

Adaption of a
COMEX procedure for
recreational bounce dives
on air

DOI: 10.13140/RG.2.2.: t.b.d.!

Info COMEX:

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COMEX sa (Compagnie Maritime x +

← → ↻ comex.fr



Pionnière mondiale dans le développement des technologies pour l'intervention humaine et robotique dans
des environnements extrêmes

La Comex (Compagnie Maritime d'Expertises)

a été fondée en 1961 par Henri Germain Delauze (1929-2012)

Nous intervenons...

Sur Terre

En Mer

Dans L'Espace

f

t

in

Info COMEX:

**Compagnie maritime d'expertises:
C&R and SAT dives;
and deep diving experiments:
for e.g.: 1992, Hydra-X, 701 m**



Comex founder (1961)
Henri Germain Delauze

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a brief history of hydreliox diving

1 H Hydrogen (1.00794 - 1.00811)	2 He Helium 4.0026	8 O Oxygen 15.9994
--	------------------------------------	------------------------------------

HYDRA 10 – deepest chamber dive to 701MSW - 1992



Théo Mavrostomos
World record holder

COMEX procedure

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- simple procedure:
- without any compartments or half-times
- without supersaturations
- only one free parameter (λ)
- „Best Fit“ to many successful C&R and SAT dives,
- and a lot of deep diving experiments,
- for e.g.: Hydra series, up to 700 m,
data base: pls. cf. next slide

Legend:

SAT : saturation dives, dive time > 72 h

C&R : construction & repair diving

Sources: [1], [2] & COMEX homepage



The data base of the COMEX
commercial SAT dives
and the deep diving experiments from
1967 until 1999:

Total (1967 à 1999)

1095

403

4571

days

divers

man dives

The COMEX procedure:

$$D(t) = \frac{D_0}{1 + \lambda * T^{-5/2} * D_0^{-3} * (t - T)}$$

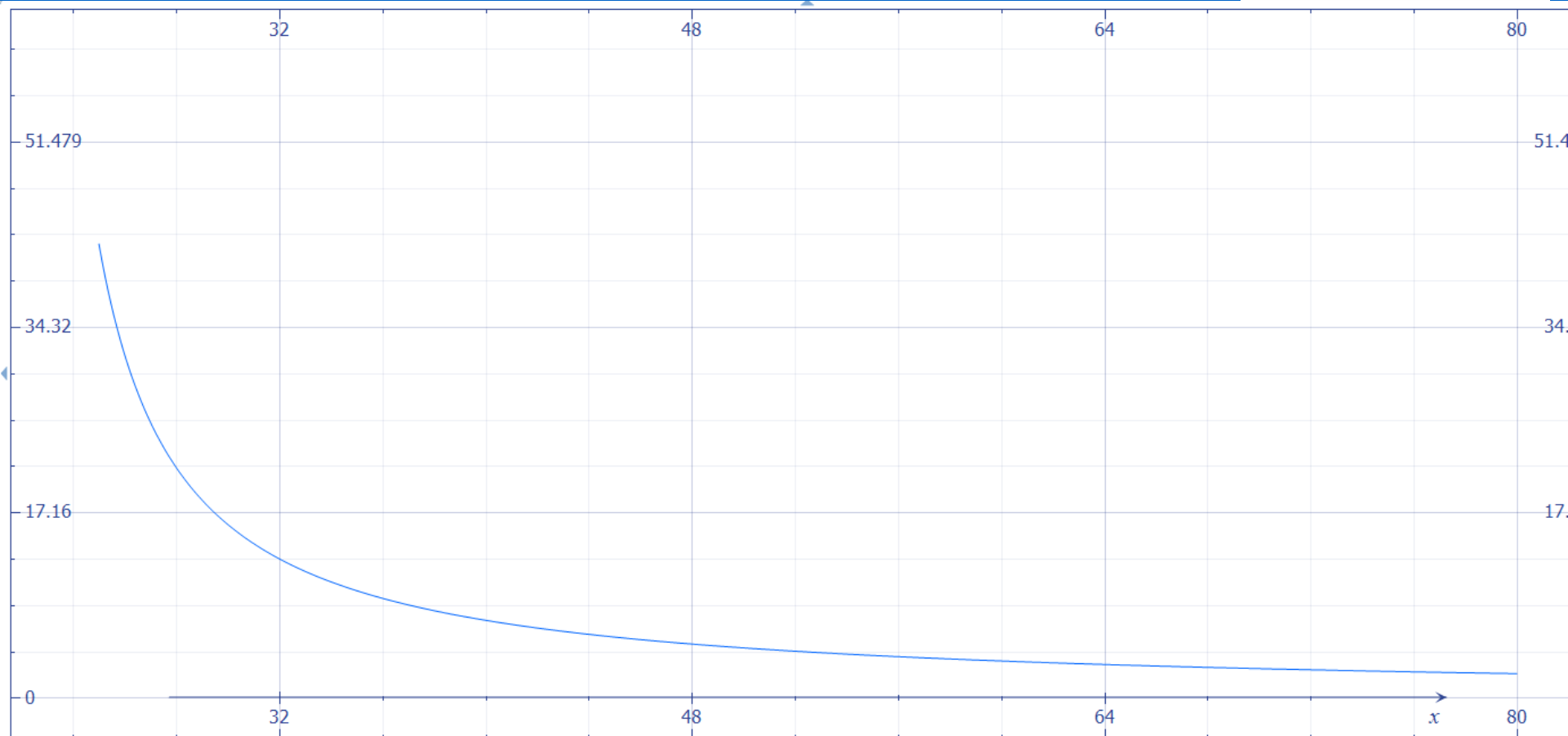
with the following parameters:

