the thorax, body muscles, and liquor respectively. Hemodynamic variables are collected in the upper section. In this case, end-systolic (APs) and end-diastolic (APd) are not shown. MAP is the mean pressure in the aortic arch, CO is the cardiac output, SV is the stroke volume, HR is the heart rate, MCAP, PES, and CVP represent mean pressures in the carotid sinus, eye arteries, and central vein respectively. Vertical dotted lines indicate time moments for acceleration start and maximal levels. In this simulation, neither G-LOC nor vision loss happened: the simulation scenario was realized totally.

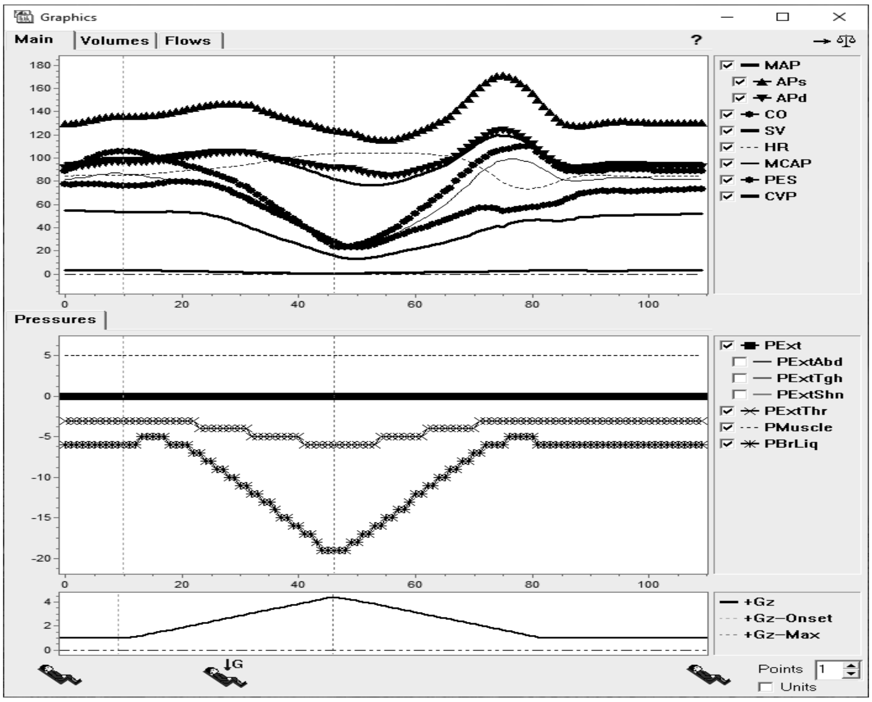


Fig. 5. The basic simulation illustrates the physiological responses of a relaxed healthy human to a slow altering (0,1 g/sec) linear profile acceleration. The person sitting in an armchair does not use protection. Before G-onset (marked with a first vertical dotted line) parameters indicate a practically steady-state mode. At the 46th second of a load (marked with a second vertical dotted line), at a value of G=4,35g, the program automatically activated break because of the G-LOC event.

