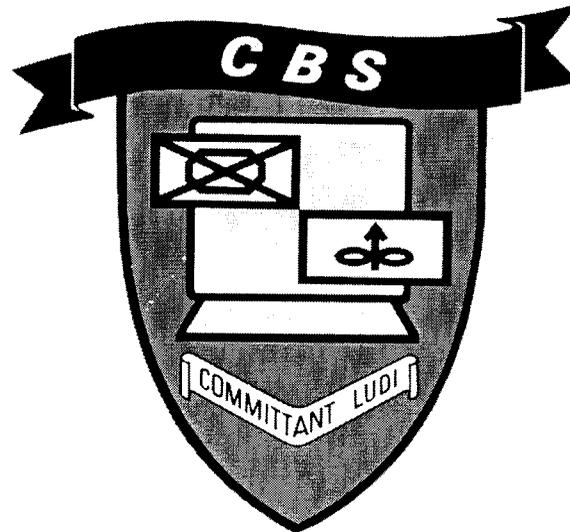


# SuperTINs

New Line of Sight Algorithm

Renders Superlative TINs Superfluous

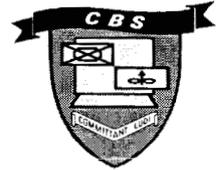


Bob Chamberlain [rgc@jpl.nasa.gov](mailto:rgc@jpl.nasa.gov)  
Joseph Gonzalez [josephg@its.caltech.edu](mailto:josephg@its.caltech.edu)



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# Three Stories for the Price of One



TINs are piecewise planar models of a surface

- Triangulated Irregular Networks
- Used by Corps Battle Simulation since 1996
- For seven years I've been planning how to make better TINs
  - » Finally, it was funded; Goal: "Superlative" TINs

Summer Research Project: Optimize the TINning Parameters

- First step: How do you know one TIN is better than another?
- Answer: Compare effectiveness re LOS assessment
  - » Assume a regular triangulation of the full DEM is "ground truth"
- Then why not just use the regular triangulation?
  - » Because ... and ... and ... — *Why not, indeed!*

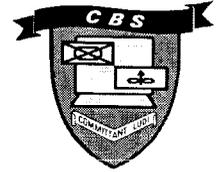
The New  $O(\log n)$  Line-of-Sight Algorithm

- Build a quadtree from quads of DEM posts, quads of quads, ...
- Store the quadtree on hard disk, use cache for access speed
- Use the quadtree to skip over many edges at once

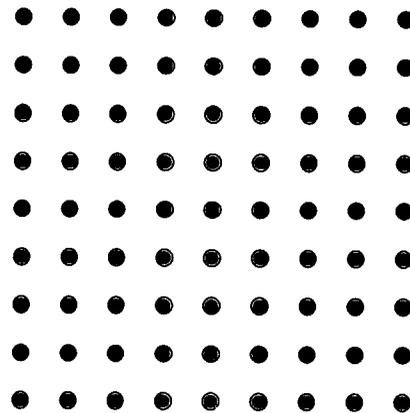


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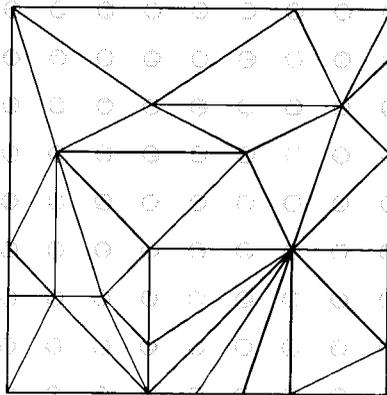
# First Story: Piece-wise Planar Terrain Skins



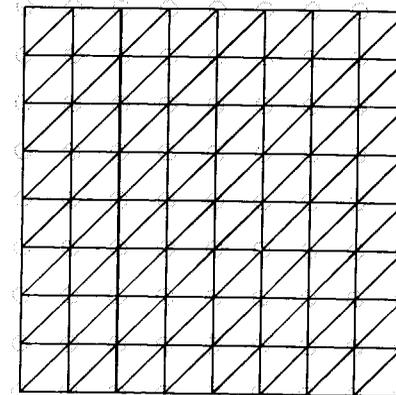
Digital Elevation Map (DEM)



Triangulated Irregular Networks (TINs)



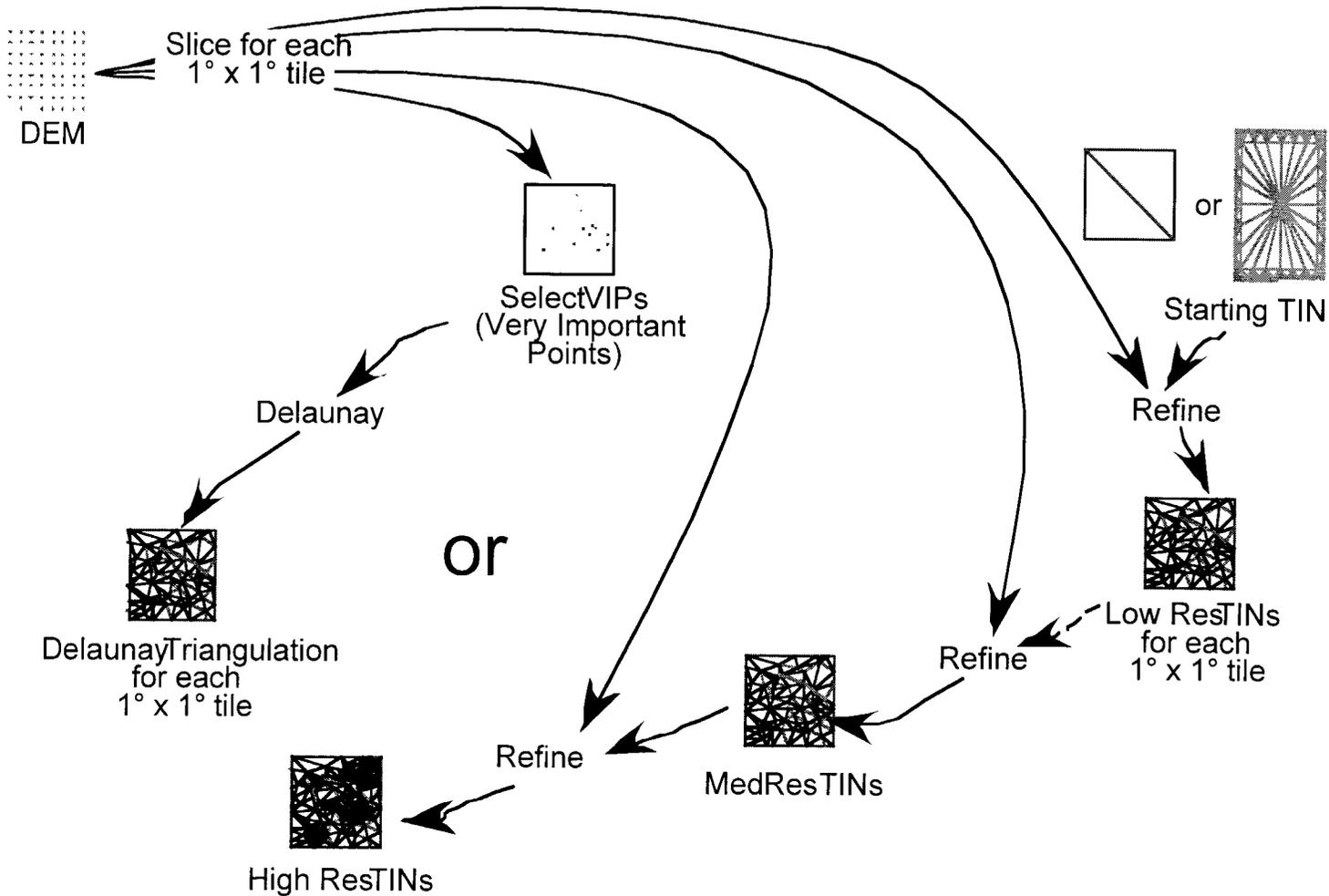
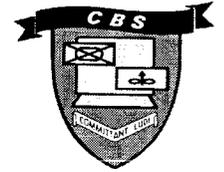
Regular triangulations