- $D(t)$: (actual) diving depth [m] as a function of diving time t , $t > T$
 T : bottom time [min]
 D_0 : bottom depth [m]
 λ : empirical parameter [min^2m^3], used to fit for:

- breathing mix, Helium- and Oxygen fraction
- water- / ambient temperature
- workload
- decompression chamber- or working dive (with immersion)

The COMEX procedure

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y axis: actual diving depth $D(t)$
x axis: diving time t , after bottom time T , i.e.: $t > T$

The COMEX procedure

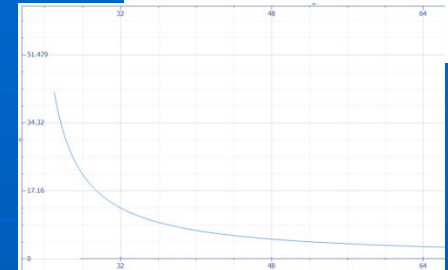
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Due to the technical nature of SAT dives & the deep diving experiments, there is headspace in the decompression procedures. There are different values for the parameters for:

- workload of divers
- Helium fraction
- pO₂ @ bottom, @ decompression
- ambient temperature, ...
- risk appetite of the company
- ...

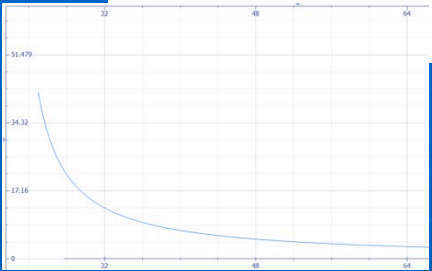
In the COMEX procedure this is reflected via the parameter λ .

As an example pls. cf. the next slides: decompression from a SAT dive in the AQUARIUS habitat (Florida, 18 m):



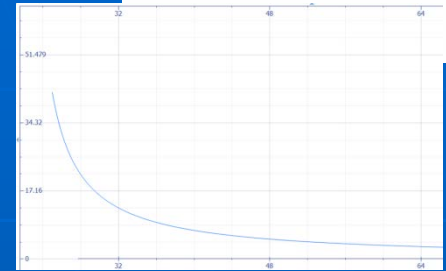
Decompression from the AQUARIUS habitat

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Decompression from the AQUARIUS habitat