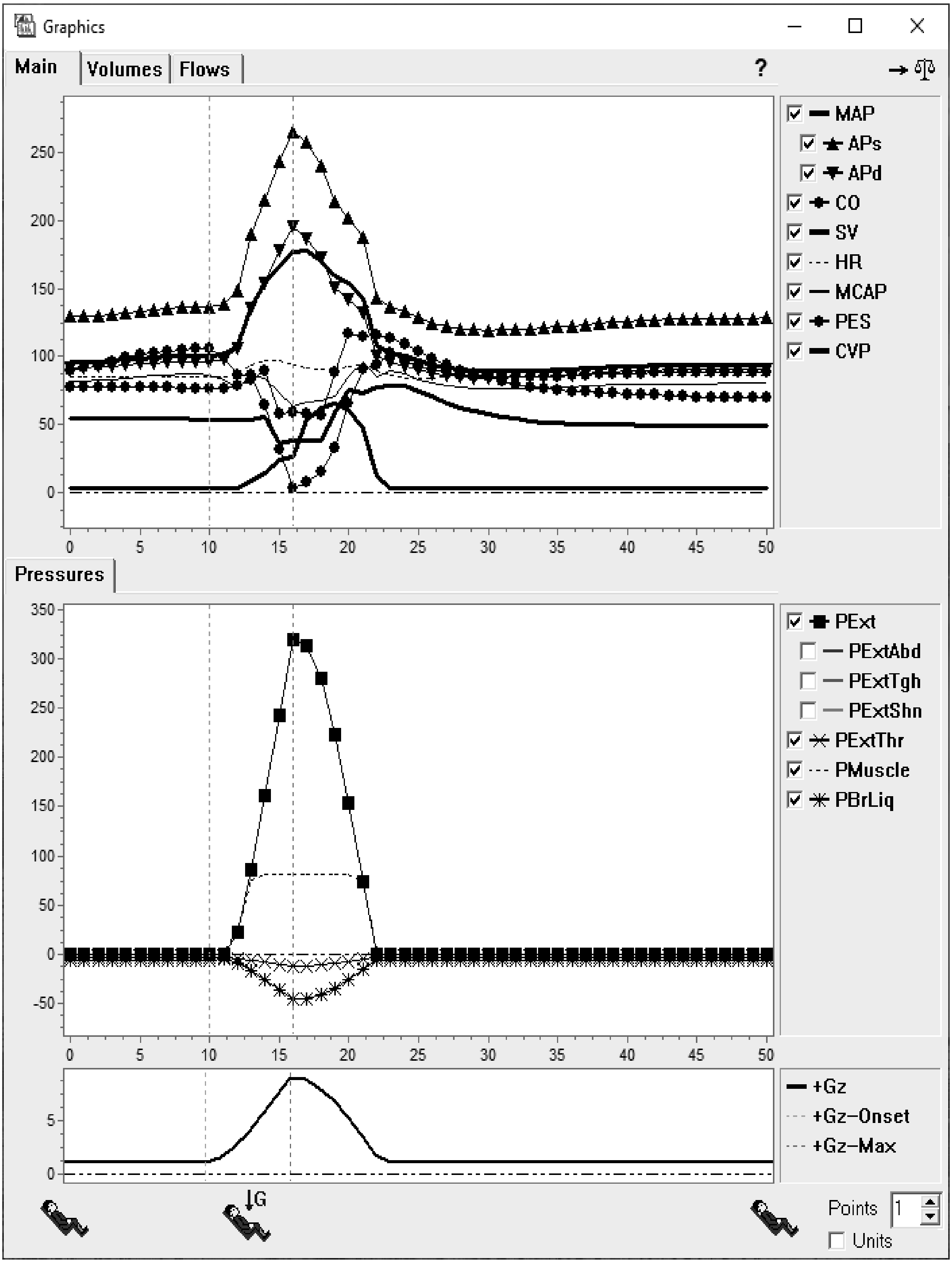


Fig. 6. A simulation scenario with a trapezoidal G-profile using a standard pneumatic anti-G suit, natural breathing, and moderate muscle stress.