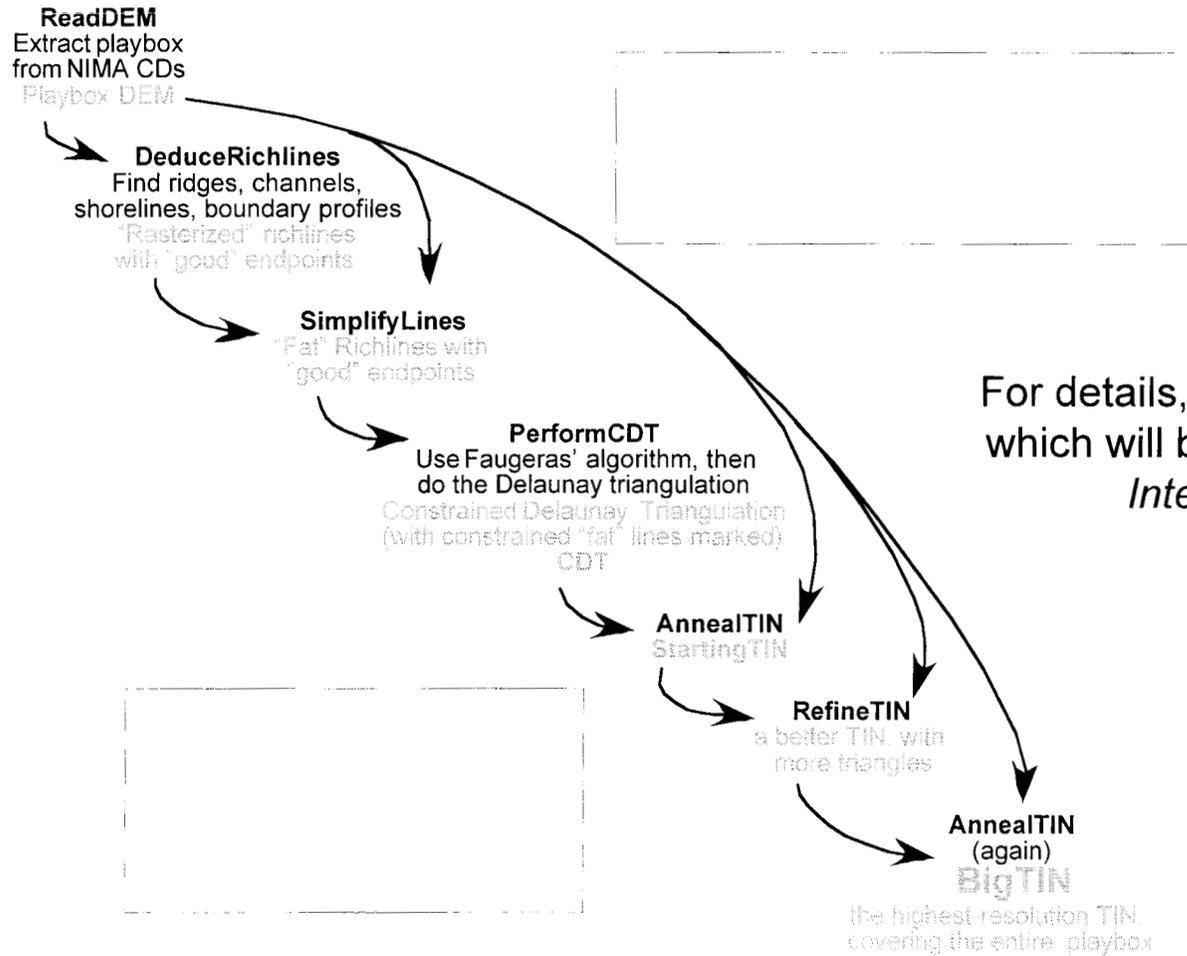




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# State-of-the-Art TIN Construction in Military Simulations



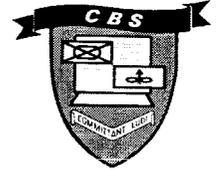


For details, see the paper,  
which will be submitted to  
*Interfaces*.



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# Second Story: The Parameter Optimization Project



Improved TIN process has three dozen free parameters

- Tolerances, minimum lengths, budgets, weights, goals
- Reasonable guesses can be made, but it would be “cool” — and maybe a lot better — to optimize

Opportunity: Summer Undergraduate Research Fellowship

- Low risk, low cost, maybe a high payoff
- Five nibbles, two bites — one, clearly superior in several ways, suggested genetic optimization

First step in optimization: Understand the response surface

- Q. How do we know one TIN is better than another?
- A. Compare LOS results vs a regular triangulation of the DEM



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And this led to the question...



Why not just use a regular triangulation of the DEM?  
LOS evaluation would be as good as on the *best possible* TIN

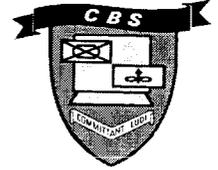
- Performance
  - Quality demands all edges be considered
  - There would be too many edge crossings to evaluate
- Memory
  - CBS playbox DEMs would need up to 13 GB for the DEM
  - TINs are only allocated 350 MB



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# “LOS looks like a special case of ray tracing”



## Algorithm

- Quadtrees (instead of octrees) allow test of LOS vs large areas
- Above the leaves, test intersections of LOS with bounding boxes
- Leaf nodes contain the terrain triangles defined by four DEM posts

## Speed

- It's an  $O(\log n)$  algorithm

## Memory

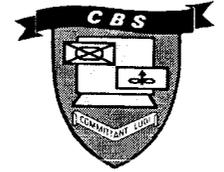
- Higher limits now than in 1996
- Regular triangles can be implicit, compression may be possible
- SRTM has 1 arc-sec (31 m) spacing; DTED1 had 3 arc-sec
  - » 6 arc-sec (185 m) spacing would fit the biggest playbox into 500 MB
- (Later:) May be able to use hard disk

## Risk

- Very low due to simplicity



# What Did We Do?



We tabled TIN implementation though it was 80% complete

- Not resumed because the Quadtree LOS Algorithm works!
- Documented in the paper, which we will submit to *Interfaces*

We looked for other possible “show stoppers”

- LOS and elevations are the *only* CBS uses of TINs
- The user interface (“the workstation”) had been using the TINs to find elevations to draw LOS fans
- Quadtrees can easily produce interpolated DEM elevations

We developed a prototype that runs with the main simulation engine as a proof of concept

- Tested on 65,000 LOS’s drawn from a CBS exercise
- LOS tests on the old TINs were right almost 81% of the time
- Achieved same speed (96%), using TCP/IP for interprocess communication; improvement is likely



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which brings us to the  
third story...

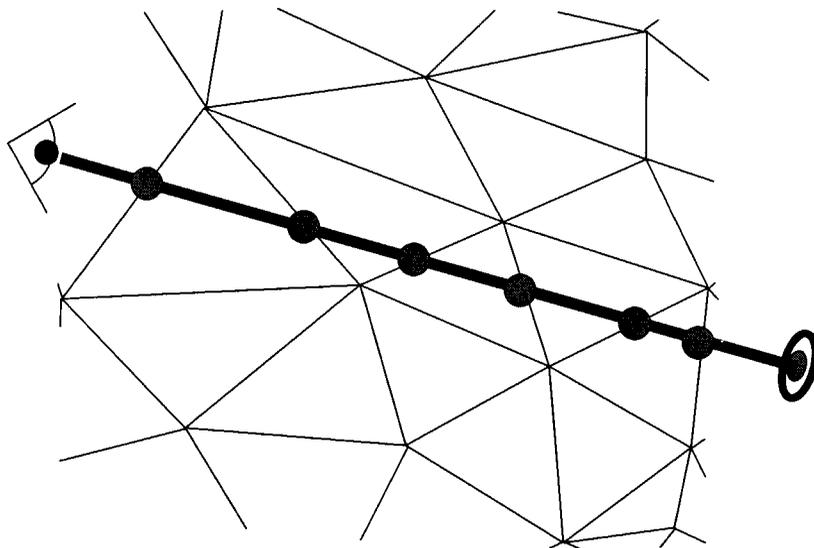
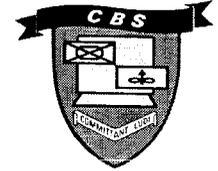