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- USN SAT procedure: **1140** min: 4 h + 15 h = 19 h (Air only)
Bühlmann SAT 20: **660** min: 11 h (with 6 h @ 100% O₂)
Aquarius procedure: **990** min: 16,5 h (with 1 h @ 100 % O₂ @ 60 feet)
COMEX procedure: **1190** min: 19,8 h (Air only) with $\lambda = 999.990.000.000$
DIVE V 3_09: **1860** min (upper limit of ascent rate) →
2700 min (lower limit of ascent rate, AIR only)
DIVE V 3_09: **1600** min (upper limit of ascent rate, from 10 m @ 100 % O₂)

Decompression from the AQUARIUS habitat

Legend:

USN SAT procedure: **1140** min: 4 h + 15 h = 19 h (Air only)
Bühlmann SAT 20: **660** min: 11 h (with 6 h @ 100% O₂)
Aquarius procedure: **990** min: 16,5 h (with 1 h @ 100 % O₂ @ 60 feet)
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- **USN: SAT procedure per USN Diving Manual, Rev. 7 2018, Chapter 13, Table 13 – 9:**

Table 13-9. Saturation Decompression Rates.

Depth	Rate
1,600 – 200 fsw	6 feet per hour
200 – 100 fsw	5 feet per hour
100 – 50 fsw	4 feet per hour
50 – 0 fsw	3 feet per hour

- **Bühlmann SAT 20: table from the DKL-USZ, pls. cf. next slide**
- **Aquarius: proprietary procedure in the habitat, which rests on the sea bed, after decompression the divers ascend to the surface**
- **COMEX: procedure with $\lambda = 9.999 \exp 11$**

Decompression from the AQUARIUS habitat

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DEEP DIVING RESEARCH LABORATORY
DEPARTMENT OF INTERNAL MEDICINE
UNIVERSITY HOSPITAL ZURICH

BREATHING MIXTURE

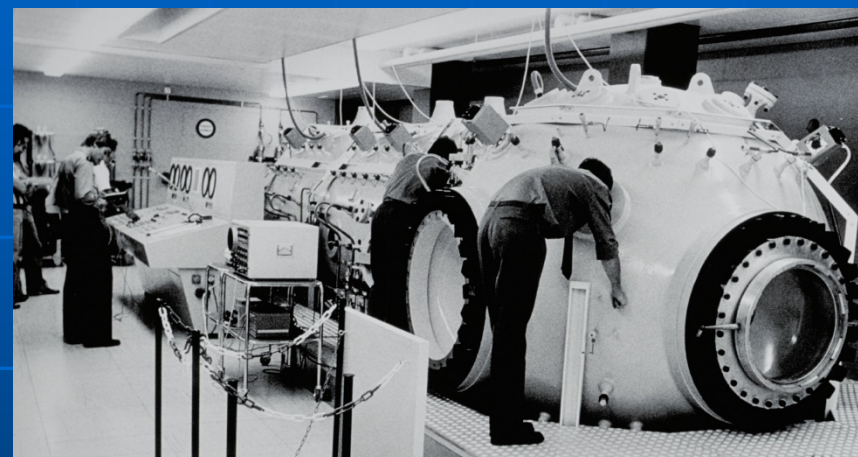
Air

DECOMPRESSION TABLE FOR SATURATION DIVES

Code No. 15 – 60 SAT. AO. 70. A1

BREATHING MIXTURE	21% O ₂ / 7									
DIVING DEPTH m	15		20		25		30		35	
	m	min	m	min	m	min	m	min	m	min
to 1. STOP	10		10		10		10		10	
STOP 1	5	110	8	110	11	110	15	110	18	110
2	4	120	7	180	10	180	13	120	17	120
3	2	120	5	120	9	180	12	180	16	120
4	0		4	120	7	180	10	180	14	180
5			2	120	5	120	9	180	12	180
6			0		4	120	7	180	10	180
7					2	120	5	120	9	180
8					0		4	120	7	180
9							2	120	5	120
10							0		4	120
11									2	120
12									0	
13										
14										
15										
16										
17										
18										
19										
20										
21										
22										
23										
24										
25										
Total Decompr. Time	6h		11h		17h		22h		27h	

