Unmanned Aerial Vehicles (UAV's)

Unmanned Underwater Vehicles (UUV's)

and Swarms

Joseph T. Wunderlich, Ph.D.

Unmanned Aerial Vehicles (UAV’s)

Unmanned Aerial Vehicle "Global Hawk"

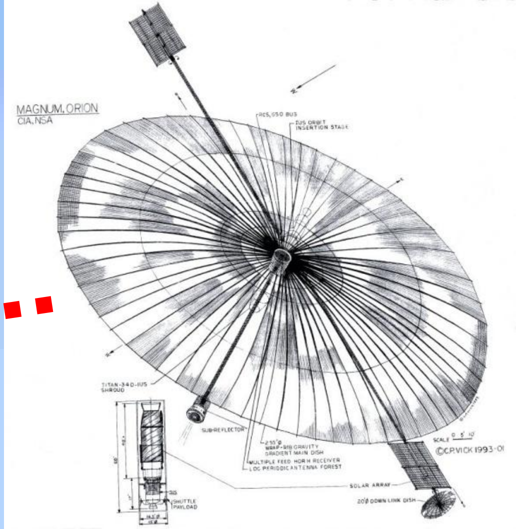
Northrop Grumman Corp.

*"**Global Hawk** provides high-resolution Synthetic Aperture Radar (SAR) and Electro-Optical/Infrared (EO/IR) imagery at long range with long loiter times over target areas. A Signals Intelligence (SIGINT) capability is also being developed. Potential missions cover the spectrum of intelligence collection capabilities to support joint combatant forces in worldwide peace, crisis, and wartime operations."*

Image and excerpt from: http://www.globalsecurity.org/military/library/budget/fy2001/dot-e/airforce/01globalhawk.html

SIGnal INTelligence Satellites

Radar detected, Global Hawk informed

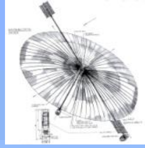


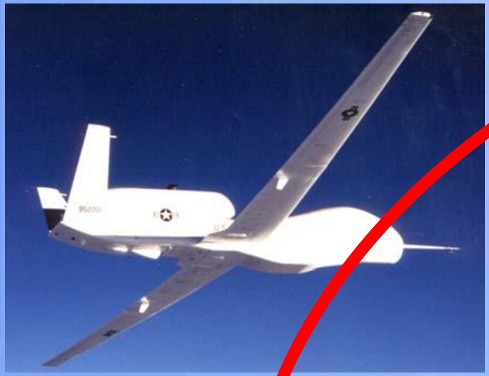
"Signals intelligence (SIGINT) satellites are designed to detect transmissions from broadcast communications systems such as radios, as well as radars and other electronic systems……The United States operates four constellations of signals intelligence satellites"

Images and excerpt from: http://www.globalsecurity.org
Radar image from: http://www.stuffintheair.com/NOAA-radar-weather.html

UAV "Global Hawk" with its own SIGINT in 2010

Northrop Grumman Corp.





Radar detected by Global Hawk

Images and excerpt from: http://www.globalsecurity.org
Radar image from: http://www.stuffintheair.com/NOAA-radar-weather.html

UAV “Global Hawk”

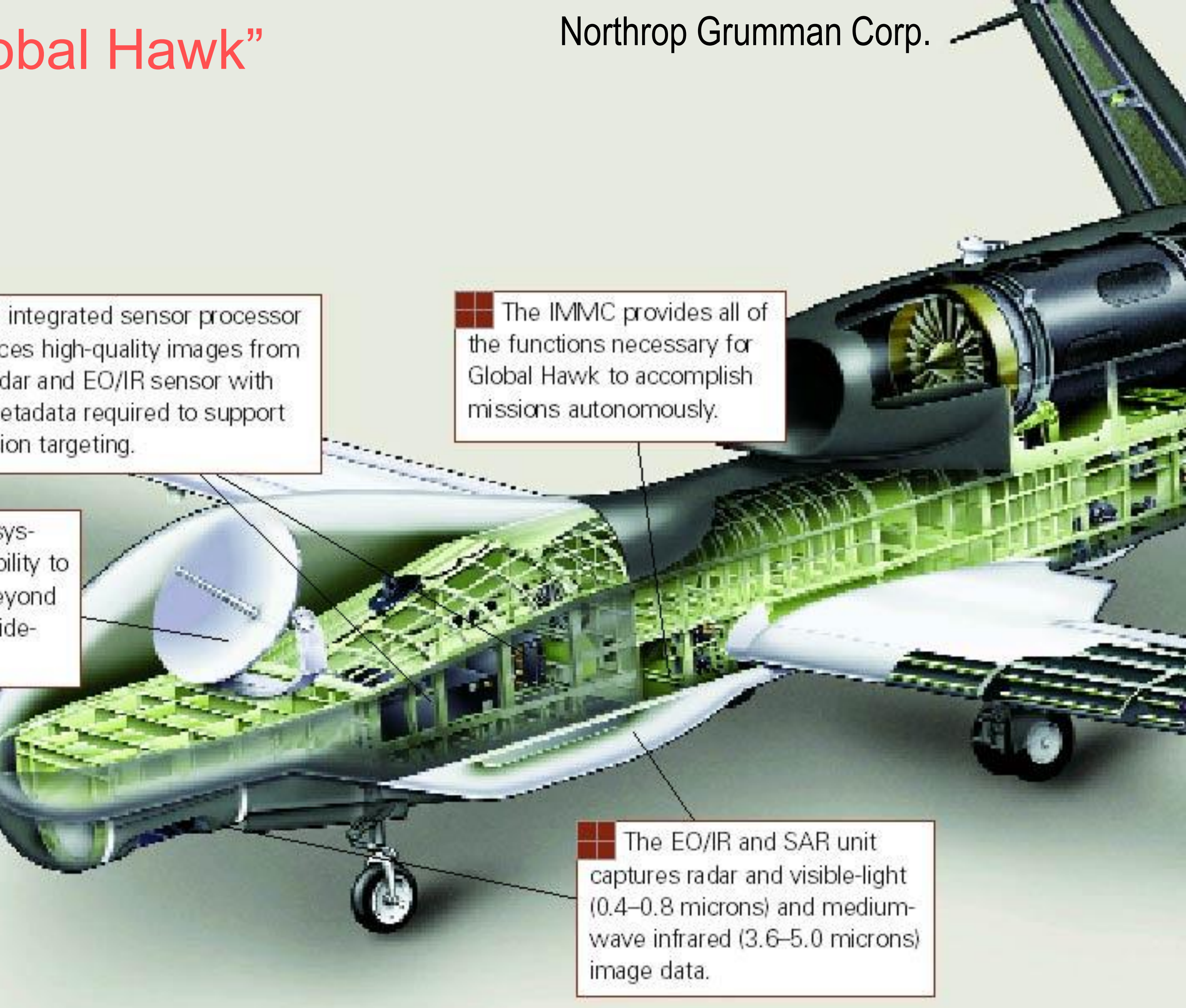
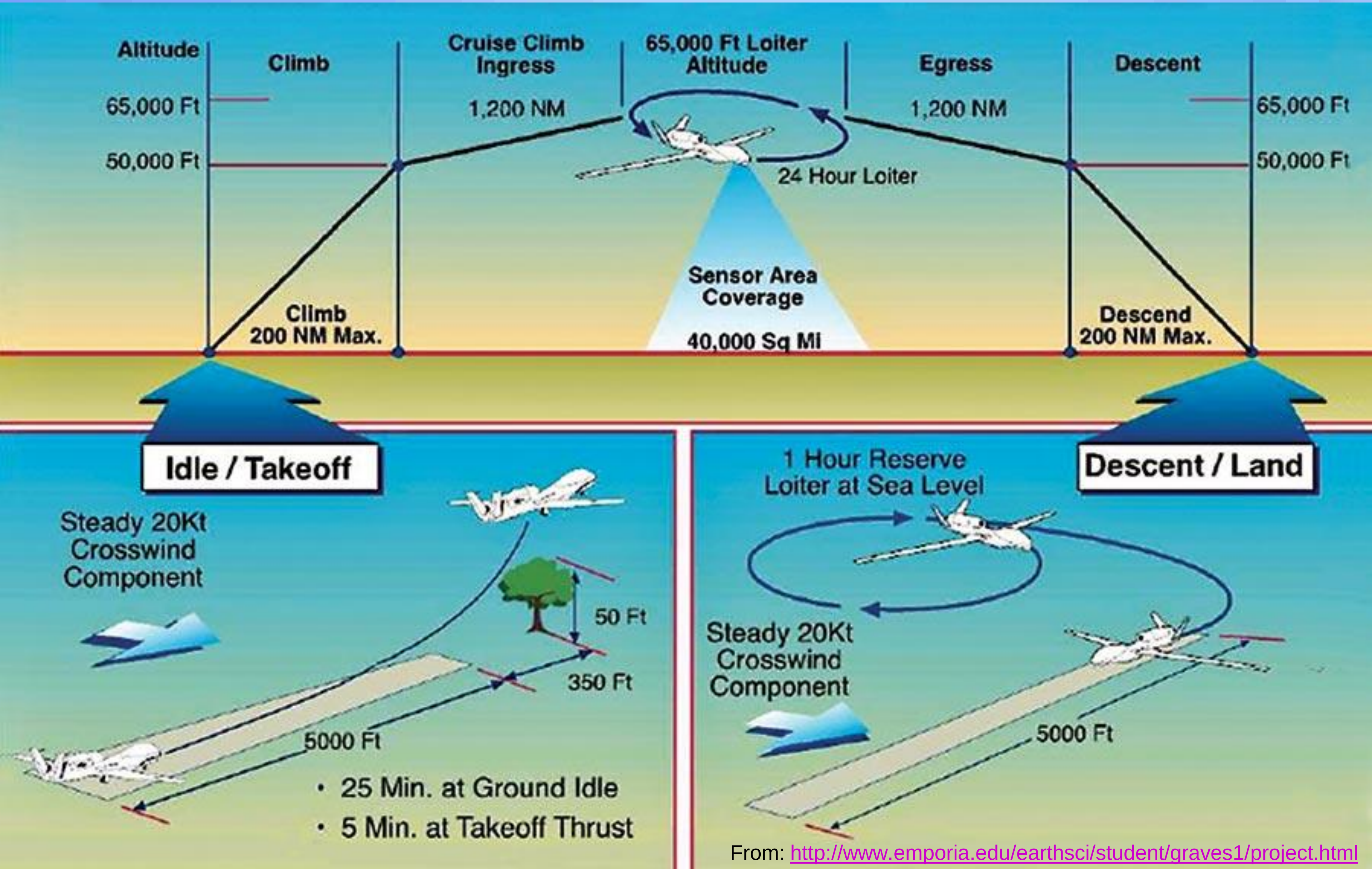


image from: http://www.emporia.edu/earthsci/student/graves1/project.html

UAV "Global Hawk"

Mission profile

Northrop Grumman Corp.



