

#### 7<sup>th</sup> USER CONGRESS DEBRECEN, 13 – 16 SEPTEMBER 2019



German Air Force Center of Aerospace Medicine

METHODS TO DETERMINE AND OBJECTIFY THE PERFORMANCE OF ANTI-G SUITS

EXPERIENCES OF HUMAN-USE CENTRIFUGE STUDIES

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The *performance increase* in *recent combat aircraft* generations:

- makes a *reliable anti-G protection* a condition sine qua non,
- prompted the development of *new* anti-G protection systems.





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# MODERN ANTI-G PROTECTION



Systems became *much more complex:* 

*body surface covered* has been *increased* by using ECAGT or full coverage anti-G suits.

*assisted PBG* has been integrated into the G-protection systems.

Methods for evaluating the efficiency of anti-G protection systems have to improve continuously.



# EVALUATION OF ANTI-G PROTECTION



*Evaluation* of the system efficiency of these AGS became *much more complex*.

#### Traditionally

- subjective data and
- objective data (performance data like G-level tolerance and G-time tolerance) were used.

However, even today it is difficult to noninvasively gather valid objective data in an high-G environment.





- Review options to validate the performance of AGS
- Present complementary means for an *objective AGS evaluation* evolved in our lab during several comparative studies conducted in the centrifuge of the GAFCAM.
- Demonstrate objective, reliable and valid data which could serve as a decision-making aid for the validation of the efficiency and ultimately the improvement of the AGS and/or measures.





# *CSU-13*

#### Company: RFD Beaufort

- Operating principle: pneumatic
- Composed of five interconnected bladders
- Covers legs and abdominal region
- Pressurized with air from the jet engine compressor during increases of G
- Worn over the flight suit





# LIBELLE G-Multiplus®

Company: Autoflug GmbH

- Operating principle: hydrostatic with fluid muscles
- Self contained anti-G ensemble
- Comfortable whole body anti-G suit
- Arms covered
- No PBG used





# E-LIBELLE

### Company: Autoflug GmbH

- Operating principle: hydrostatic with fluid muscles
- Self contained anti-G ensemble
- Comfortable whole body AGS
- Arms protected
- No PBG used
- Changes made: Fluid muscles (wider, different run)

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#### **VOLANTI SUBVENIMUS**

13.09.2019

8





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### AIRCREW EQUIPMENT ASSEMBLY

#### Company: RFD Beaufort

- Operating principle: pneumatic
- Whole body anti-G suit consisting of full coverage anti-G trousers and flight jacket with chest counter pressure vest
- PPG is used
- Arms not covered
- Worn over the flight suit
- Weight: just around 6-8 kg

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### PAGE+

### Company: Autoflug GmbH

- Libelle G-Multiplus<sup>®</sup> and AEA hybrid form
- Operating principle: combined pneumatic and hydrostatic
- Whole body anti-G suit
- Trousers and belly bladder pneumatic
- Arms covered (fluid muscles)
- PBG up to 20 mmHg





# G-RAFFE

#### Company: G-NIUS / iii solutions

- Operating principle: pneumatic
- Comfortable whole body anti-G suit
- Arms covered
- Worn underneath the flight suit
- Weight: just around 1000 g
- No PBG used



# ASPECTS OF CARDIOVASCULAR FUNCTION CRUCIAL FOR THE PERFORMANCE UNDER HIGH G<sub>z</sub>



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12





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13



#### COMPONENTS OF THE PPG SIGNAL





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#### SETUP OF THE TESTSTATION





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# SUBJECTS



#### 100 Gradual Onset Runs

	AGE	HEIGHT	WEIGHT	SUIT
PILOTS	36.53	180.6	81.71	AEA
N = 17	± 3.76	± 6.49	± 6.89	vs
				LIB
PILOTS	36.06	179.7	86.4	O-AEA
N = 18	± 4.9	± 5.7	± 11.6	vs
				E-LIB
NOVICES	20.50	181.92	80.83	NO
N = 10	± 0.85	± 4.54	± 6.20	AEA
				LIB





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Original recording of amplitude changes in the pulse wave during a GOR with an onset rate of  $0.1 G_z/s$ 



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# DETERMINING THE EFFICIENCY OF ANTI-G SUITS BY USING THE AC PORTIONS OF THE PPG IN GOR



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#### *QUANTITATIVE EVALUATION OF AC PORTIONS OF THE PULSE WAVE*





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#### AC PORTIONS IN NOVICES AND AIRCRAFT PILOTS





### PRESSURE-VOLUME DIAGRAM OF THE AORTA CHANGES WITH AGE





### AEA WITH AND WITHOUT PRESSURE BREATHING







# DETERMINING THE EFFICIENCY OF ANTI-G SUITS BY USING THE DC PORTIONS OF THE PPG IN GOR

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23



#### *QUANTITATIVE EVALUATION OF THE DC PORTIONS OF THE PULSE WAVE*



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#### DC PORTIONS OF THE PULSE WAVE AS AN INDICATOR OF VASCULAR BED FILLING IN GOR