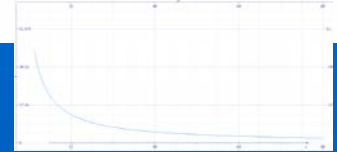
USN SAT procedure: 1140 min: 4 h + 15 h = 19 h (Air only)
 Bühlmann SAT 20: 660 min: 11 h (with 6 h @ 100% O₂)
 Aquarius procedure: 990 min: 16,5 h (with 1 h @ 100 % O₂ @ 60 feet)
 COMEX procedure: 1190 min: 19,8 h (Air only) with $\lambda = 999.990.000.000$
 DIVE V 3_09: 1860 min (upper limit of ascent rate) →
 2700 min (lower limit of ascent rate, AIR only)
 DIVE V 3_09: 1600 min (upper limit of ascent rate, from 10 m @ 100 % O₂)



The COMEX procedure

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The formula describes the diving depth $D(t)$ in relation to the diving time t , after bottom time T .



As there are no PTC/bells available for rec/TEC dives, a continuous ascent is technically not feasible: decompression is done in stages, usually 10 feet / 3 m apart. The stop times are listed with each stage.

Thus for a rec/TEC bounce dive, the times from the COMEX procedure have to be integrated (summed up) around a median, i.e.: $(N * 3) \pm \Delta$.

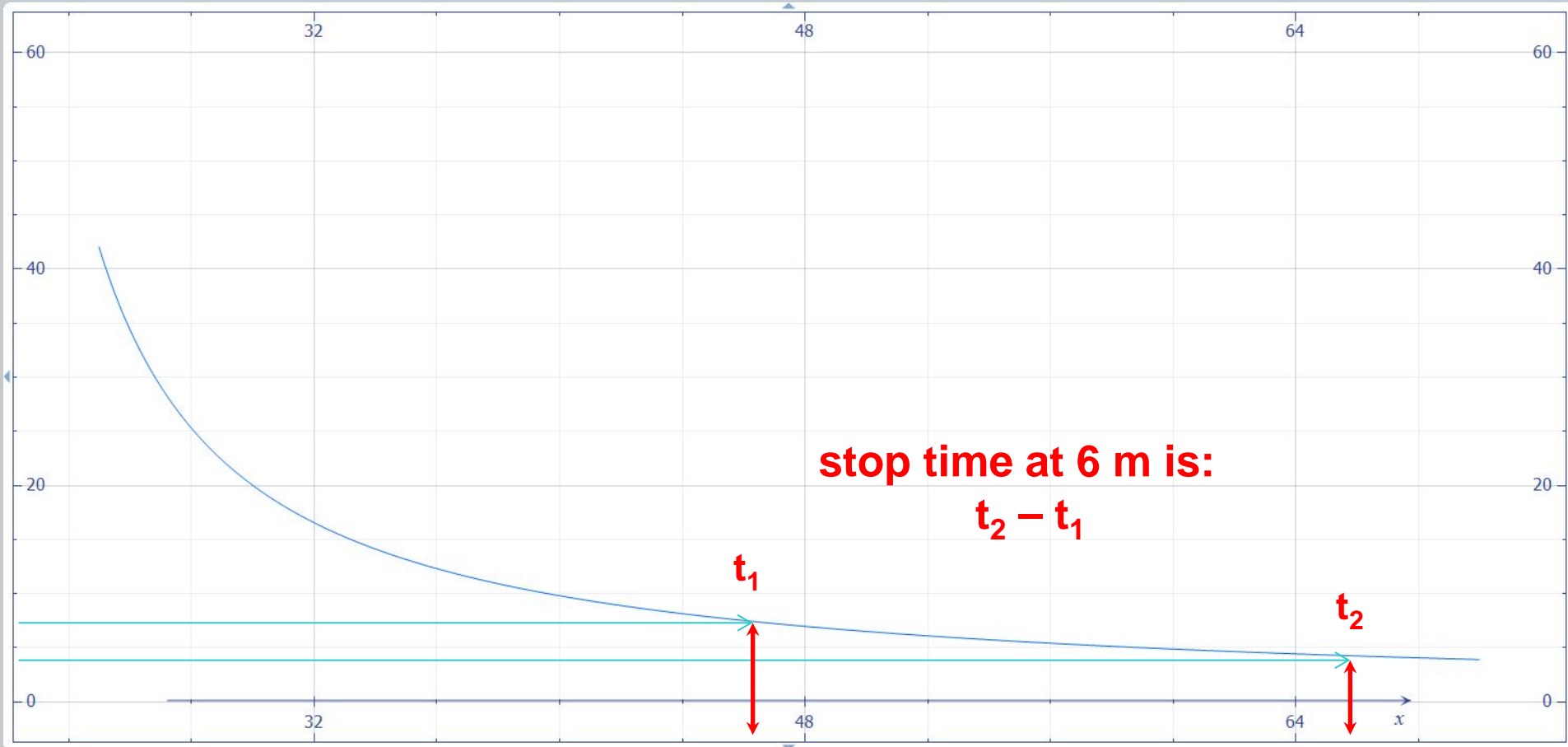
Example with $\Delta = 1.5$ m for a 6 m stop ($N = 2$):
the integration in the time-domain for this 6 m stop is then done from
 $6 + 1.5 = 7.5 \rightarrow 6 - 1.5 = 4.5$ m