# Line of Sight Algorithms

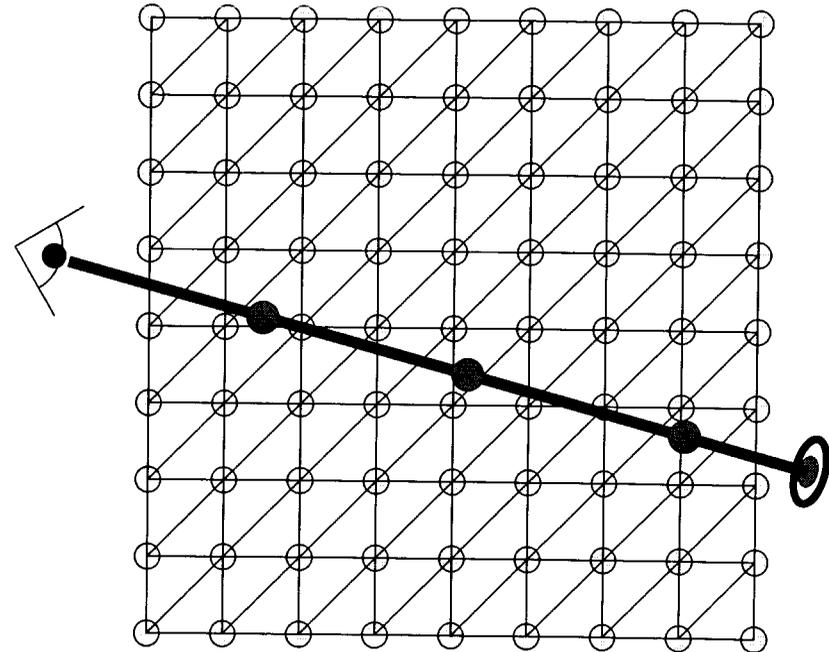


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# State-of-the-Art LOS Assessment in Military Simulations



**Edge Traversal**  
— demands efficient TINs

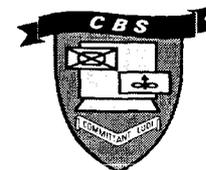


**Periodic Sampling**  
— flexible at the expense of accuracy



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# The Quadtree LOS Algorithm



As with the TIN algorithm, there are two steps:

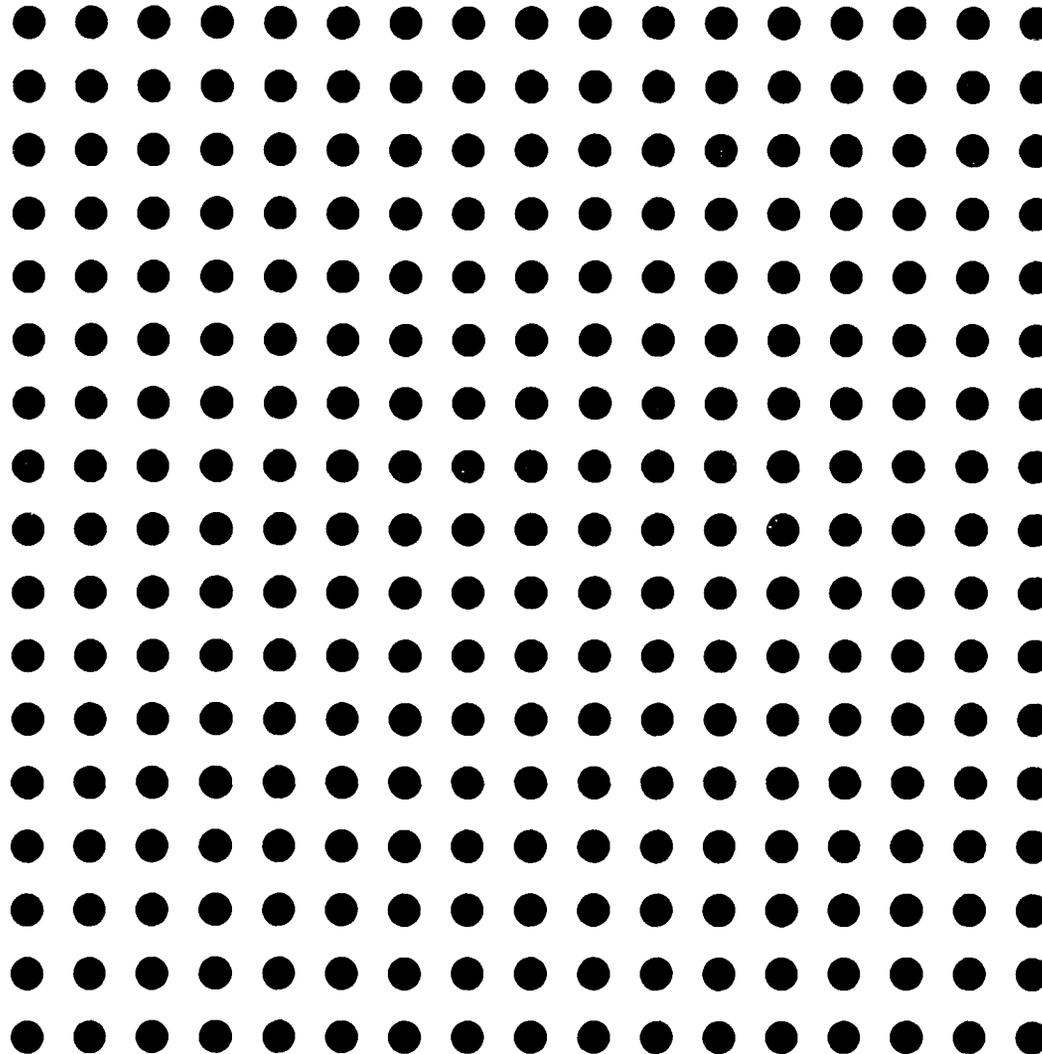
- Pre-exercise preparation:
  - » Instead of a TIN, build a quadtree
- During the exercise:
  - » Apply the quadtree algorithm to evaluate LOS
  - » Interpolate to determine elevations



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# Constructing an LOS Quadtree

## First, the DEM (elevation posts)

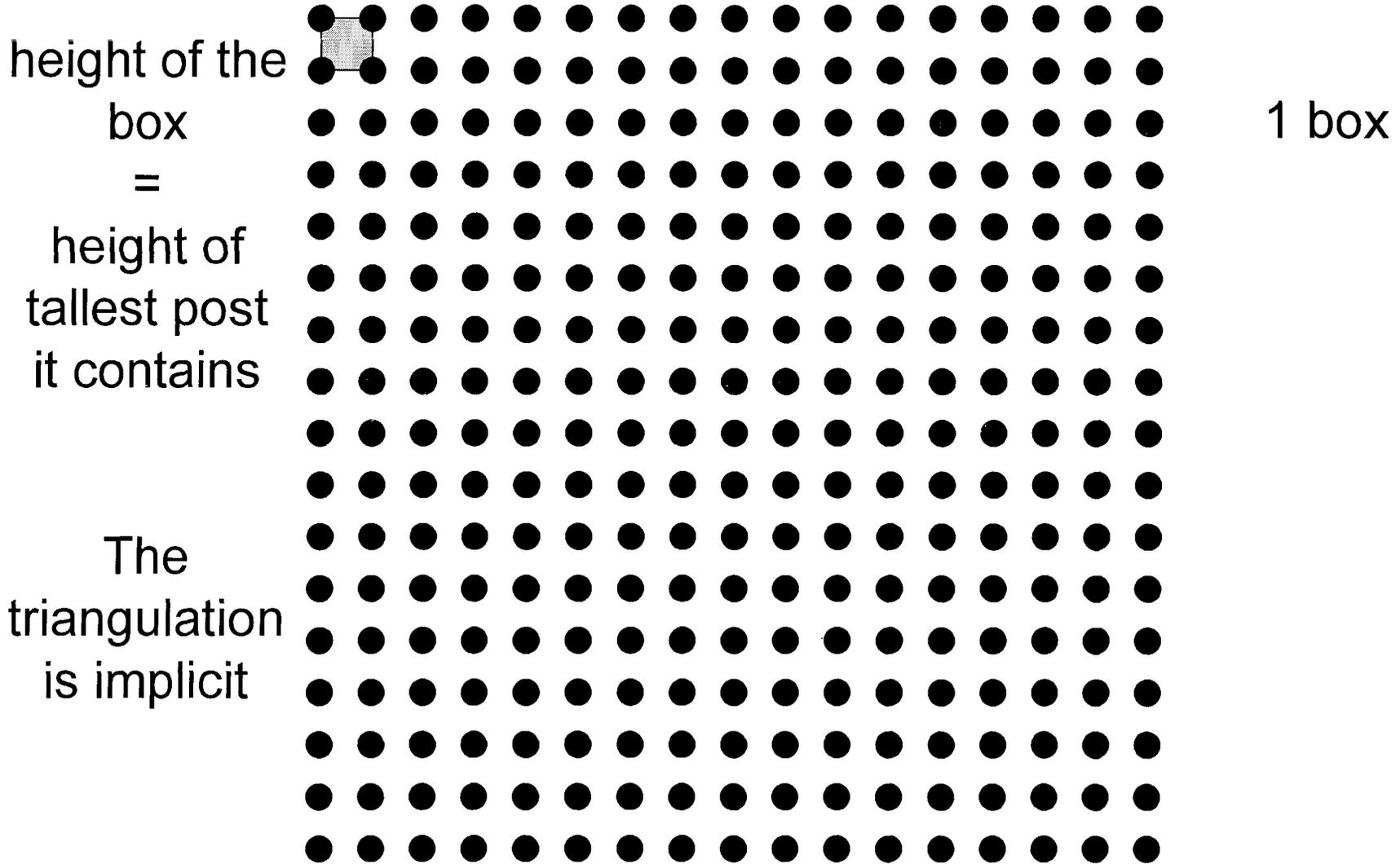
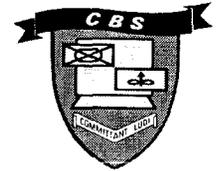