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#### DC PORTIONS OF THE PULSE WAVE AS AN INDICATOR OF VASCULAR BED FILLING IN GOR



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## DETERMINING THE EFFICIENCY OF ANTI-G SUITS BY USING THE DC PORTIONS OF THE PPG IN FREE ROR



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### PROFILES USED

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#### PARAMETERS MEASURED









Determined by using the time integral over  $G_z$  values reached and by integrating selected  $G_z$  values.



















$$DC_{810} = \frac{1}{15} \sum_{i=-1}^{-15} DC_{810}(t_i)$$

 $DC_{810normalized}(t_i) = DC_{810}(t_i) - DC_{810}$ 

$$\overline{DC_{810normalized}} = \frac{1}{n} \sum_{j=0}^{n-1} (DC_{810normalized}(t_i)) \qquad j=0,1,2,3,\ldots,n-1$$

$$\overline{DC_{810normalized}} = \frac{1}{n} \sum_{j=0}^{n-1} (DC_{810}(t_i) - DC_{810}) \qquad j=0,1,2,3,\ldots,n-1$$

$$\overline{DC_{\$10normalized}} = \frac{1}{n} \sum_{j=0}^{n-1} ((DC_{\$10}(t_j) - \frac{1}{15} \sum_{i=-1}^{-15} DC_{\$10}(t_i))$$

j=0,1,2,3,...,n-1





# DETERMINING THE EFFICIENCY OF ANTI-G SUITS BY USING THE VOLUME LOSS INDEX IN ROR



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33



# SUBJECTS

N = 17

### 34 Rapid Onset Runs (ROR)

	AGE	HEIGHT	WEIGHT	SUIT
PILOTS N = 17	36.06 ± 4.9	179.7 ± 5.7	86.4 ± 11.6	O-AEA vs E-LIB

Luftwaffe Wir. Dienen. Deutschland.



Gz [g]



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#### VLI COMPARISON OF AEA AND LIB IN ROR



\* = significantly different from 1 Gz (AEA or LIB) (p < 0.05)



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# ASPECTS OF PULMONARY FUNCTION CRUCIAL FOR OXYGEN UPTAKE AND PERFORMANCE UNDER HIGH G<sub>z</sub>



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36







Jaeger MasterScreen PFT Pro before (left) and after modification and adaptation (right) to the conditions present at the human use centrifuge







#### DETERMINATION OF PULMONARY FUNCTION

Measurements of:

 parameters of ventilation TLC, VC, RV, RV/TLC, V<sub>A</sub>

2. parameters of diffusion DLCO, DLNO, Dm

3. parameters of perfusion Vc



#### DETERMINATION OF PULMONARY FUNCTION

>Different G<sub>z</sub>-profiles resulted in disturbances of ventilation, perfusion and diffusing capacity of the lung in both systems tested.

> Independent of the AGS used, significant decreases of TLC, VC and  $V_A$  were recorded in most profiles immediately after centrifuge rides.

 $\geq$  An increase of the ratio of RV over TLC could be found, being statistically significantly higher when using a system with a belly bladder.

> DLNO<sub>SB</sub> and Dm significantly decreased, whereas Vc increased for both systems following G<sub>z</sub>-acceleration.



- Traditional methods to assess the AGS impact on the pilot's performance and cardiovascular system feature some shortfalls.
- By implementing the analysis of DC and AC portions of the PPG into the assessment process it is possible to uncover even small performance differences of AGS and verify them objectively.
- The necessary methodology (PPG) is easy to use and applicable in both, GOR and in freely eligible ROR even in a high-G<sub>z</sub> environment and even irrespective of pilots' cooperation.
- By calculating a volume loss index (VLI), it is also possible to reveal even small differences in the performance of different AGS, allowing them to be verified and compared objectively.
- When PBG is used, the evaluation process should also focus on pulmonary function. This allows to determine the degree of disturbances of lung function parameters and the formation of acceleration atelectasis accompanying G-forces.







#### Eurofighter pilots from:

- Laage (JG 73 "S")
- Neuburg (JG 74)
- Nörvenich (JaboG 31 "B")
- •Wittmund (JG 71 "R")
  - Austria





- Team of the Department of Flight Physiology of the GAF IAM in Koenigsbrueck
- Rainer Stuwe and team / Autoflug
- Andreas Reinhard and team/ iii solutions
- > Team of **G-nius** / Pte. Ltd. Singapore



#### THANK YOU VERY MUCH FOR YOUR ATTENTION!





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