From: http://www.emporia.edu/earthsci/student/graves1/project.html

UAV “Killer Bees”

Image and excerpt from: http://www.dodevice.com/raytheon-introduces-killer-bee-uav-to-compete-with-boeing/


UAV "KillerBees"
"It has systems for land or sea launch, recovery and ground control……During the land-based test, KillerBee was recovered in a net mounted on a rapidly moving truck, demonstrating that the guidance system enables aircraft recovery from platforms moving at speeds similar to a naval vessel.
"…… represents a major upgrade to today's embedded airborne surveillance, reconnaissance and target acquisition capability."
Raytheon Corp.

NETCENTRIC WARFARE

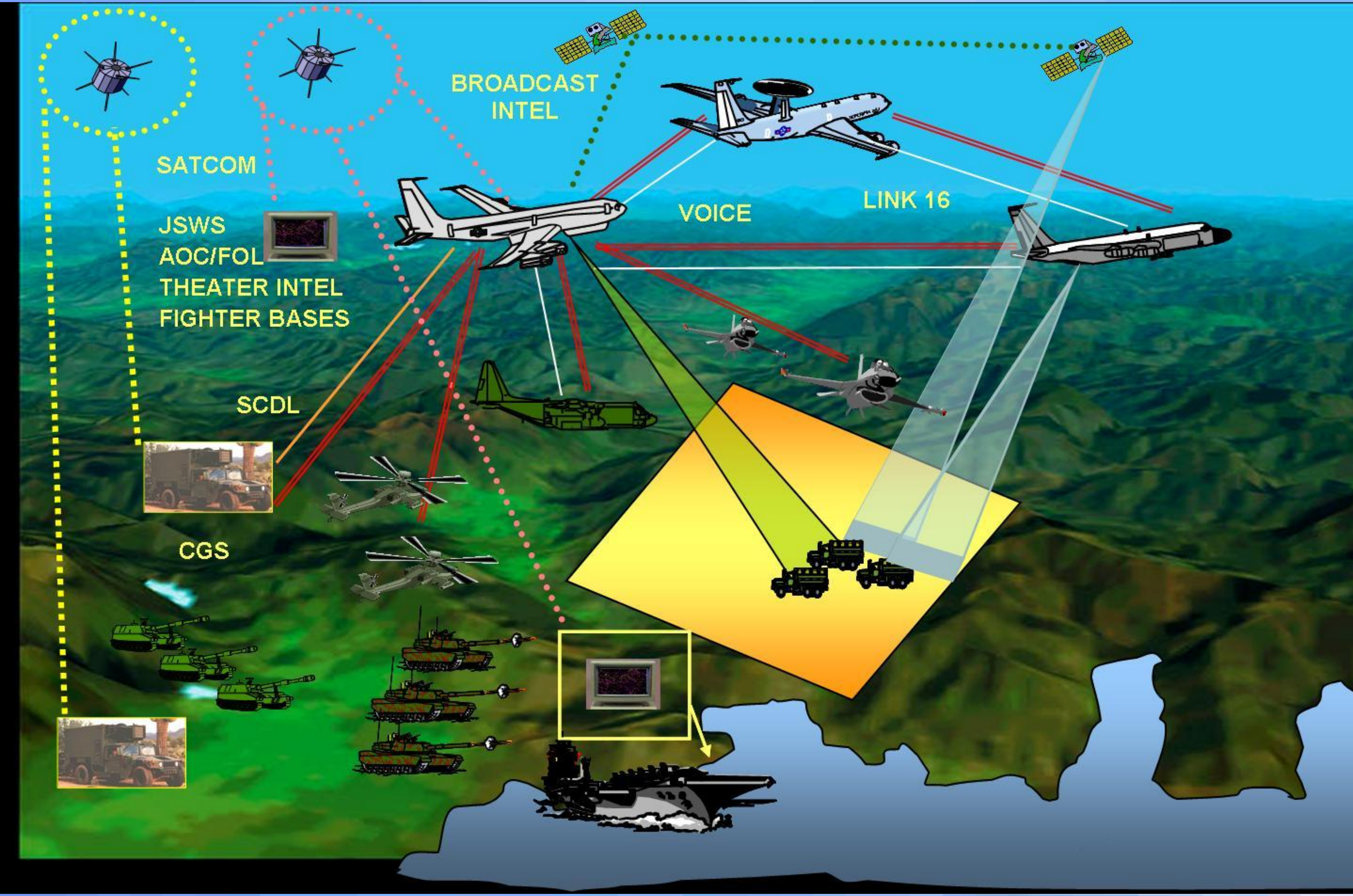


image from: http://www.emporia.edu/earthsci/student/graves1/project.html

NETCENTRIC WARFARE

SWARM