This rationale is feasible for deep rec/deep TEC dives, usually much like a box profile due to limited supply of breathing gas & thermal protection:

if it fits to SAT diving, it fits even more so to bounce dives, since the more sensitive body tissues are not affected by short bounce dives.

the test dive: $D_0 = 42$ m, $T = 25$ min,
parameter λ

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Integration in time-domain is done from:

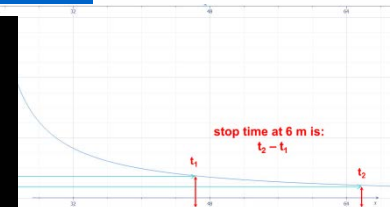
$N * 3 \text{ m} - / + \Delta$

Example for $N = 2$, i.e.: 6 m stop with $\Delta = 1.5$ m, i.e.: $7.5 \rightarrow 4.5$ m

the test dive: $D_0 = 42$ m, $T = 25$ min

Output from DIVE Version 3_09:

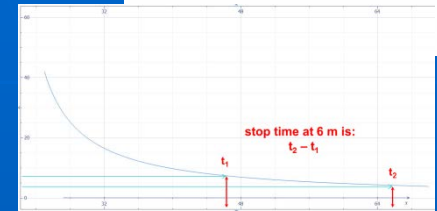
```
Deko Prognose:
9m Stopp Prognose Dekozeit:      2.0  Komp.#:  3
6m Stopp Prognose Dekozeit:      6.0  Komp.#:  4
3m Stopp Prognose Dekozeit:     16.0  Komp.#:  6
TTS =      28.0
was jetzt?cp
COMEX Prozedur fuer BOUNCE DIVES  !!!!
Eingabe COMEX Prozedur Parameter Lambda
als Dezimalzahl * 10 EXP 6!   70. <= Lambda <= 250. :122.
GESZ:  25.00 MAXT:  42.00 CPLAMBDA: 122.00 KONSTANT:  79.705
max. TTS:    104.4 Prozedur-Ende bei m:  0.8
max. TTS:    51.2 Prozedur-Ende bei m:  1.5
max. TTS:    38.0 Prozedur-Ende bei m:  2.0
max. TTS:    30.0 Prozedur-Ende bei m:  2.5
max. TTS:    24.7 Prozedur-Ende bei m:  3.0
*****
*****
Standard Deko-Stopps:
 3.m Deko-Stopp:      19.9 min
 6.m Deko-Stopp:       4.6 min
 9.m Deko-Stopp:       2.0 min
12.m Deko-Stopp:       1.1 min
15.m Deko-Stopp:       0.7 min
18.m Deko-Stopp:       0.5 min
21.m Deko-Stopp:       0.4 min
24.m Deko-Stopp:       0.3 min
27.m Deko-Stopp:       0.2 min
TTS:      29.7
```



the test dive: $D_0 = 42$ m, $T = 25$ min

Output from DIVE Version 3_09:

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$\lambda = 122.0$ exp 6 matches a standard ZH-L16 C decompression schedule
top of slide # 16, with TTS = 28 min

$\lambda = 100.5$ exp 6 \rightarrow conservative, similar to VPM: TTS = 37 min

$\lambda = 165.0$ exp 6 \rightarrow aggressive, similar to RGBM: TTS = 22 min

details: pls. cf. the next 2 slides

Legend:

TTS: time-to-surface, i.e.:

(bottom depth/ascent rate) + sum of all stop times

VPM: Varying Permeability Model, Ref. [3]

RGBM: Reduced Gradient Bubble Model, Ref. [4]

the test dive: $D_0 = 42$ m, $T = 25$ min

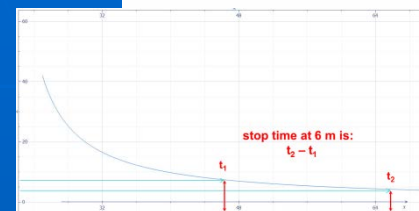
Output from DIVE Version 3_09:

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$\lambda = 100.5$ exp 6 matches a conservative ZH-L16 C
decompression schedule with gradient factors

GF High = 0.9 / GF Low = 0.8

and deeper stops like VPM:



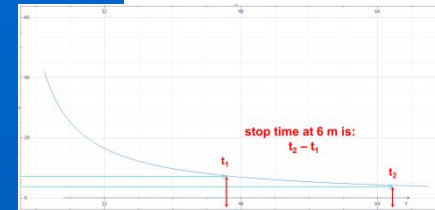
```
Deko Prognose:
9m Stopp Prognose Dekozeit: 2.0 Komp.#: 3
6m Stopp Prognose Dekozeit: 6.0 Komp.#: 4
3m Stopp Prognose Dekozeit: 16.0 Komp.#: 6
TTS = 28.0
Deko Prognose mit Gradientenfaktoren: GFHI= 0.90 GFLO= 0.80
12m Stopp Prognose Dekozeit: 1.0 GF = 0.80 Komp.#: 2
9m Stopp Prognose Dekozeit: 4.0 GF = 0.83 Komp.#: 3
6m Stopp Prognose Dekozeit: 8.0 GF = 0.85 Komp.#: 5
3m Stopp Prognose Dekozeit: 20.0 GF = 0.88 Komp.#: 6
TTS = 37.0
was jetzt?cp
COMEX Prozedur fuer BOUNCE DIVES !!!!
Eingabe COMEX Prozedur Parameter Lambda
als Dezimalzahl * 10 EXP 6! 70. <= Lambda <= 250. :100.5
GESZ: 25.00 MAXT: 42.00 CPLAMBDA: 100.50 KONSTANT: 96.757
max. TTS: 126.7 Prozedur-Ende bei m: 0.8
max. TTS: 62.2 Prozedur-Ende bei m: 1.5
max. TTS: 46.1 Prozedur-Ende bei m: 2.0
max. TTS: 36.4 Prozedur-Ende bei m: 2.5
max. TTS: 29.9 Prozedur-Ende bei m: 3.0
*****
*****
Standard Deko-Stops:
3.m Deko-Stopp: 24.2 min
6.m Deko-Stopp: 5.5 min
9.m Deko-Stopp: 2.4 min
12.m Deko-Stopp: 1.4 min
15.m Deko-Stopp: 0.9 min
18.m Deko-Stopp: 0.6 min
21.m Deko-Stopp: 0.4 min
24.m Deko-Stopp: 0.3 min
27.m Deko-Stopp: 0.3 min
TTS: 36.0
```

the test dive: $D_0 = 42$ m, $T = 25$ min

Output from DIVE Version 3_09:

$\lambda = 165.0$ exp 6 matches an aggressive ZH-L16 C decompression schedule with gradient factors
GF High = 1.2 / GF Low = 0.6, short deep stops and truncated shallow stops, like aggressive RGBM:

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```
Deko Prognose mit Gradientenfaktoren: GFHI= 1.20 GFLO= 0.60
15m Stopp Prognose Dekozeit: 1.0 GF = 0.60 Komp.#: 2
12m Stopp Prognose Dekozeit: 1.0 GF = 0.72 Komp.#: 3
 9m Stopp Prognose Dekozeit: 3.0 GF = 0.84 Komp.#: 3
 6m Stopp Prognose Dekozeit: 5.0 GF = 0.96 Komp.#: 4
 3m Stopp Prognose Dekozeit: 11.0 GF = 1.08 Komp.#: 6
TTS = 25.0
was jetzt?cp
COMEX Prozedur fuer BOUNCE DIVES !!!!
Eingabe COMEX Prozedur Parameter Lambda
als Dezimalzahl * 10 EXP 6! 70. <= Lambda <= 250. :165.
GESZ: 25.00 MAXT: 42.00 CPLAMBDA: 165.00 KONSTANT: 58.934
max. TTS: 77.2 Prozedur-Ende bei m: 0.8
max. TTS: 37.9 Prozedur-Ende bei m: 1.5
max. TTS: 28.1 Prozedur-Ende bei m: 2.0
max. TTS: 22.2 Prozedur-Ende bei m: 2.5
max. TTS: 18.2 Prozedur-Ende bei m: 3.0
*****
*****
Standard Deko-Stopps:
 3.m Deko-Stopp: 14.7 min
 6.m Deko-Stopp: 3.4 min
 9.m Deko-Stopp: 1.5 min
12.m Deko-Stopp: 0.8 min
15.m Deko-Stopp: 0.5 min
18.m Deko-Stopp: 0.4 min
21.m Deko-Stopp: 0.3 min
24.m Deko-Stopp: 0.2 min
27.m Deko-Stopp: 0.2 min
TTS: 21.9
```

Sources / References:

[1] Bernard Gardette (November 2009) : THEORIE GENERALE UNIFIEE DE LA DECOMPRESSION;

Directeur Scientifique COMEX, BG/sc-060/09

[2] Alexis Blasselle, Michael Theron, Bernard Gardette, Emmanuel Dugrenot (2020) A new form of admissible pressure for Haldanian decompression models

[3] Yount, D.E. Hoffman, D.C. (1986) On the use of a Bubble Formation Model to calculate diving tables

[4] Wienke, B. R. (2003) RGBM in-depth

Bonus Material: Source for DIVE Version 3_09

Download free of charge:

→ DIVE V 3_09

(https://www.divetable.info/DIVE_V3/index.htm)

→ and the german manual

https://www.divetable.info/DIVE_V3/DOXV3_0.pdf

The release train for

→ the english version (V3_04) is somewhat slower ...

https://www.divetable.info/DIVE_V3/V3e/index.htm

Fine tuning of DIVE:

Fine tuning could be done via the commands:

- ascent rate („**AR**“)
- ambient atmospheric pressure at start („**L**“)
- the respiratory coefficient („**R**“)
- the ambient (water)-temperature („**te**“)
- the water density („**di**“)
- Buehlmann Safety Factor („**B**“)
- last stop depth („**LS**“)

And with: „**a**“ we receive the complete decompression prognosis;

i.e.: the stop times in min per stage, modulo 3 m

and the **responsible leading compartment & the rounded up TTS** in min. The latest DIVE Version for beta testing is always staged there:

<https://www.divetable.info/beta/index.htm>

along with information on production date, size in bytes, new features and the checksums for verifying the download.

Handling of DIVE:

The test dive from above via the commands,
the input of commands and parameters are in the quotes: „“

- (ZH-L 16 C is the default coefficients matrix)
- „d“ (simulation of a box profile with these parameters:)
- „42.“ (bottom depth)
- „25.“ (bottom time)
- „a“ „“ (yields this standard decompression prognosis):

```
Deko Prognose:  
9m Stopp Prognose Dekozeit:      2.0  Komp.#:  3  
6m Stopp Prognose Dekozeit:      6.0  Komp.#:  4  
3m Stopp Prognose Dekozeit:     16.0  Komp.#:  6  
TTS =      28.0
```

- the COMEX procedure is simulated via: „cp“
- pls. cf. slides #16, 18 & 19
- the dialogue to manipulate the gradient factors is invoked with: „GF“