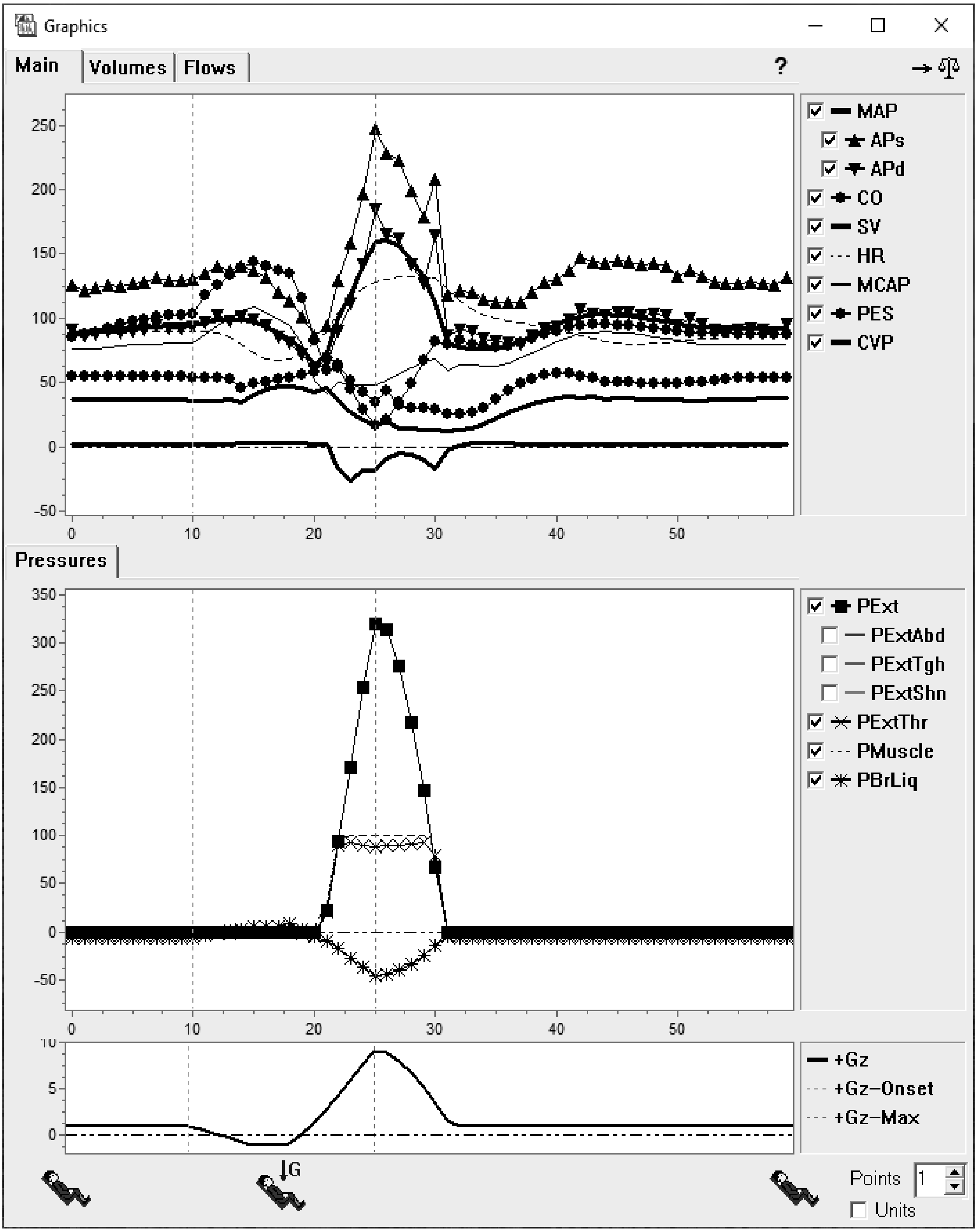


Fig. 7. A simulation of a "Push-Pull" scenario using standard pneumatic anti-G suit, natural breathing, and AGSM-technique with maximal muscle stress of 100 mm Hg accompanied with inspiration time of 2 sec and duration of AG-stress of 20 sec.

As Fig. 7. illustrates, our "mean man" resisted up to 9g accelerations for a 20 sec plateau. Pay attention that end-systolic (APs) and end-diastolic (APd) pressures are also shown.

