SELECTING OPTIMAL GRADIENT FACTORS FOR USE BY BELGIAN MILITARY DIVERS

MORE CONSERVATIVE SETTINGS ARE NOT NECESSARILY SAFER

S.B.M.H.S. – B.V.O.O.G. scientific meeting 10/12/2022

ir. Sven De Ridder

Royal Military Academy Belgium – VIPER Research Unit

Military Hospital Brussels – Centre for Hyperbaric Oxygen Therapy

1

2

Selecting optimal Gradient Factors for use by Belgian military divers: more conservative settings are not necessarily safer

What is the issue?

Shearwater Perdix - default gradient factors (30/70) are too restrictive:

- Shorter usable work time under water
- Introduction of mandatory deco-stops

⇒ ***Belgian Navy divers asked us to have a closer look at the dive computer algorithm and gradient factors settings***

⇒ Recommendations to increase usable work time under water while maintaining safety

⇒ Guidelines for gradient factor settings

3

BÜHLMANN ZHL-16C AND GRADIENT FACTORS

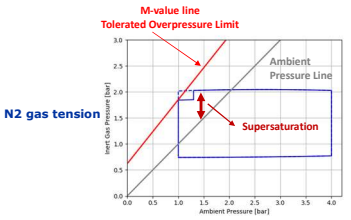
Bühlmann ZH-L16C

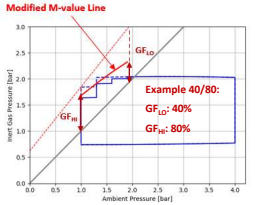
16 parallel compartments, each having its own:

- theoretical half-time
- tolerated overpressure limit

Gradient Factors (GF)

- GF_{LO} / GF_{HI}
- GF: fraction of the difference between Pamb and M-line (100% is the original M-line)
- **Convention: $GF_{LO} \leq GF_{HI}$**



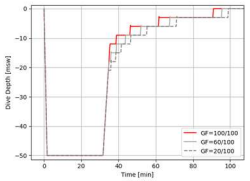


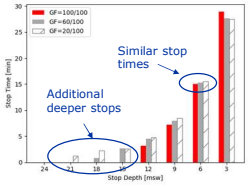
Gradient Factors modify validated decompression profiles and the validated Bühlmann ZH-L16 model by changing the original M-value lines.

4

EFFECT OF GF_{LO}/GF_{HI} ON DECO PROFILE

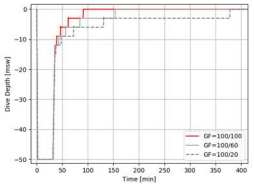
GF_{LO} is decreased;
GF_{HI} is kept to 100%

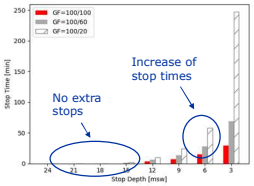




GF_{LO}: controls the stop depths

GF_{LO} is kept to 100%;
GF_{HI} is decreased





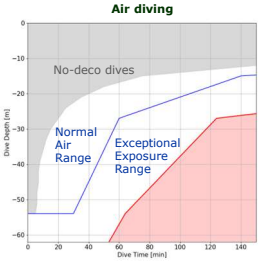
GF_{HI}: extends the stop times at shallower stops

5

RESEARCH STUDY

Which dives?

Air diving:
- No-decompression dives (No-Deco Limits)
- Standard Air Decompression diving



Which data sets?

Belgian Navy standard for safe decompression:
- DCIEM dive tables serve as basic reference
- Thalmann (US Navy)

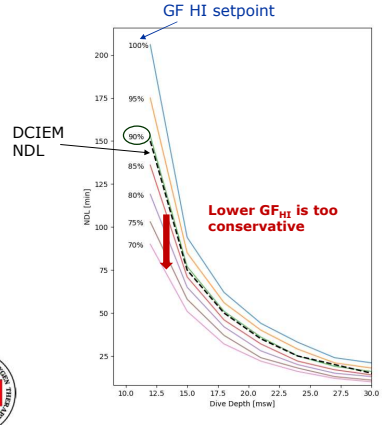
⇒ **Select GFs to approach DCIEM/Thalmann procedures**

How?