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# — The Leaves of the Tree —

Boxes containing 4 posts each

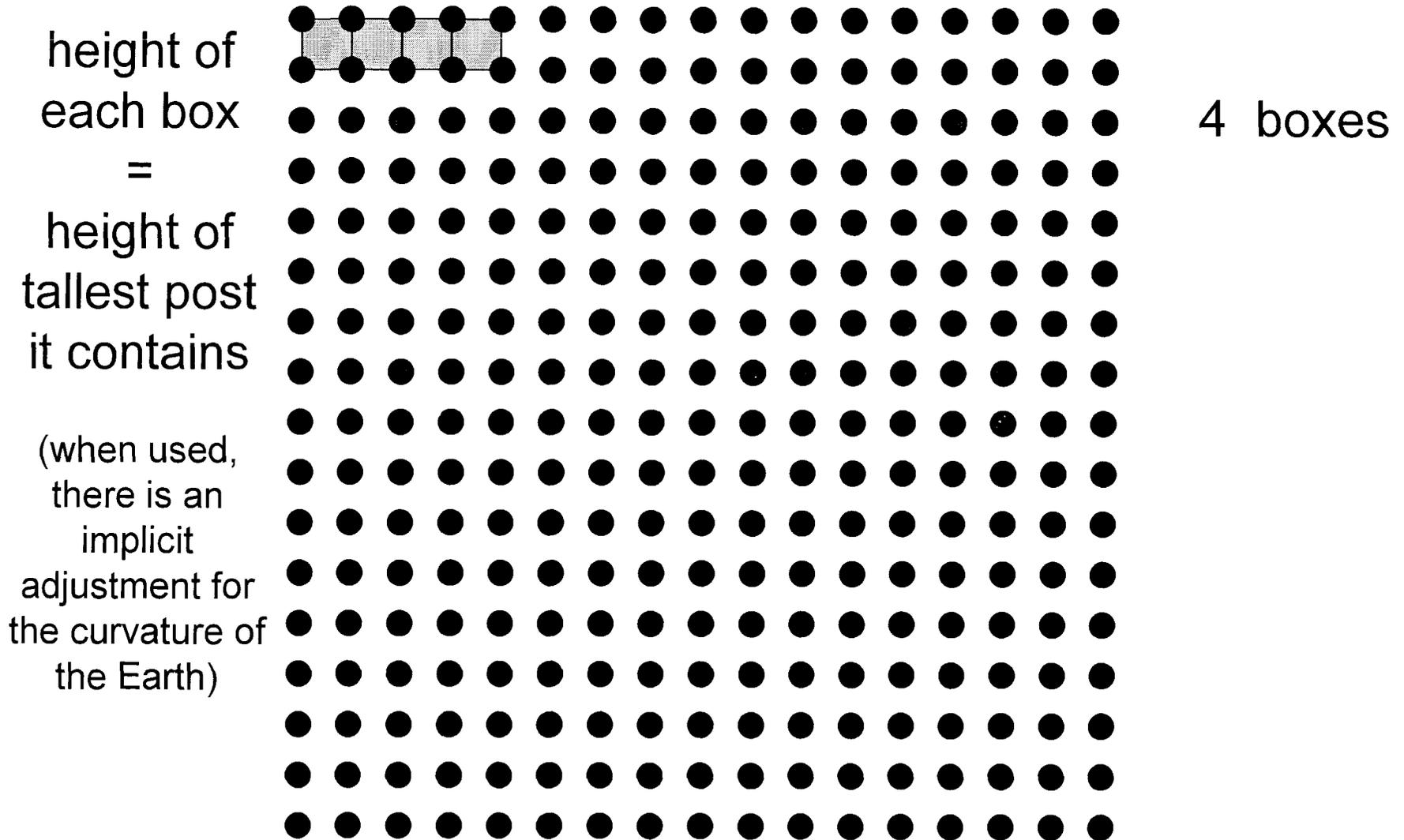
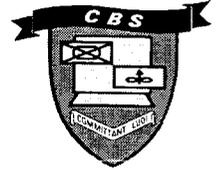




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# — The Leaves of the Tree —

Boxes containing 4 posts each

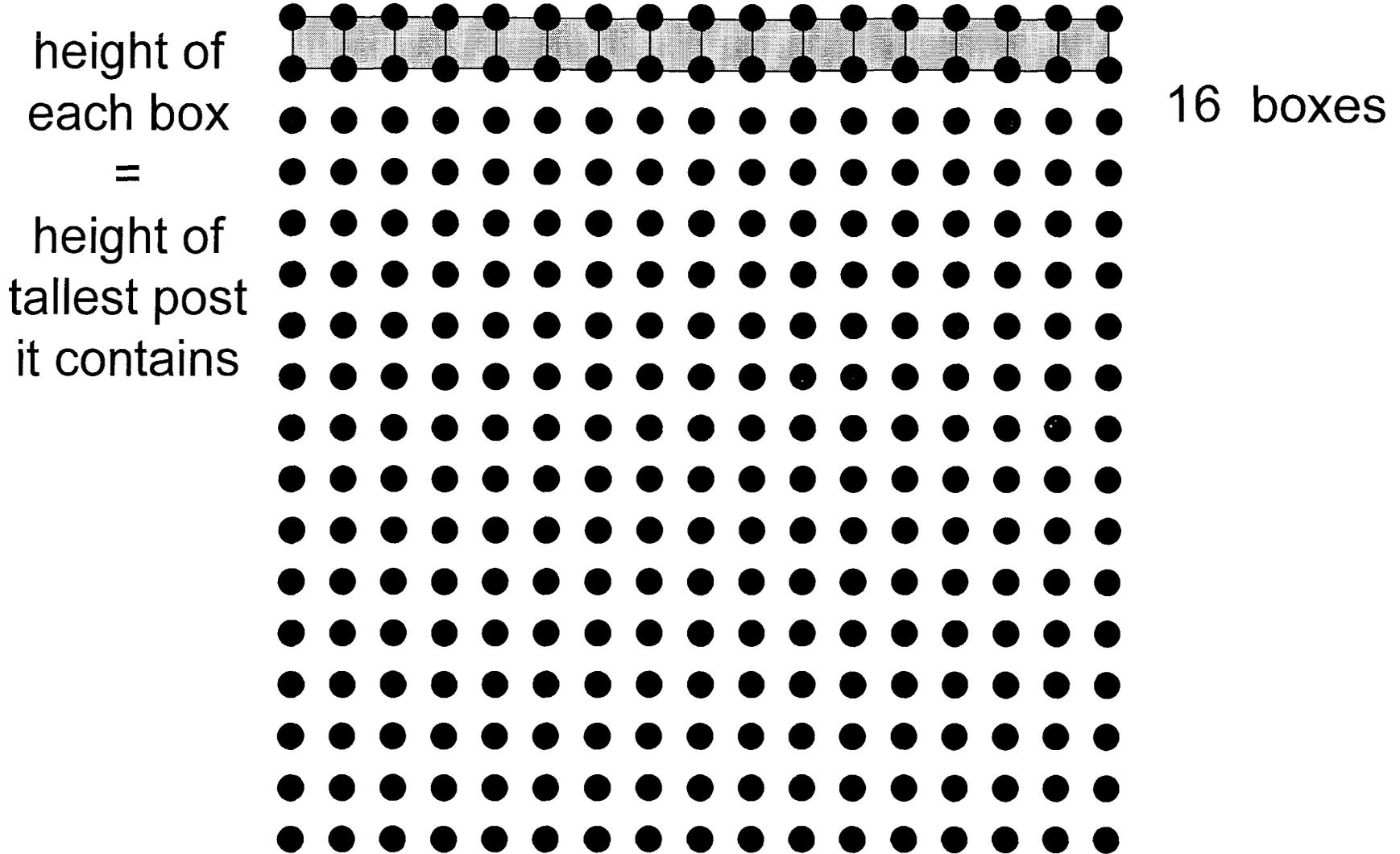
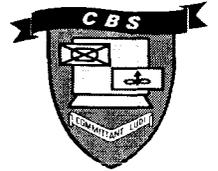