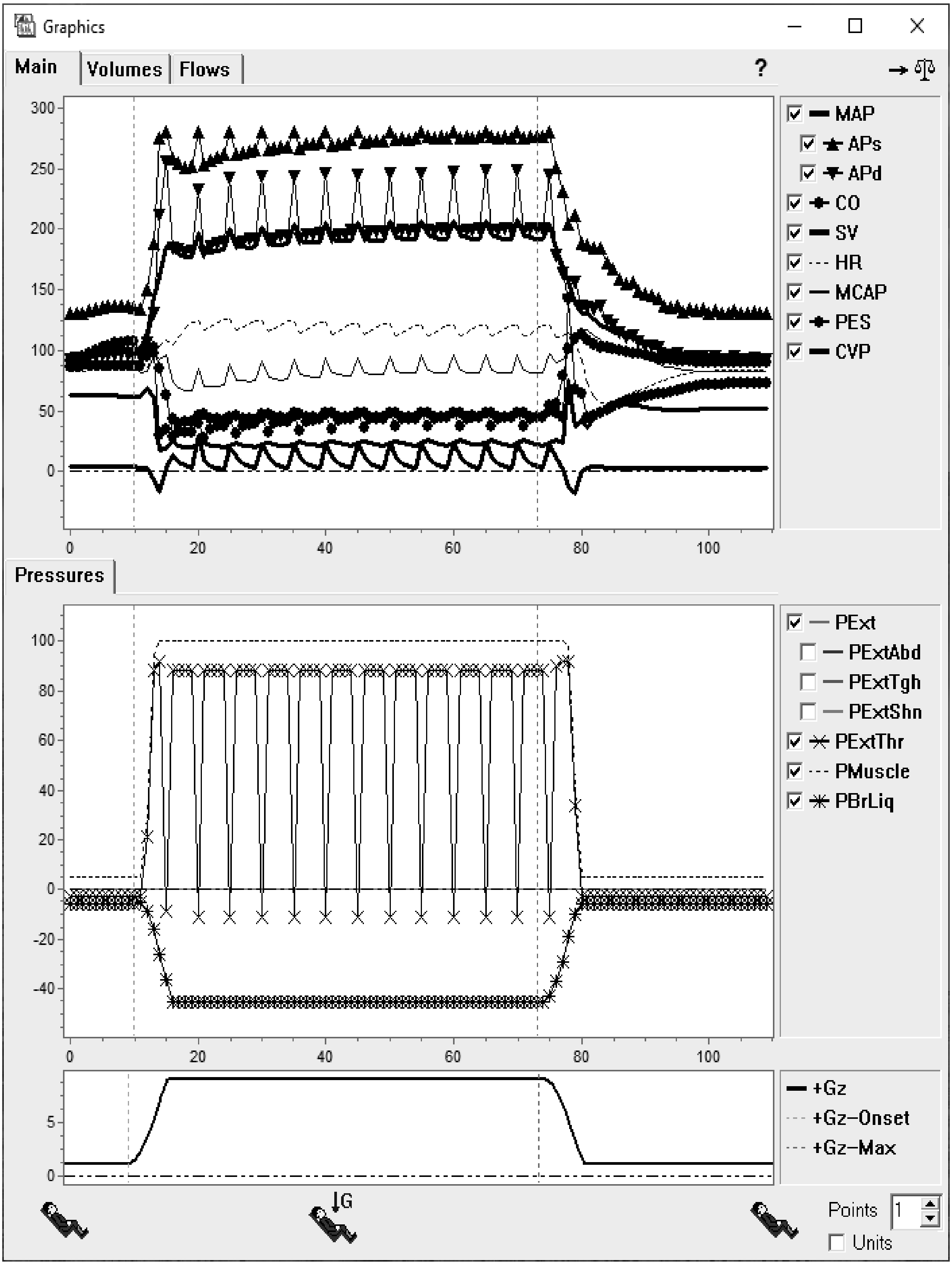


Fig. 8. A simulation of a trapezoidal acceleration scenario with a long-lasting plateau using a hydraulic anti-G suit, natural breathing, and special technique of AGSM (sharp inspirations of 2 sec, maximal muscle stress of 100 mm Hg for 3 sec, and sharp expirations of 2 sec).

Discussion

Not all the information concerning the capabilities of our "G-Sim", in particular, describing functionalities of the icons of UI was presented in this article. In addition to the space limit, another reason is that the version of "G-Sim" used in this publication is not yet the final software. We continue to work on upgrading software to make it maximally useful and convenient in practice.

Although the mean man model used in this "G-Sim" already provides the student-pilot with important visualized dynamics of physiological and technical data. Every pilot has specific anatomical, physiological, and psychological individualities that potentially can modify the pilot's resistance to negative effects of accelerations. Therefore, we are working on algorithms that, being not very complex, could provide the individualizations of basic mathematical models. Principally, we hope to achieve acceptable results using relatively simple algorithms that correct initial parameters of BMM mainly using passport and anthropological data (namely, such data is reflected in the window form in Figure 4A).