Computer-based simulations with algorithms programmed in Python and validated against publicly available data.

6

NO DECOMPRESSION LIMIT (NDL)



NDL is determined by **GF_{Hi}** (surfacing value)

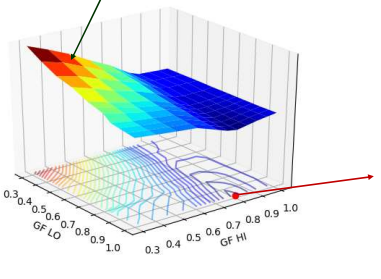
DCIEM no-deco limits are approached with **GF = 0.9**

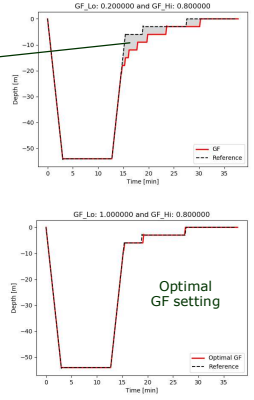
Recommended safe setting is GF=70%, but reduces the NDL excessively (too conservative)

7

DECOMPRESSION DIVING OPTIMIZATION

Integrated difference between GF profile and reference profile





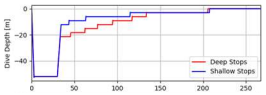
8

NEDU REFERENCE PROFILE – DECO PROFILES

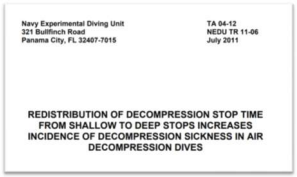
Dive: Air / 170fsw / 30min bottom time / 174min deco

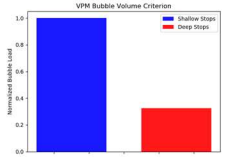
2 different deco-schedules :
- Shallow stops (Thalmann gas content model)
- Deep stops (bubble model BVM(3))

390 simulated dives; 86 divers



TBDM Predicted Bubble Growth



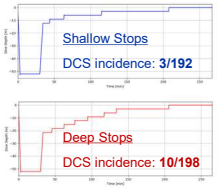


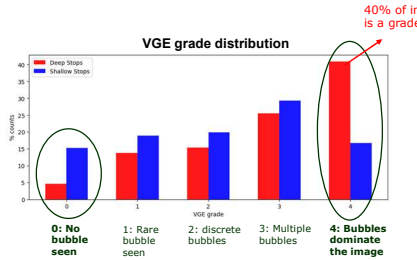
TBDM model and VPM model predict a lower decompression stress using the Deep Stops profile.

9

NEDU REFERENCE PROFILE – EXPERIMENT RESULTS

Selected reference profile





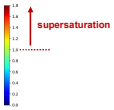
Deep Stops profile results in an increased DCS incidence and higher VGE score.

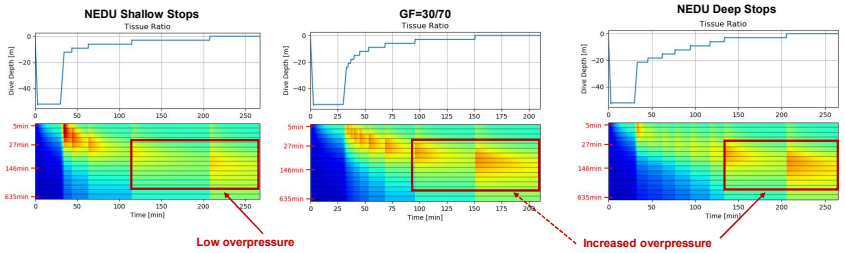
⇒ **Shallow Stops** profile is selected as our reference profile

10

DEFAULT GF SETTINGS: 30/70

$$TR = \frac{P_T}{P_{amb}}$$





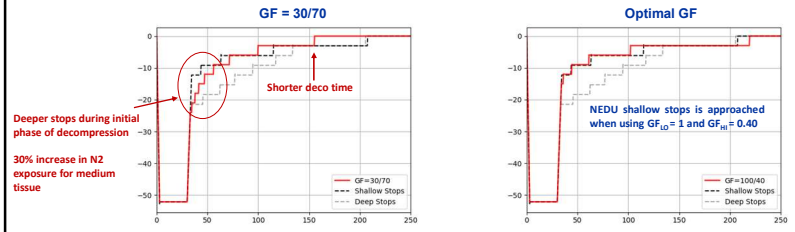
GF=30/70

⇒ Increased supersaturation of medium and slow tissues late in the decompression and after surfacing