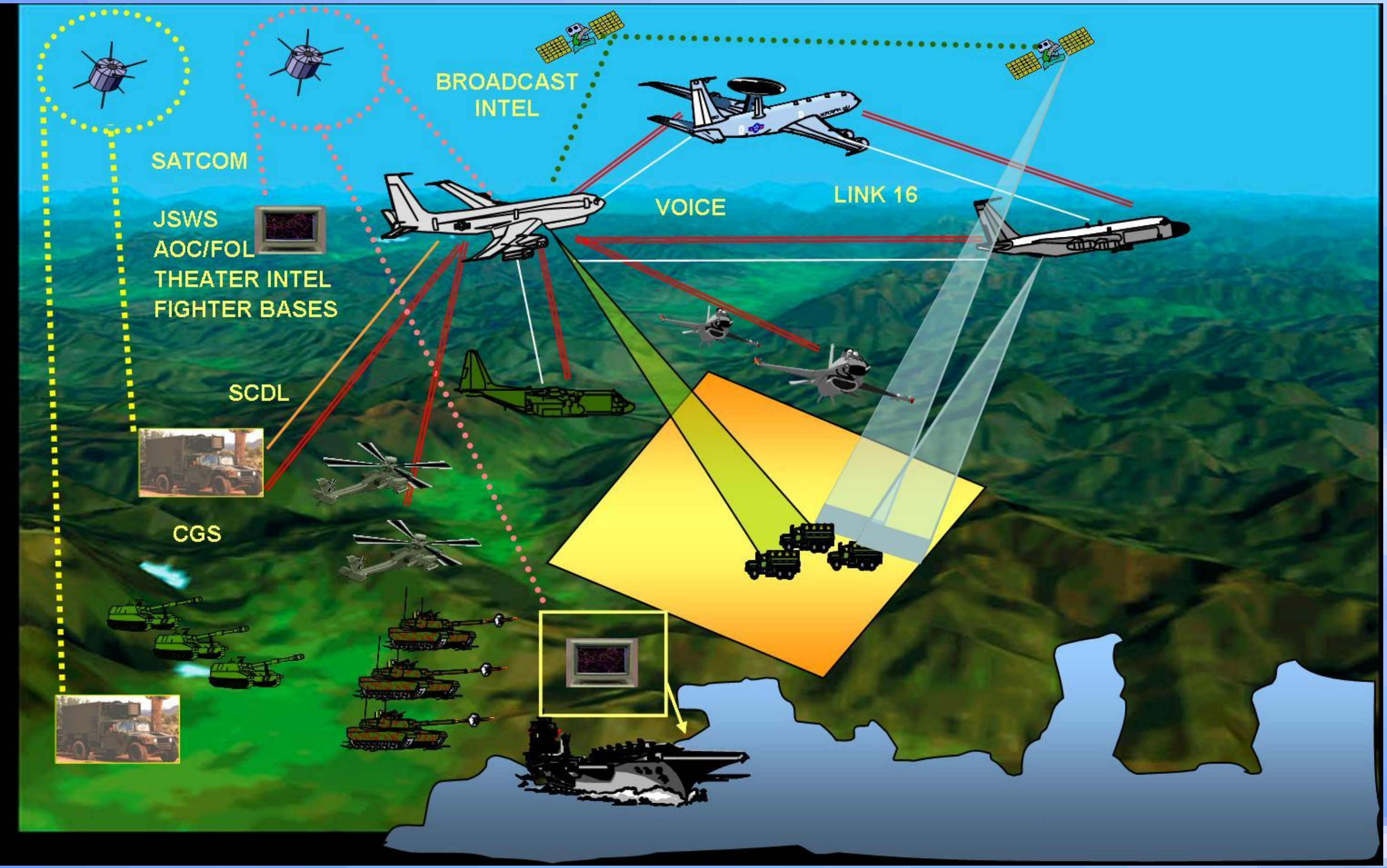
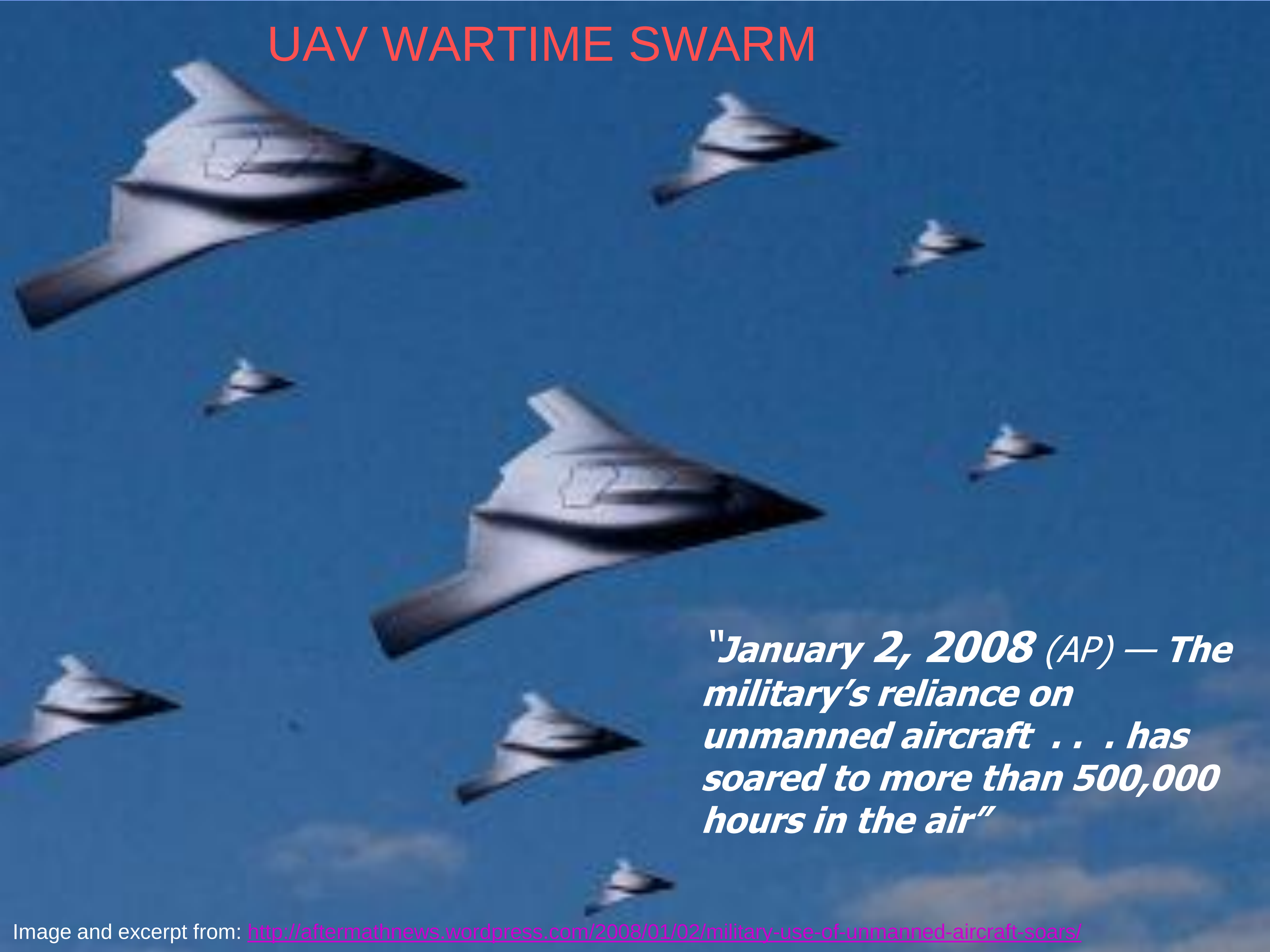


image from: http://www.emporia.edu/earthsci/student/graves1/project.html

UAV WARTIME SWARM



"January 2, 2008** (AP) — **The military's reliance on unmanned aircraft . . . has soared to more than 500,000 hours in the air"

Image and excerpt from: http://aftermathnews.wordpress.com/2008/01/02/military-use-of-unmanned-aircraft-soars/

PEACETIME SWARM

Search and Rescue

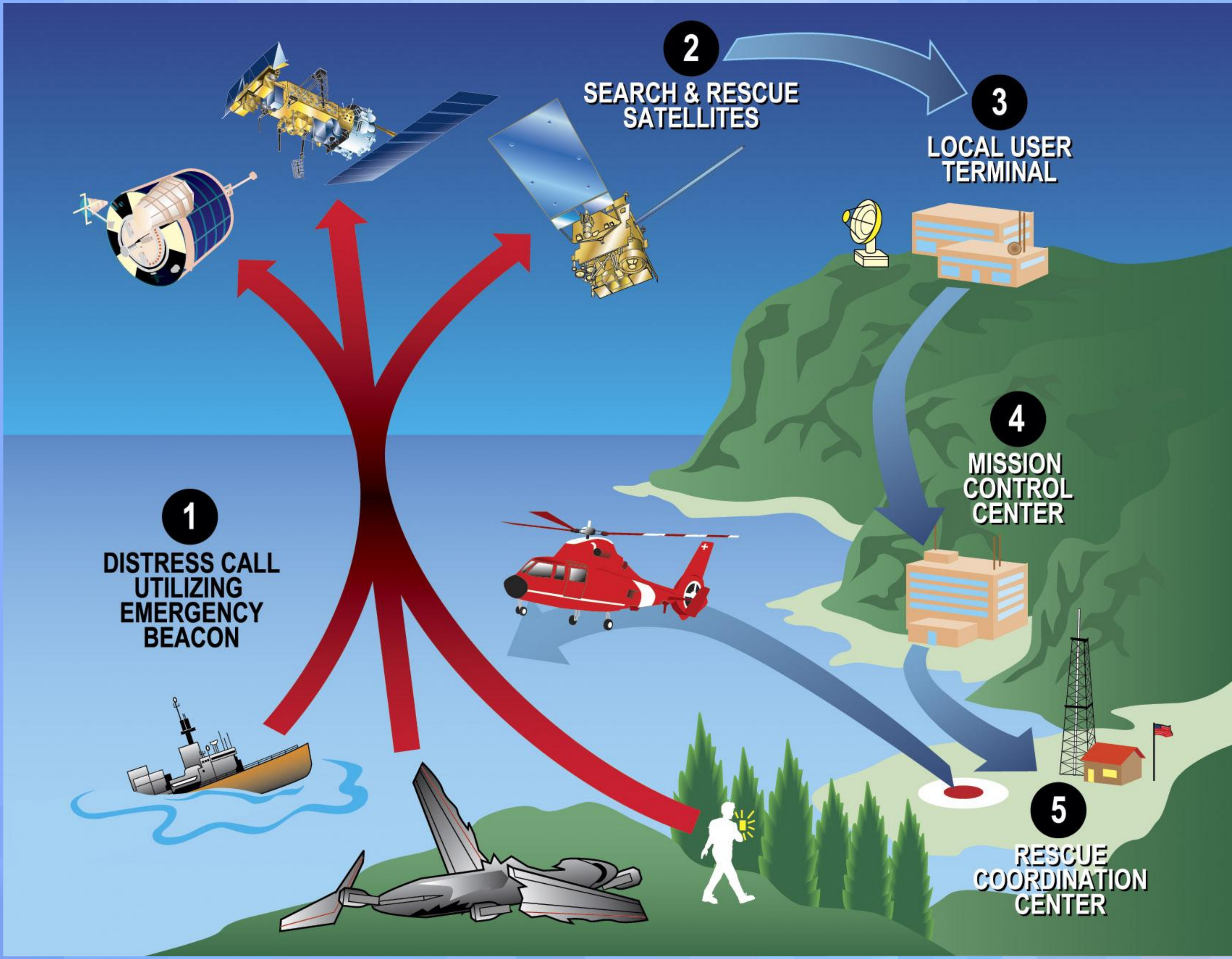


image from: http://www.semp.us/publications/securitas_reader.php?SecuritasID=33

PEACETIME SWARM

Search and Rescue

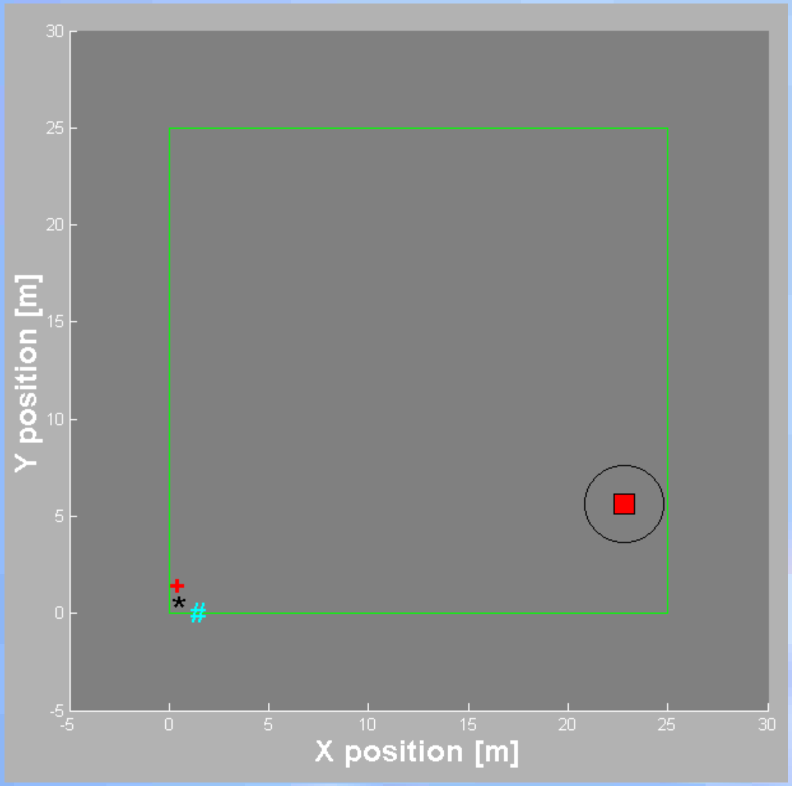


Figure 1: Simulation Output Window. Grey designates unknown area, robots shown: scout (black), medic (blue), fire-suppressant (red), and a light source (red).