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# — The Leaves of the Tree —

Boxes containing 4 posts each





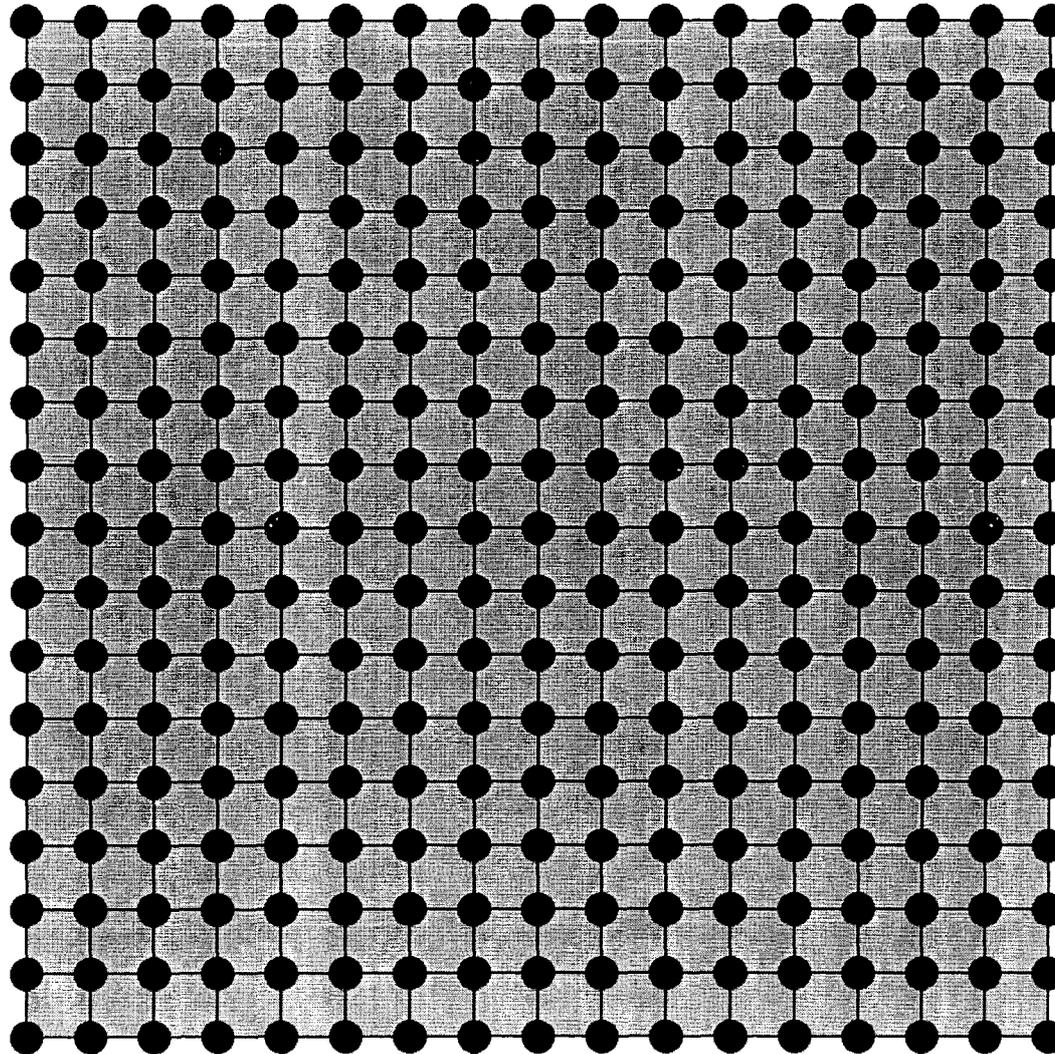
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# — The Leaves of the Tree —

## Boxes containing 4 posts each



height of  
each box  
=  
height of  
tallest post  
it contains



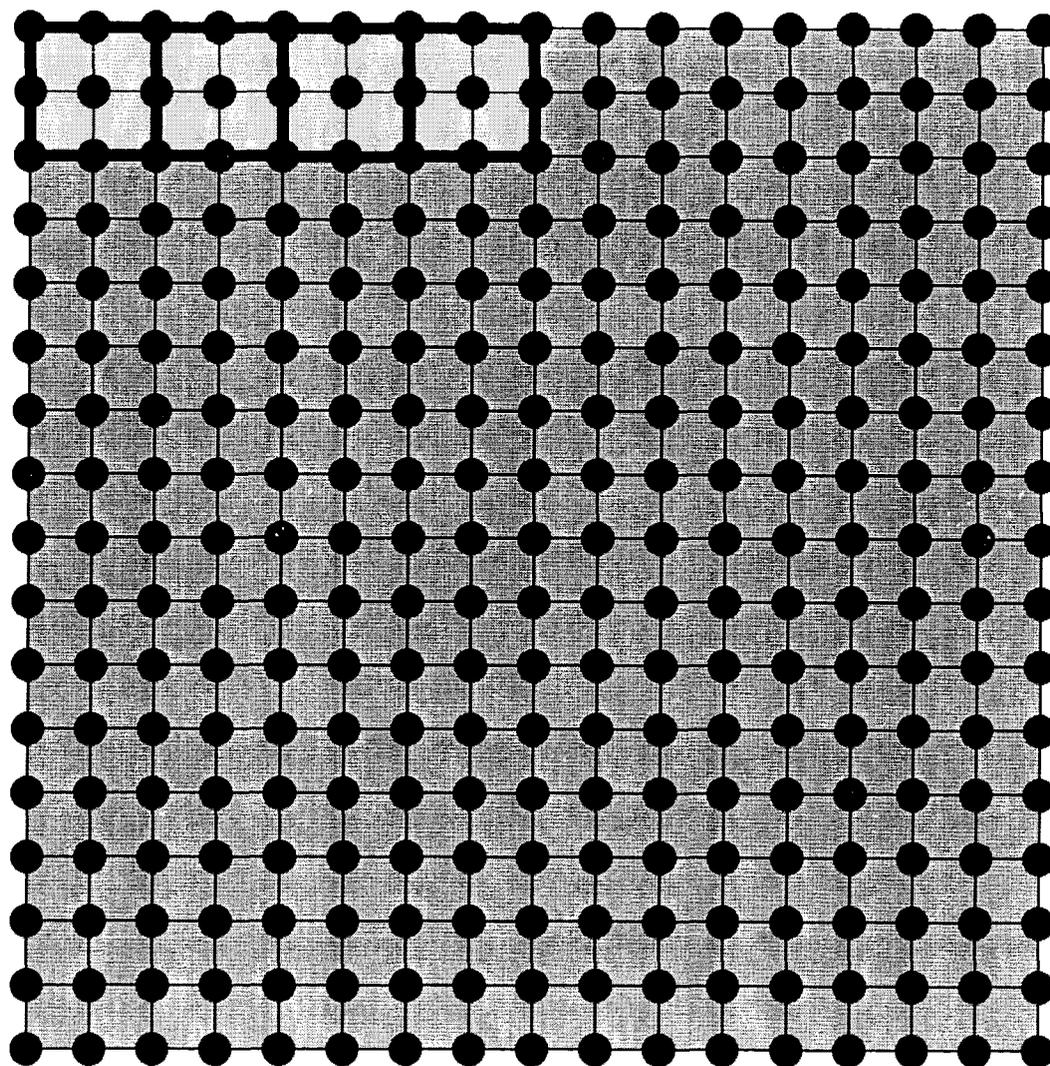
256 boxes  
(in this  
example)