⇒ *Potentially leading to an increased DCS risk*

11

NEDU REFERENCE PROFILE – GF OPTIMIZATION

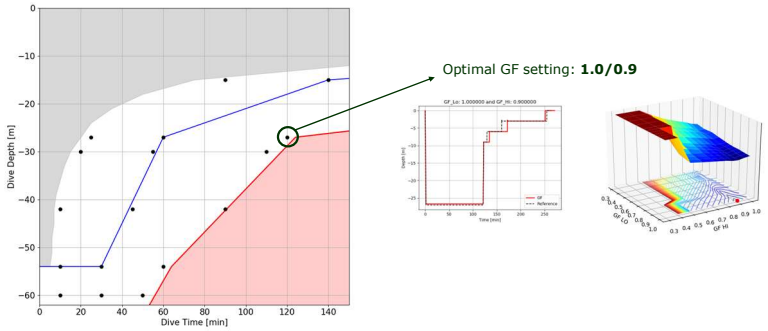


Optimal strategy:
1. Set **GF_{LO} = 1** to keep the first stop depth as shallow as possible
2. Increase 'safety' by selecting a **lower GF_{HI}** to increase the stop times

⇒ **In contrast with current convention that $GF_{LO} \leq GF_{HI}$**

12

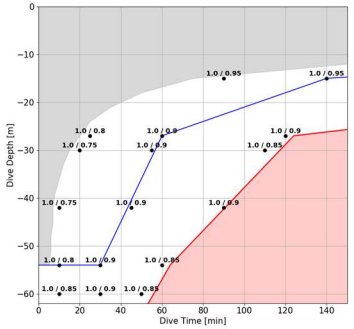
DCIEM REFERENCE DIVE TABLE: OPTIMAL GF



Optimal GF setting: **1.0/0.9**

13

DCIEM REFERENCE DIVE TABLE: OPTIMAL GF



All dives have **GF_{Lo} = 1** as the optimal setting

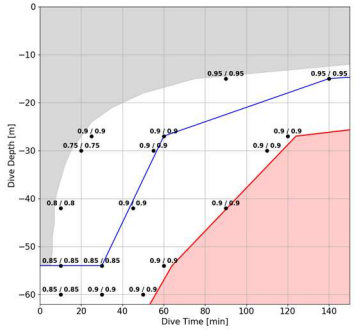
GF_{Hi} is decreased to enlarge the stop times

In agreement with NEDU optimisation result: no need to lower GF_{Lo} and induce deeper stops

Shearwater Perdix SW constraints => **sub-optimal settings**

14

DCIEM REFERENCE DIVE TABLE: SUB-OPTIMAL GF



SW constraints:
- $GF_{LO} \leq GF_{HI}$
- $GF_{HI} > 30$
- $GF_{LO} > 10$
- ($GF_{HI} \leq 90$ when $GF_{LO} > 50$)

Sub-optimal solution:
- **Symmetric GF setting**
- No need for (very) low GFs

15

CONCLUSIONS

1. **Think of Gradient Factors as 'parameters to change the profile', rather than in terms of 'conservatism'**
2. **No-decompression dives: DCIEM NDL are approached with GF_{Hi} = 90%**
3. **Decompression diving: there is no scientific evidence that the default 30/70 (GF_{Lo}/ GF_{Hi}) setting leads to a more 'conservative' or safer decompression profile**
   - **Optimal GF setting: GF_{Lo} = 100% and decrease GF_{Hi}**
   - **Current software restriction do not allow these optimal settings, therefore use symmetrical GF settings, e.g. 90/90, 80/80, etc.**

⇒ ***Belgian Navy divers have been advised to refrain from using the default settings of the Shearwater Perdix and instead adopted the symmetric GF setting approach.***

16

This research is funded by the Royal Higher Institute for Defence via study HFM 21-06

Sven.DeRidder@mil.be
Peter.Germonpre@mil.be

17