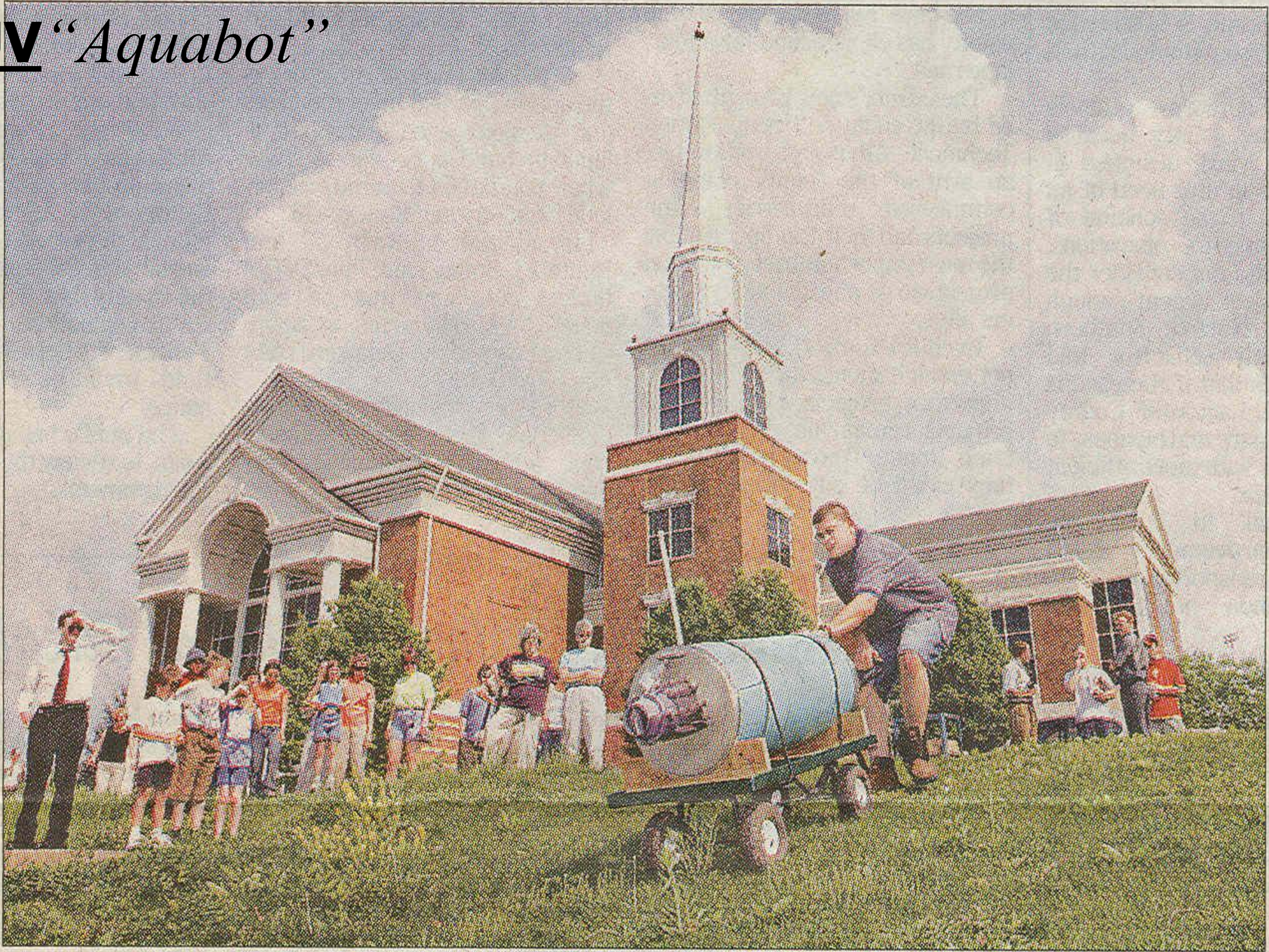
Campos, D. and Wunderlich, J. T. (2002). **Development of an interactive simulation with real-time robots for search and rescue**. In *Proceedings of IEEE/ASME International conference on Flexible Automation*, ***Hiroshima, Japan***: (session U-007). ASME Press.

Unmanned Underwater Vehicles (UUV’s)

<u>U</u>nmanned <u>U</u>nderwater <u>V</u>ehicles *"Aquabot"*

Henderson, S., Shreshtha, S., Wunderlich, J.T. (2004). **<u>A high speed AUV test platform</u>** *(submitted to military conference).*

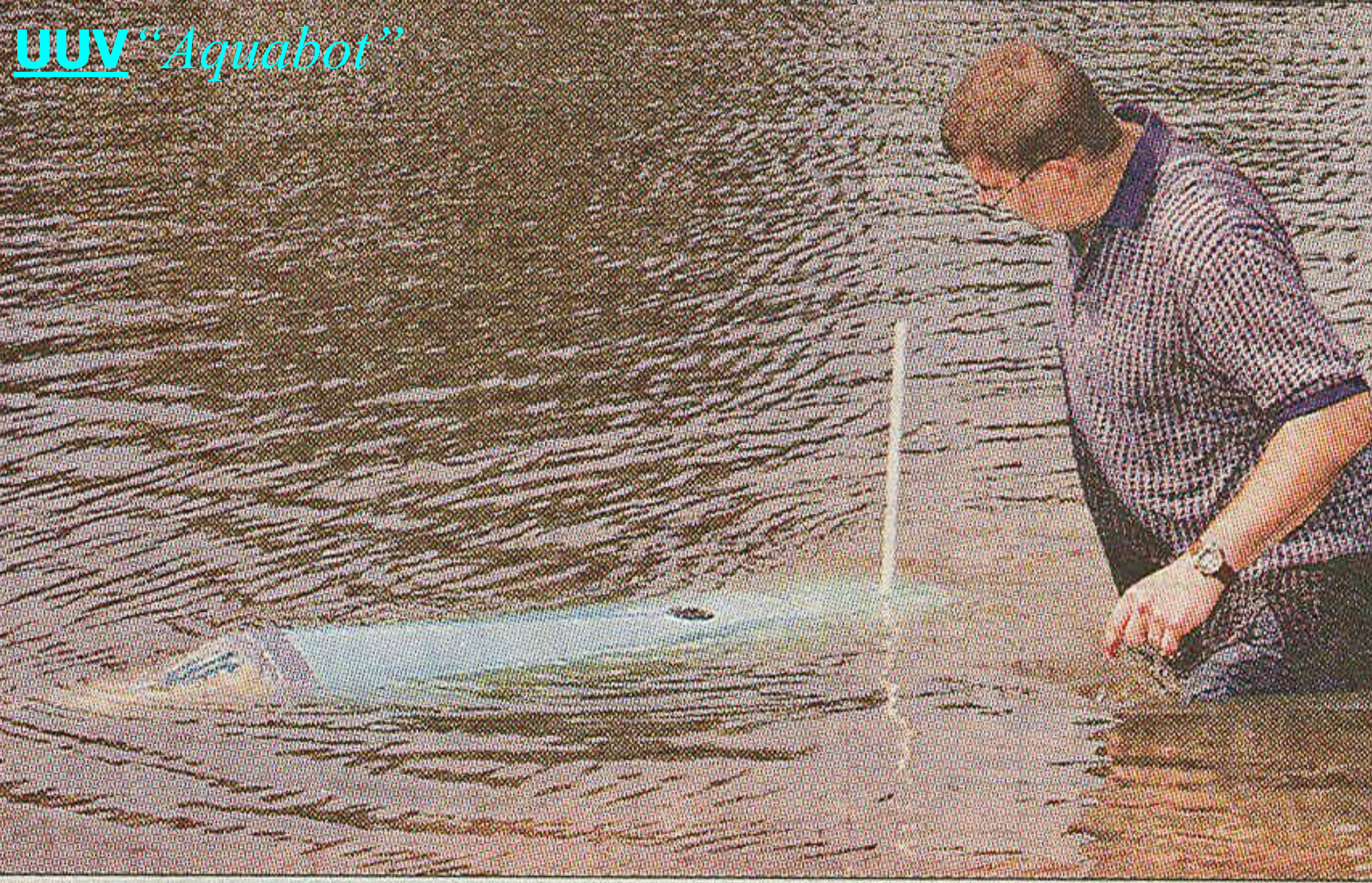
UUV *"Aquabot"*



Intelligencer Journal photos by Suzette Wenger

Elizabethtown College student Steve Henderson prepares to put his robot submarine into Lake Placida in front of Leffler Chapel Wednesday. Below, Henderson checks the sub as it goes for a swim.