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# The Lowest Nodes in the Tree

## Combine quads of boxes



4 quads

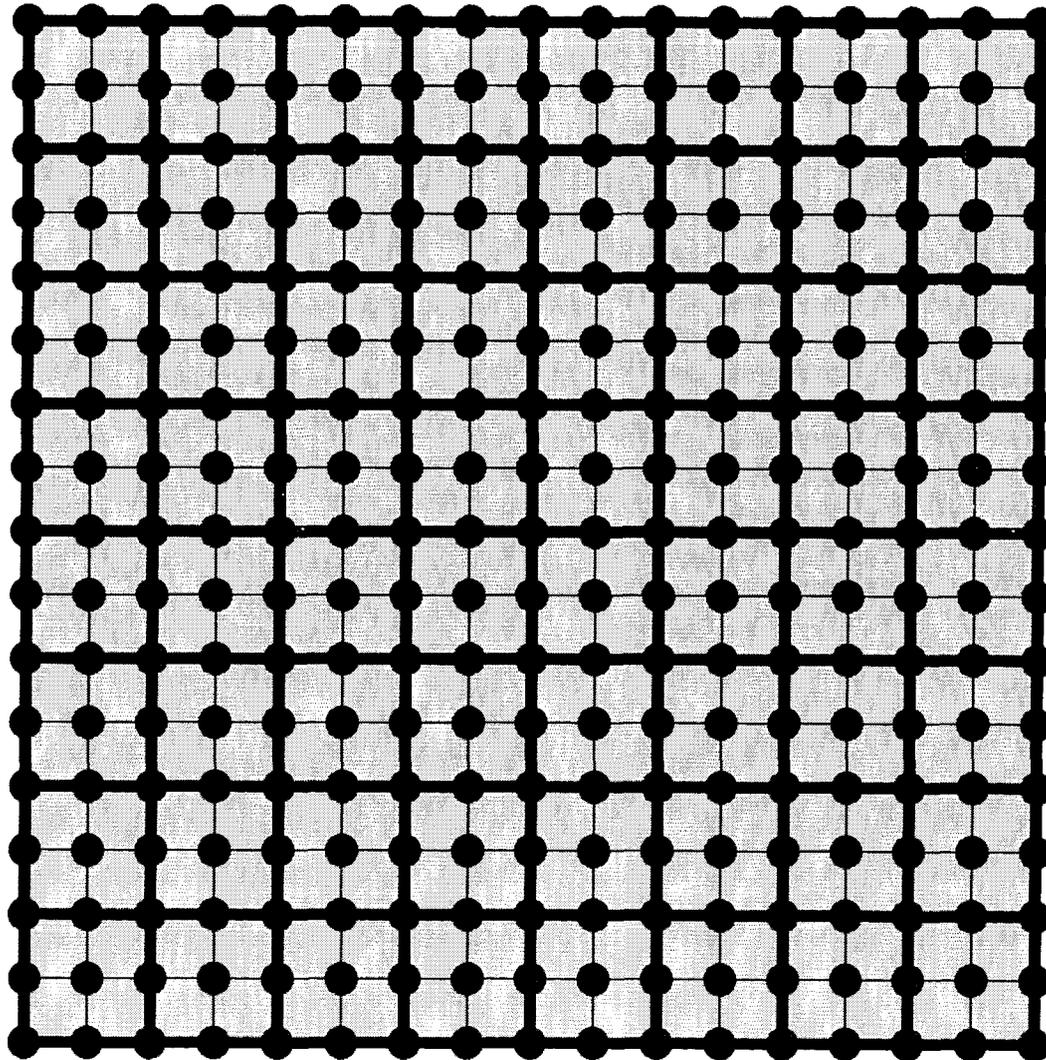
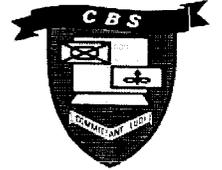
height of  
each quad  
=  
height of  
tallest post  
it contains



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# The Lowest Nodes in the Tree

## Combine quads of boxes



64 quads

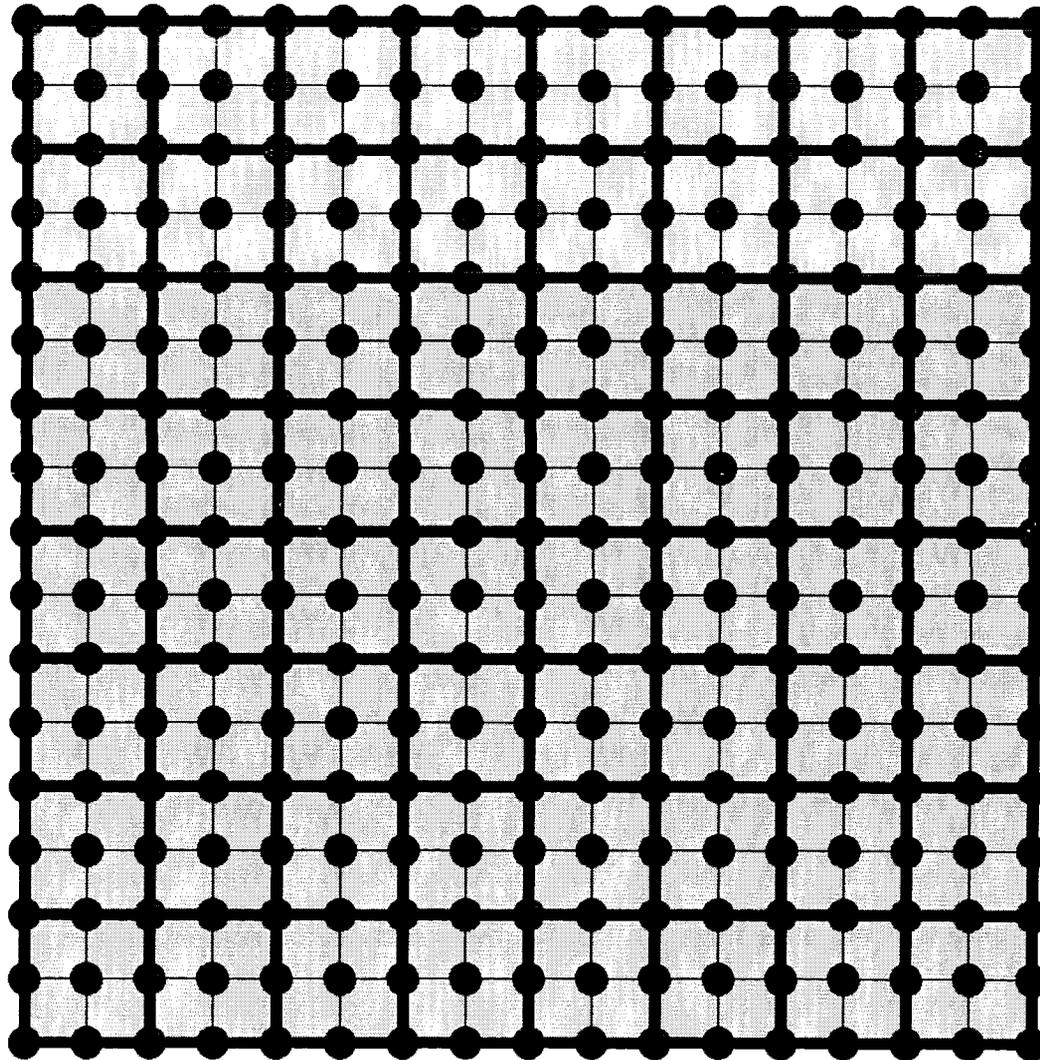
height of  
each quad  
=  
height of  
tallest post  
it contains