Another aspect of upgrading our "***G-Sim***" we see in imitating characteristic phenomena, caused by a deterioration of the eyes and brain oxygen supply. We already have created a model and program modules visually imitating: 1) the narrowing of the field of peripheral vision including the loss of vision; 2) loss of consciousness as an extreme manifestation (G-lock).

Certainly, the main goal of our "G-Sim" is to facilitate the pilot's acquiring the needed skills. In this context, an essential role does play the factor of dynamics. As physical events develop to speed, in-time counteracts are extremely important to provide effective resistance. "***G-Sim***" is the single technology using which the student-pilot can imitate every thinkable scenario and find the most effective combination of algorithms for maximizing the protective effect.

An additional use of "***G-Sim***" is that it can be used to provide "post-factum" simulations for analysis and understanding non-trivial causes of failures.

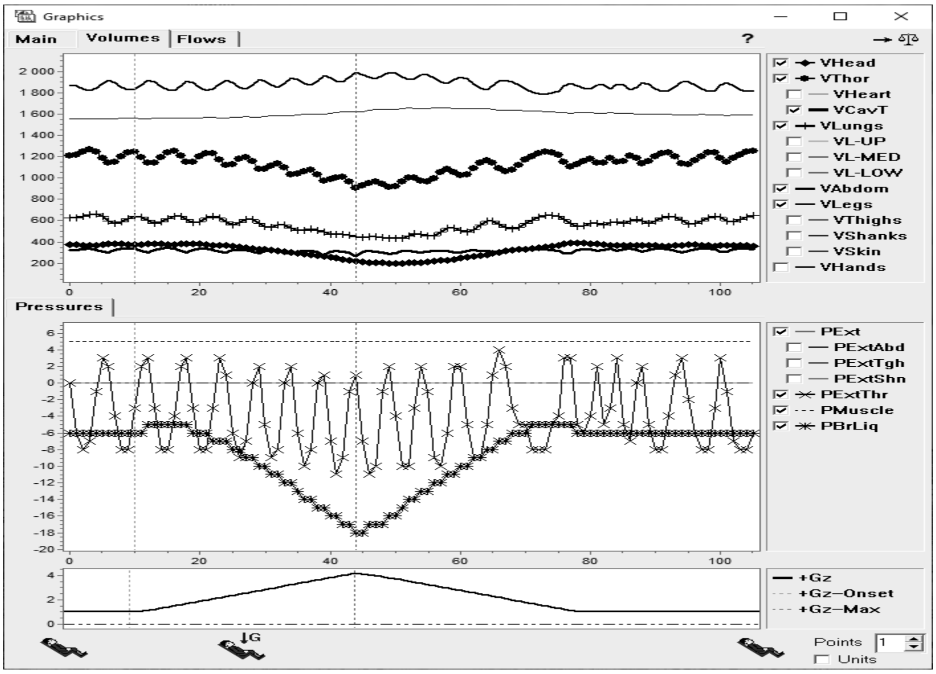


Fig. 9. The simulation scenario described in Fig.5. This case the dynamics of blood volumes in certain body sections are illustrated.

Conclusion

Combat maneuvers of modern fighter aircraft originate extreme accelerations negatively influencing on pilot's physiology and operability. Until recently, empirical investigations were the only way to develop and test protective methods and tools providing fighter pilots functionality under combat maneuvers. The main tools used for acquiring student pilot initial skills necessary to resist the negative effects of dynamic extreme accelerations were centrifuges. The skilling process of student pilots of modern fighter aircraft is not duly formalized yet. Our special computer simulator "***G-Sim***" provides the user with a user-friendly intuitive interface for construction and execution of a computer experiment (a simulation) that visualizes additional dynamic variables concerning characteristics of both human physiology and protections under arbitrarily formed acceleration profiles. By comparing human physiological responses under different simulated scenarios (without use of protections, with use of their different combinations), student-pilots and their instructors can optimize the individually optimal tactics for maximizing the resistance and performance capability of the future fighter pilot.

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