UUV *"Aquabot"*



Henderson, S., Shreshtha, S., Wunderlich, J.T. (2004). **A high speed AUV test platform** *(submitted to military conference).*

Unmanned **U**nderwater **V**ehicles

*"**Nereus** will be the first autonomous vehicle to visit the 11,000m (36,089ft) Challenger Deep in the Pacific Ocean. Only two other vehicles have ever visited the spot before, both of them human operated."*

Image and excerpt from: http://news.bbc.co.uk/2/hi/science/nature/8035499.stm

UUV *"Nereus"*

Developed at:
Woods Hole Oceanographic Institute

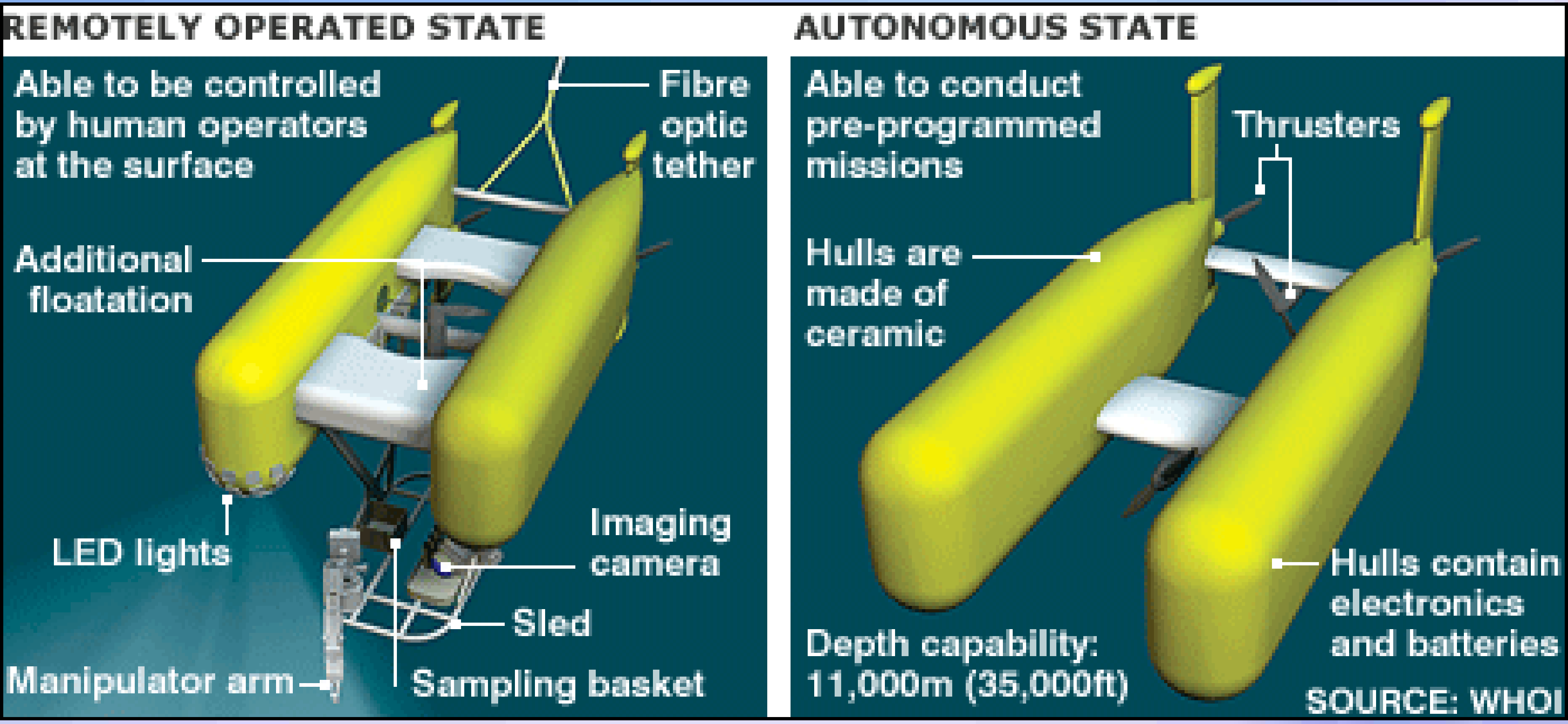
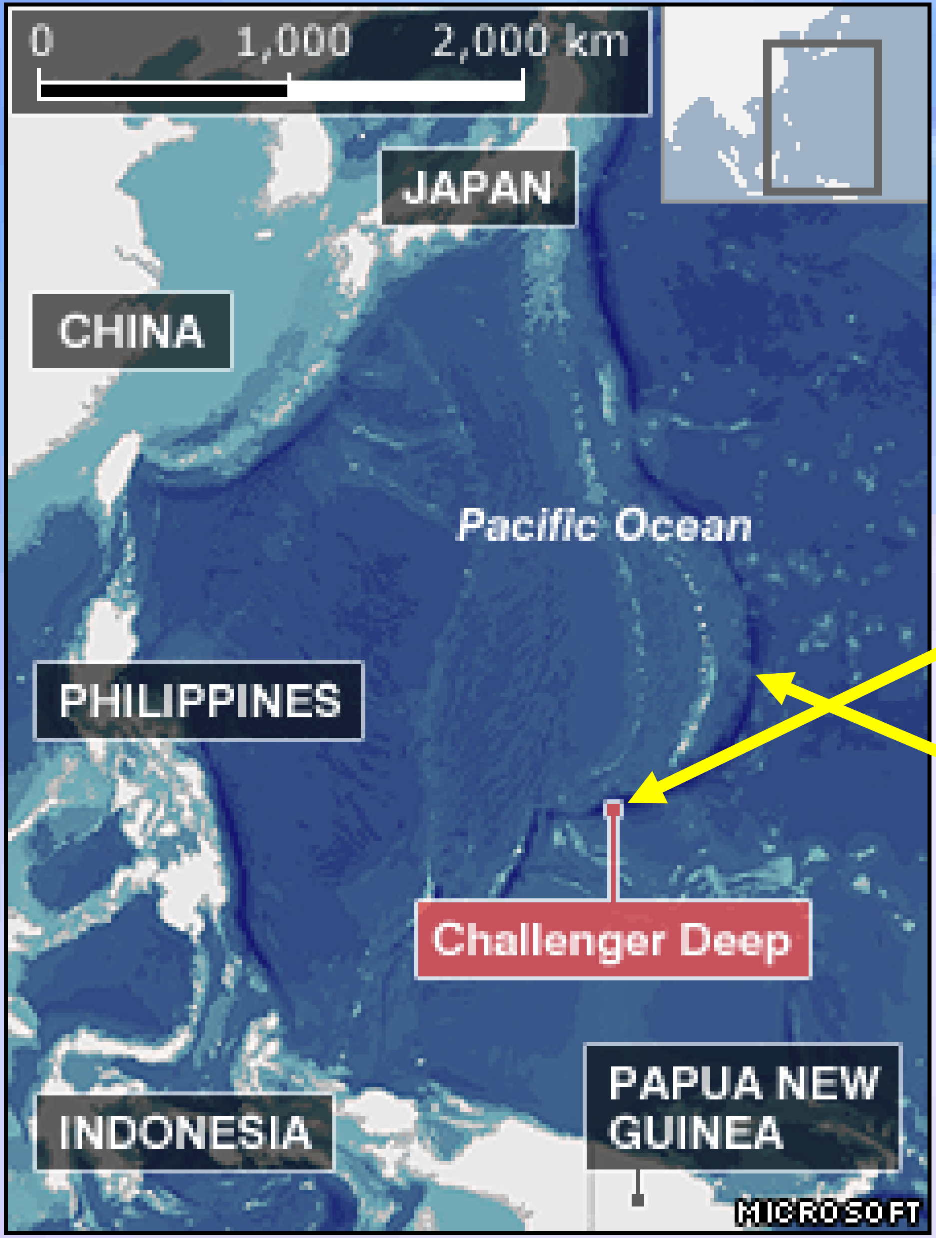


Image and excerpt from: http://news.bbc.co.uk/2/hi/science/nature/8035499.stm

UUV *"Nereus"*



"Challenger Deep" is the name of the deepest place in the Mariana Trench

It is the deepest point in any of the Earth's oceans (11,000 meters) (36,000 feet)

Image and excerpt from: http://news.bbc.co.uk/2/hi/science/nature/8035499.stm

UUV *"Nereus"*

Image and excerpt from: http://news.bbc.co.uk/2/hi/science/nature/8035499.stm

UUV *"Nereus"*

VIDEO: http://video.aol.com/video-detail/sub-will-map-deepest-trenches/626778029

UUV SWARM

"A decentralized control scheme for large packs of unmanned underwater vehicles (UUV) is being proposed and investigated. This scheme is based on shared knowledge of a template, which includes operational plans, modes of operation, contingencies including the ability to adapt individual plans within the template to changing operational conditions, and the protocols for disseminating individual state, network, and command information between UUVs"