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# The Next Level of Nodes

## Combine quads of quads



4 quads  
of quads

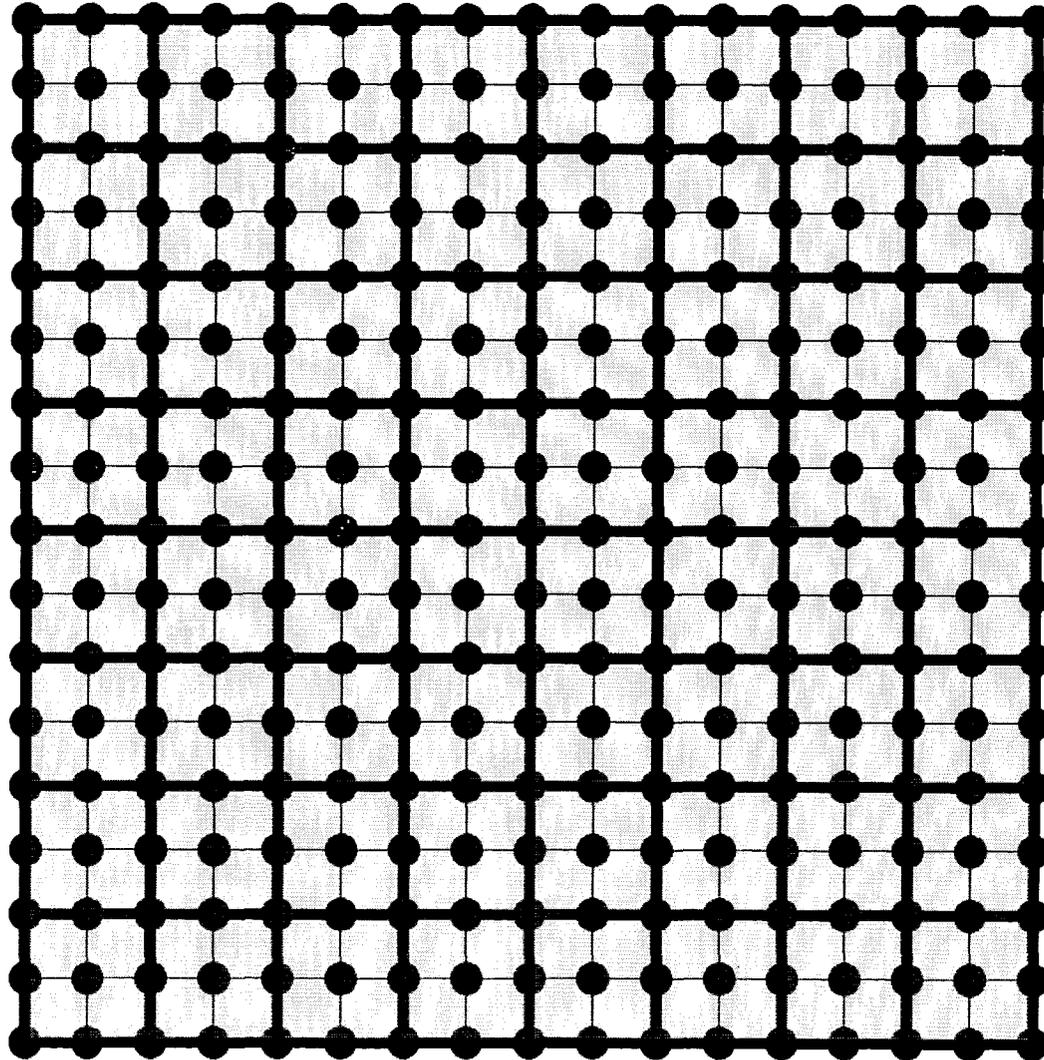
height of  
each quad  
=  
height of  
tallest post  
it contains



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# The Next Level of Nodes

## Combine quads of quads



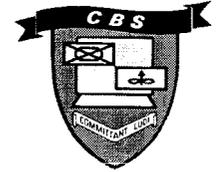
16 quads  
of quads

height of  
each quad  
=  
height of  
tallest post  
it contains



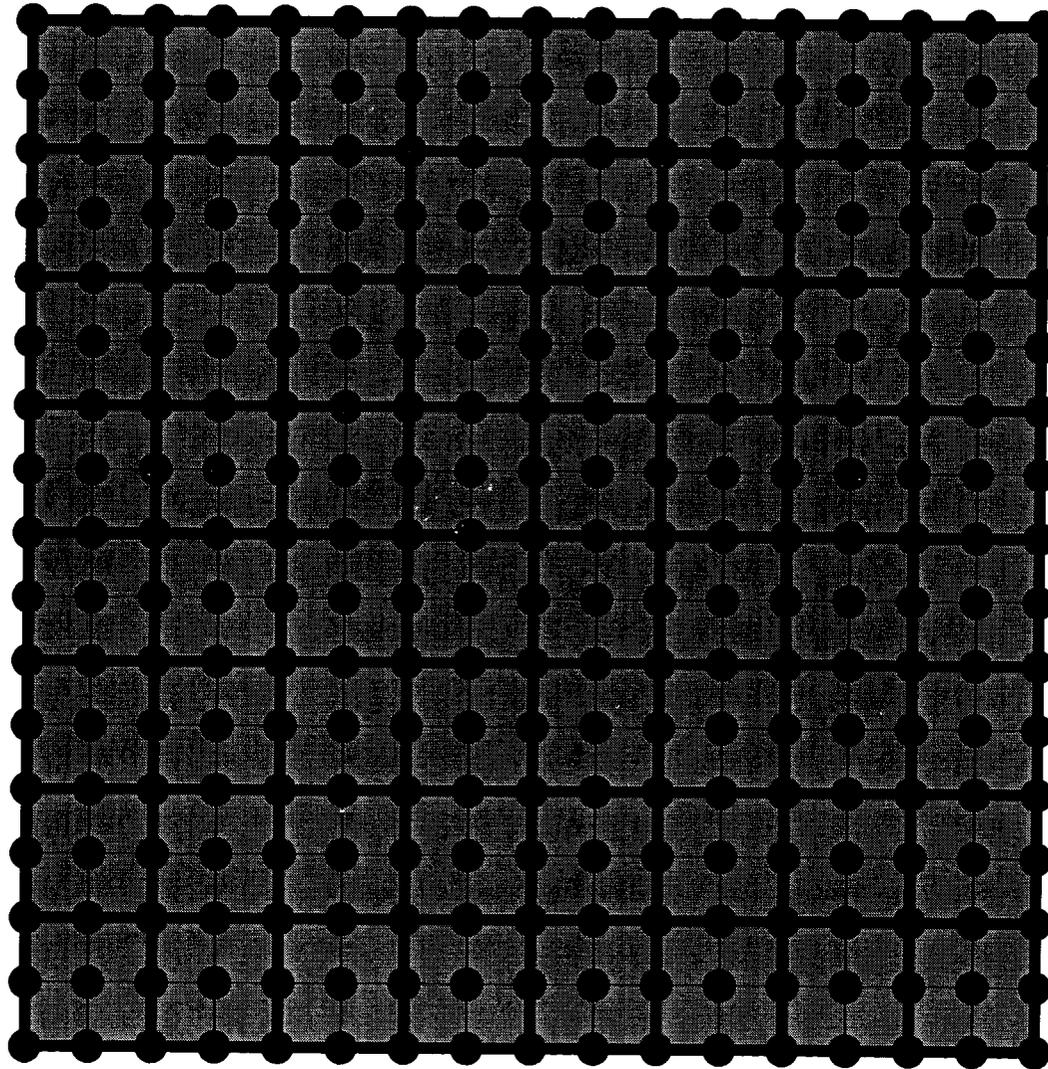
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And so on...  
quads of quads of quads