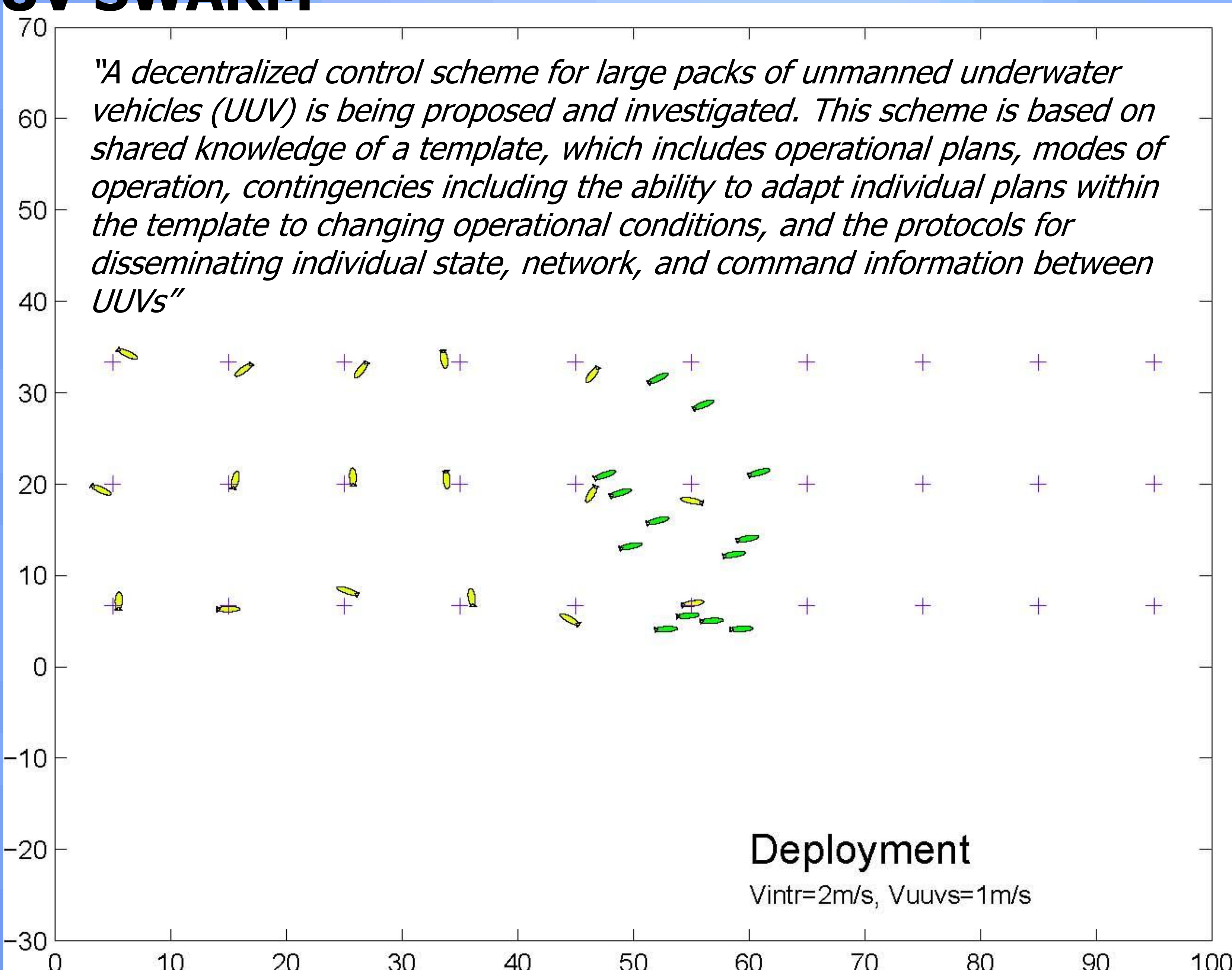


Image and excerpt from: https://buffy.eecs.berkeley.edu/PHP/resabs/resabs.php?f_year=2006&f_submit=advgrp&f_advid=10249548

Europa Rover Navigation

Possible course project

Maneuver on flat icy surface, then drill through 200 meters of ice

When water reached, either:
(1) Act as UUV, or
(2) **Deploy a swarm of 100 10cm long UUV's**

Communicate with UUV's if option (2) chosen

Communicate with base station that is also communicating with several orbiters and earth. The base station is also running a **concurrent simulation** to the rover's real-time code and will be building a "GLOBAL" environmental map of the region of Europa being explored. This information should also be communicated back to the rover, -- and then to UUV's if option (2) is chosen.

Image from: http://www.mapaplanet.org/explorer/help/data_set.html

Wunderbot 4 Wireless Communication
by Jeremy Crouse (advisor: Dr. Wunderlich)

Swarms

Although Wunderbots are fully autonomous, the IGVC awards those who can respond to “JAUS” for **Networked unmanned systems**

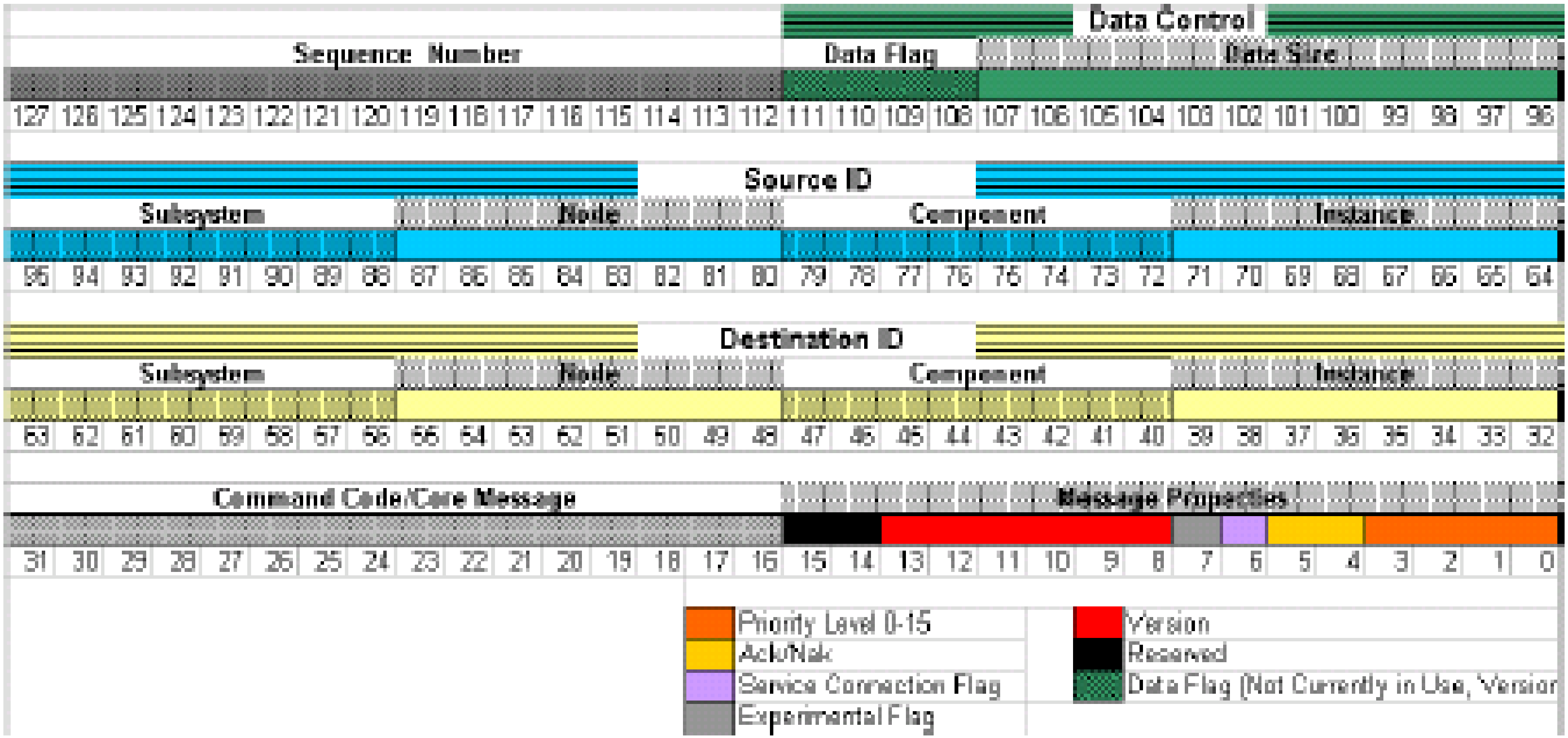


Figure 7: JAUS message header detailed structure [6]

SOURCE: : Crouse, J. (2008). **The joint architecture for unmanned systems: a subsystem of the wunderbot 4**. *Elizabethtown College research report.*

MORE ON THIS in COMPUTING LECTURES

Wunderbot 4 Wireless Communication
by Jeremy Crouse (advisor: Dr. Wunderlich)

Swarms

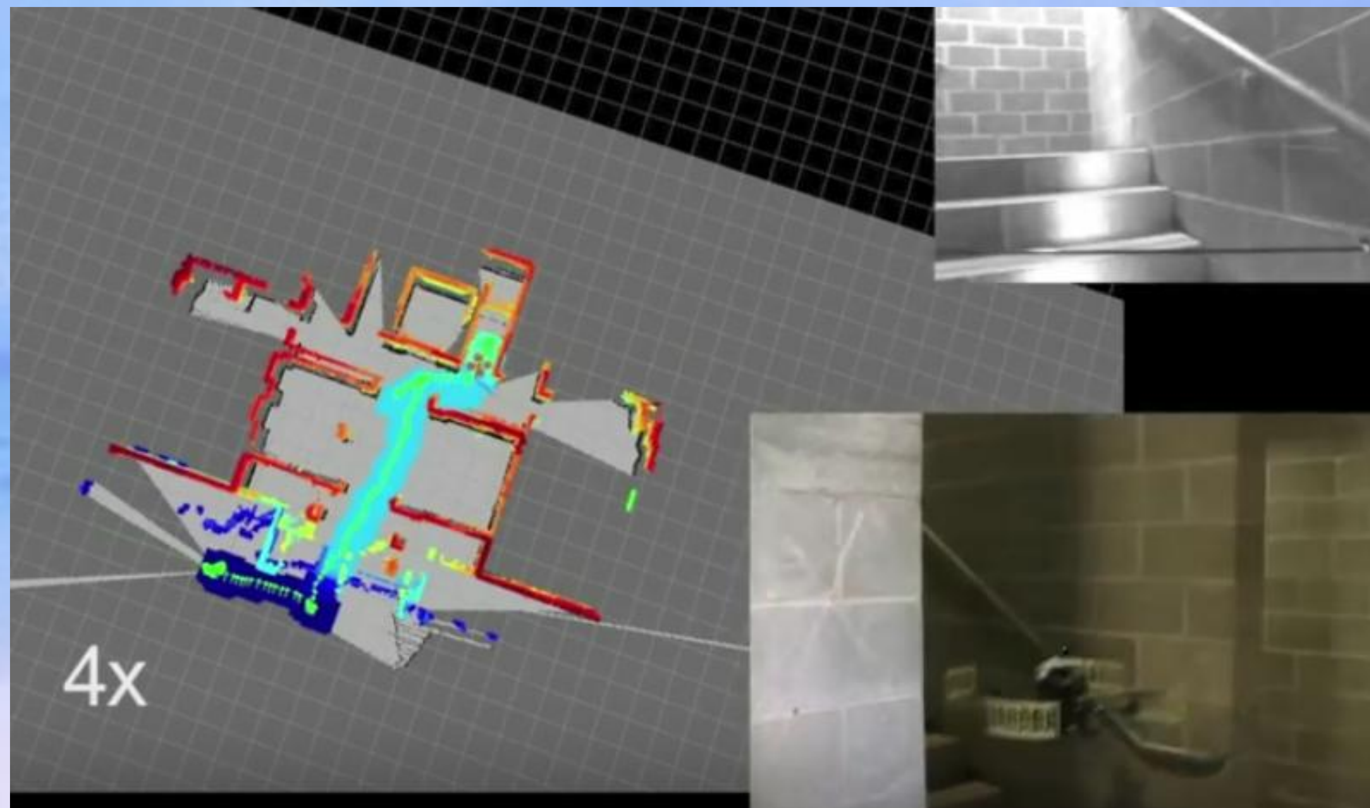
SOURCE: : Crouse, J. (2008). **The joint architecture for unmanned systems: a subsystem of the wunderbot 4**. *Elizabethtown College research report.* ***MORE ON THIS in COMPUTING LECTURES***

Dr. Vijay Kumar, U. of Pennsylvania

Swarms

(Dr. Wunderlich worked with Dr. Kumar at the AI DuPont Children's Hospital Applied Science and Engineering Lab, 1993-94)

2012 Dr. Kumar TED Talk: https://www.youtube.com/watch?v=4ErEBkj_3PY



2013 Dr. Kumar Talk
https://www.youtube.com/watch?v=4ErEBkj_3PY

2014 TED Talk
by Magnus Egrstedt
https://www.youtube.com/watch?v=ULKyXnQ9xWA

Agility with Scaling

- Blade tip speed

$$v \sim \sqrt{R}$$

- Lift

$$F = C_L A v^2 \sim R^3$$

- Inertia

$$m \sim R^3, \; I \sim R^5$$

- Acceleration

Linear $\quad a \sim 1$

Angular $\quad \alpha \sim \frac{1}{R}$

So, the smaller you make it, the faster you can turn

SOURCE: https://www.youtube.com/watch?v=4ErEBkj_3PY

Dr. Vijay Kumar,
U. PENN

Swarms

If we start by looking at the **displacement** of an object (i.e. the distance from where it started to where it currently is) then when we look at the first derivative (by time) of displacement, (i.e. dividing the displacement of an object for how long it took to be displaced) we have calculated the object's **velocity**.

$$v = \frac{dx}{dt}$$

If we look at the rate of change of velocity, the second derivative (by time) of the object's displacement (i.e. the rate of change of the rate of change of its displacement), then we have calculated the object's **acceleration**.

$$a = \frac{dv}{dt} = \frac{d^2x}{dt^2}$$

If we now look at the rate of change of acceleration, the third derivative of the object's displacement (i.e. the rate of change of the rate of change of the rate of change of its displacement) then we have calculated the object's **jerk**.

$$j = \frac{da}{dt} = \frac{d^2v}{dt^2} = \frac{d^3x}{dt^3}$$

The first two derivatives of displacement, velocity and acceleration, are well known and reasonably well-understood by most people. But jerk is a little bit more difficult to understand. If we apply a force to an object it will accelerate, and we usually assume that this force is applied instantaneously. But this is not correct – it takes time to apply a force. As a result, the rate of acceleration will not be constant, and thus we have the jerk.

The fourth derivative of an object's displacement (the rate of change of jerk) is known as **snap** (also known as **jounce**), the fifth derivative (the rate of change of snap) is **crackle**, and – you've guessed it – the sixth derivative of displacement is **pop**. As far as I can tell, none of these are commonly used.

SOURCE:
https://www.youtube.com/watch?v=4ErEBkj_3PY

In physics, **jounce** or **snap** is the fourth derivative of the position vector with respect to time, with the first, second, and third derivatives being velocity, acceleration, and jerk, respectively; hence, the jounce is the rate of change of the jerk with respect to time. Jounce is defined by any of the following equivalent expressions:

$$\vec{s} = \frac{d\vec{j}}{dt} = \frac{d^2\vec{a}}{dt^2} = \frac{d^3\vec{v}}{dt^3} = \frac{d^4\vec{r}}{dt^4}$$

The following equations are used for constant jounce:

$$\vec{j} = \vec{j}_0 + \vec{s}\,t$$

$$\vec{a} = \vec{a}_0 + \vec{j}_0\,t + \frac{1}{2}\vec{s}\,t^2$$

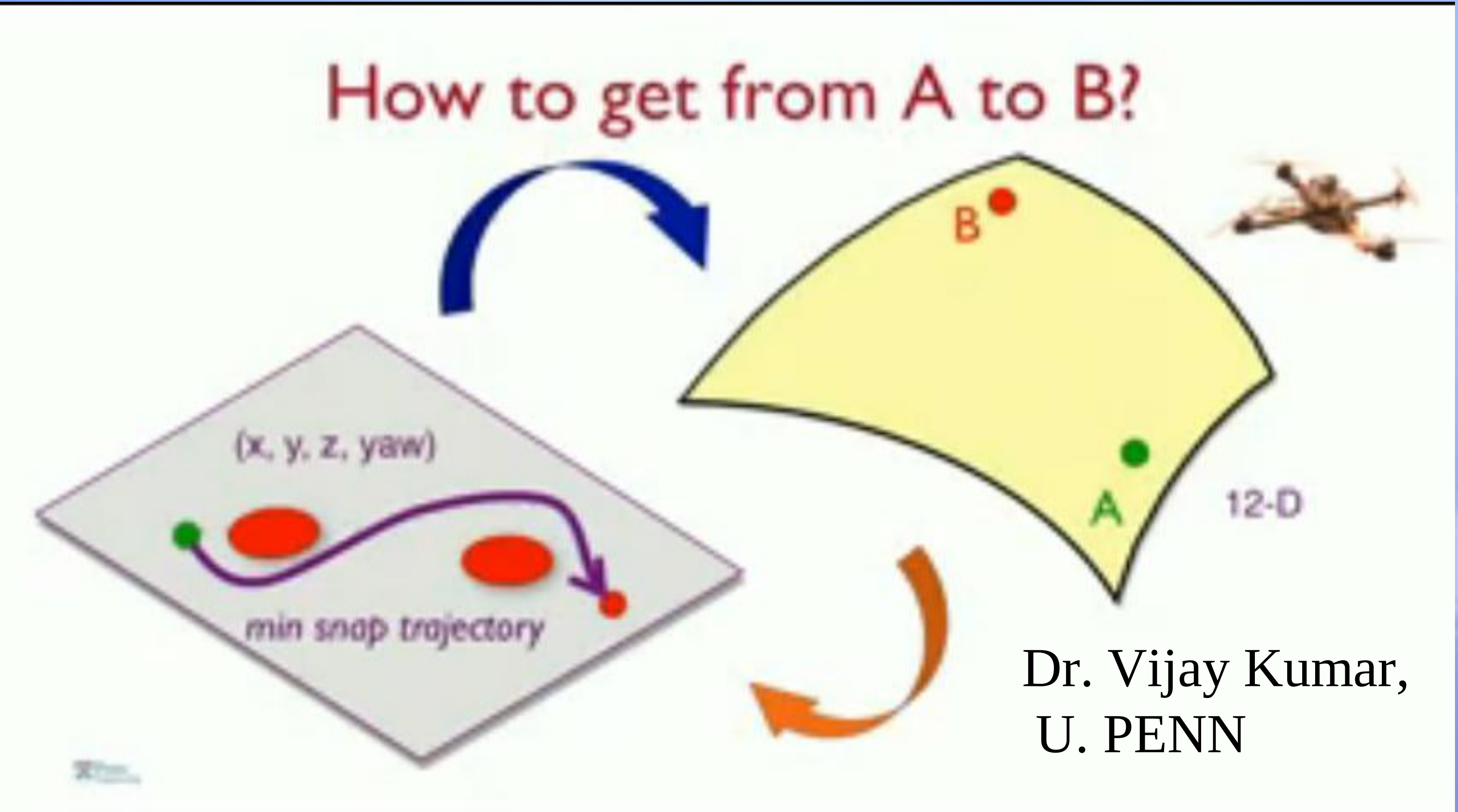
$$\vec{v} = \vec{v}_0 + \vec{a}_0\,t + \frac{1}{2}\vec{j}_0\,t^2 + \frac{1}{6}\vec{s}\,t^3$$

$$\vec{r} = \vec{r}_0 + \vec{v}_0\,t + \frac{1}{2}\vec{a}_0\,t^2 + \frac{1}{6}\vec{j}_0\,t^3 + \frac{1}{24}\vec{s}\,t^4$$

where

- $\vec{s}$: constant jounce,
- $\vec{j}_0$: initial jerk,
- $\vec{j}$: final jerk,
- $\vec{a}_0$: initial acceleration,
- $\vec{a}$: final acceleration,
- $\vec{v}_0$: initial velocity,
- $\vec{v}$: final velocity,
- $\vec{r}_0$: initial position,
- $\vec{r}$: final position,
- t : time between initial and final states.

SOURCE
https://en.wikipedia.org/wiki/Jounce



Dr. Vijay Kumar,
U. PENN

Curved 12D space transformed into flat 4D space
(x, y, x, yaw) , and then robot plans a trajectory through this 4D space. This is called a SNAP trajectory

VIDEO SOURCE: https://www.youtube.com/watch?v=4ErEBkj_3PY

Publication: http://www-personal.acfr.usyd.edu.au/spns/cdm/papers/Mellinger.pdf

Dr. Vijay Kumar,
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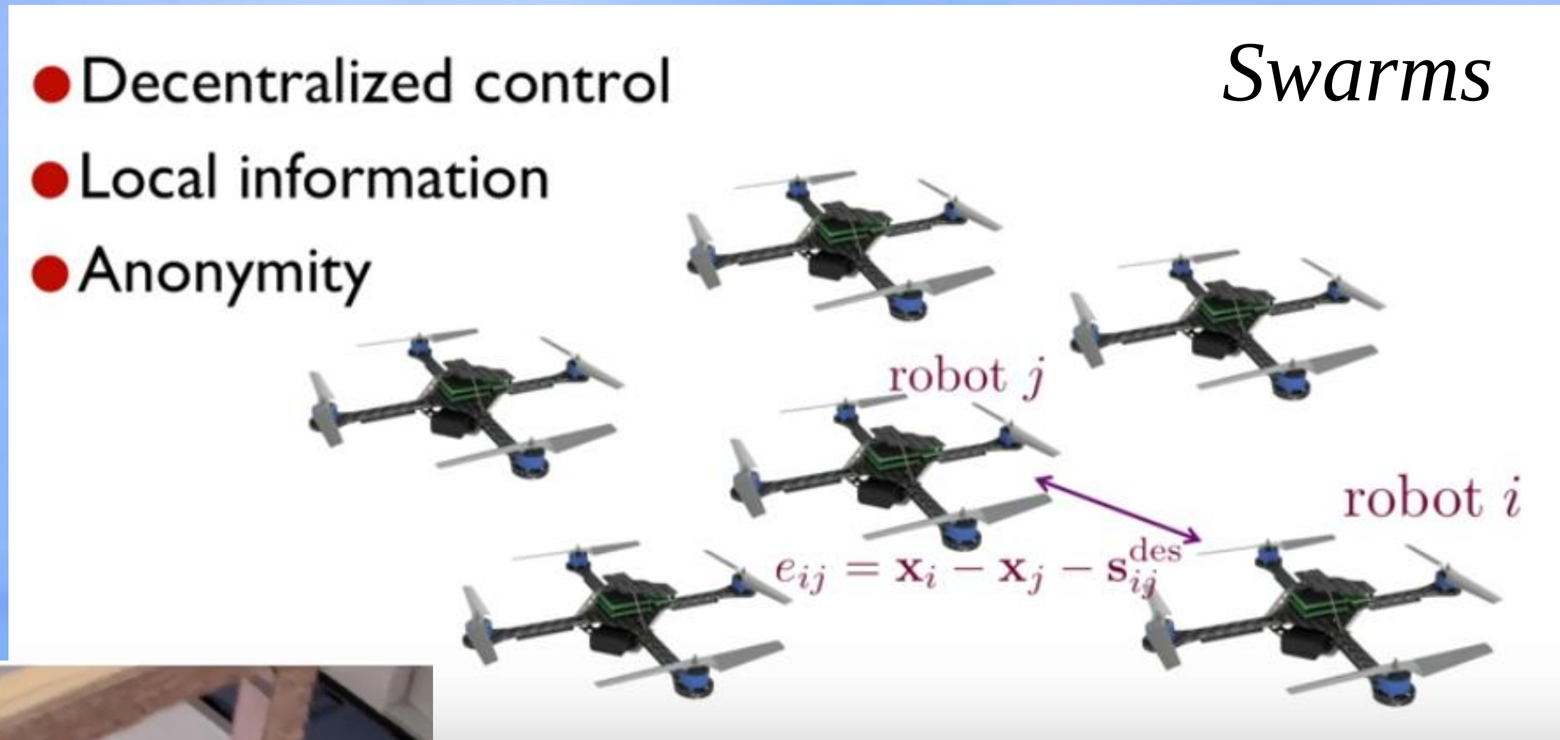


LOCAL Path Planning, but very complex ! – and collective

SOURCE: https://www.youtube.com/watch?v=4ErEBkj_3PY

Dr. Vijay Kumar,
U. PENN

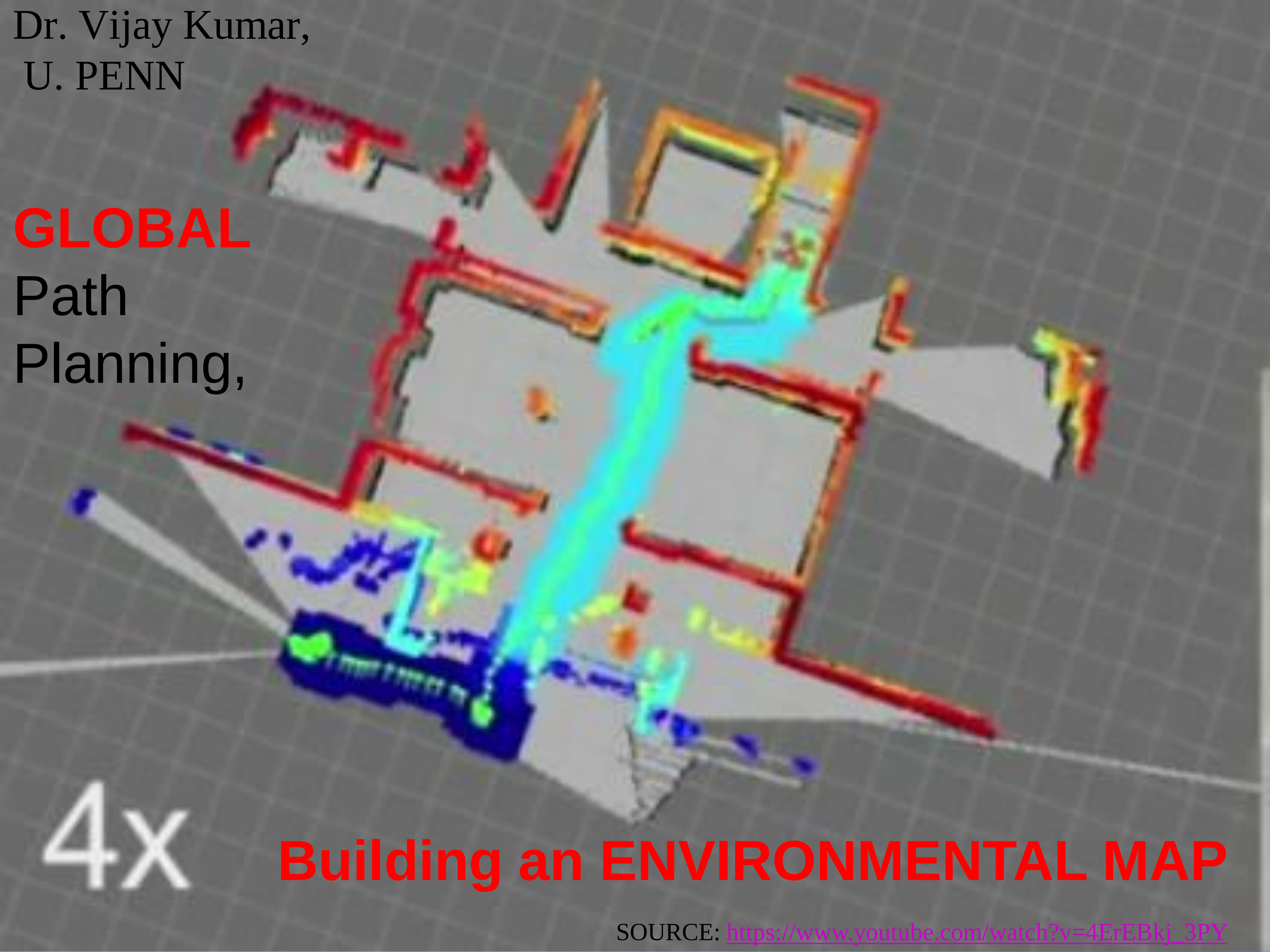
Swarms

Just give swarm Working Drawings, they Build !

SOURCE: https://www.youtube.com/watch?v=4ErEBkj_3PY

Dr. Vijay Kumar,
U. PENN

GLOBAL Path Planning,



Building an ENVIRONMENTAL MAP

SOURCE: https://www.youtube.com/watch?v=4ErEBkj_3PY