4 quads  
of quads  
of quads

height of  
each quad  
=  
height of  
tallest post  
it contains



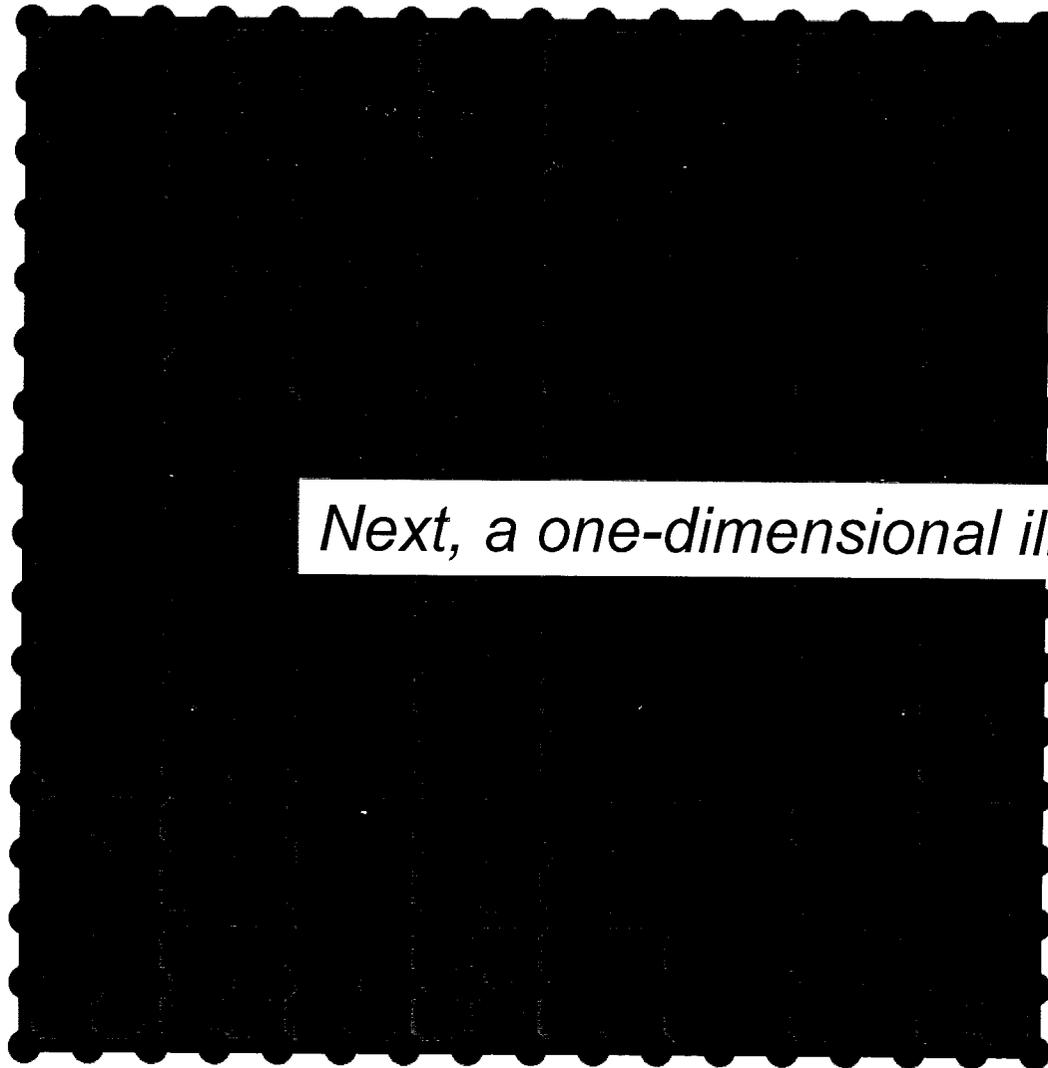


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# Finally (in this example), a quad of quads of quads of quads



height of the top of this quad = height of tallest elevation post anywhere in the playbox (plus an adjustment for the curvature of the Earth)



*Next, a one-dimensional illustration*

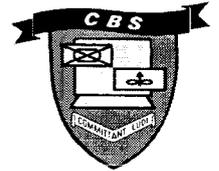
Finally, 1 quad of quads of quads of quads



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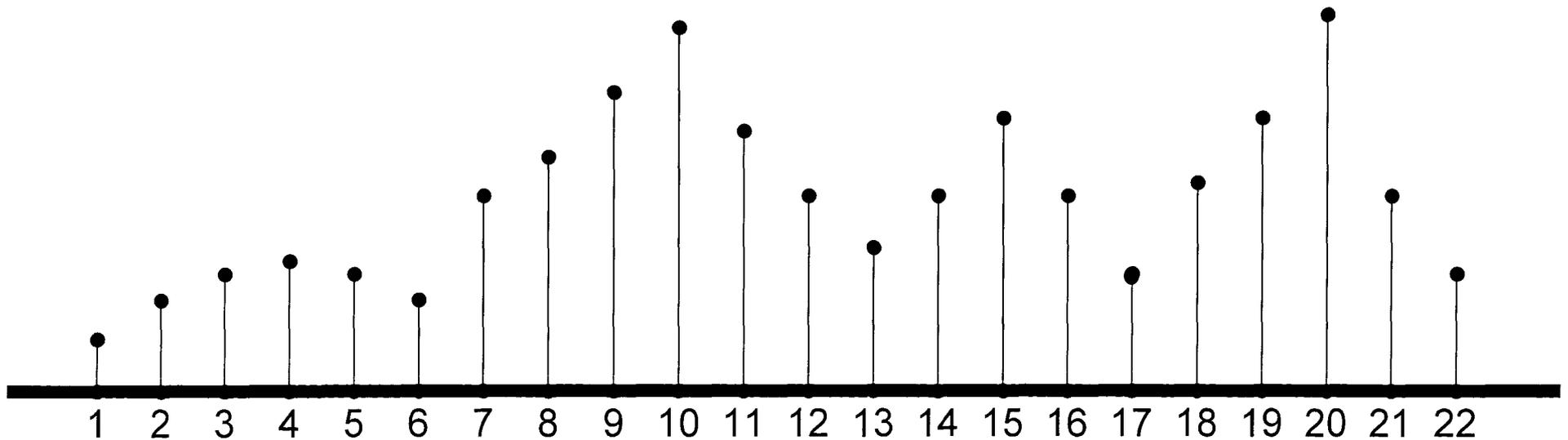
# A One-Dimensional Illustration

now looking from the side instead of downward



Make the tree

First, read the elevation data (the DEM)

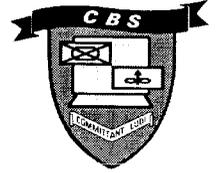




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# A One-Dimensional Illustration

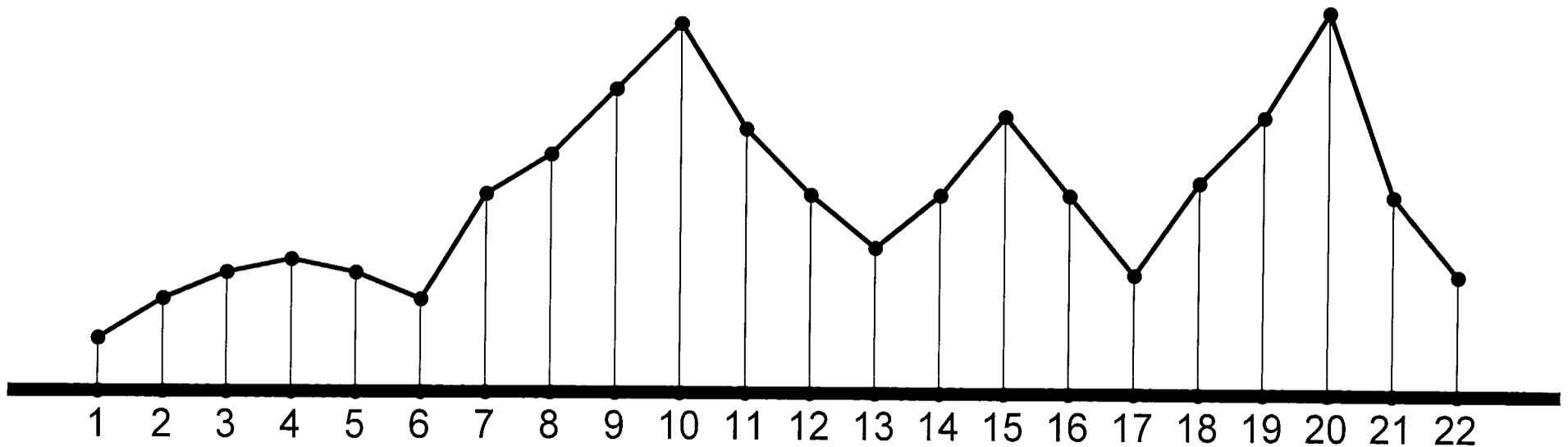
looking from the side



Make the tree

First, read the elevation data (the DEM)

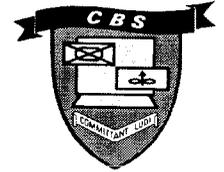
Drape a skin over the DEM posts





# A One-Dimensional Illustration

looking from the side



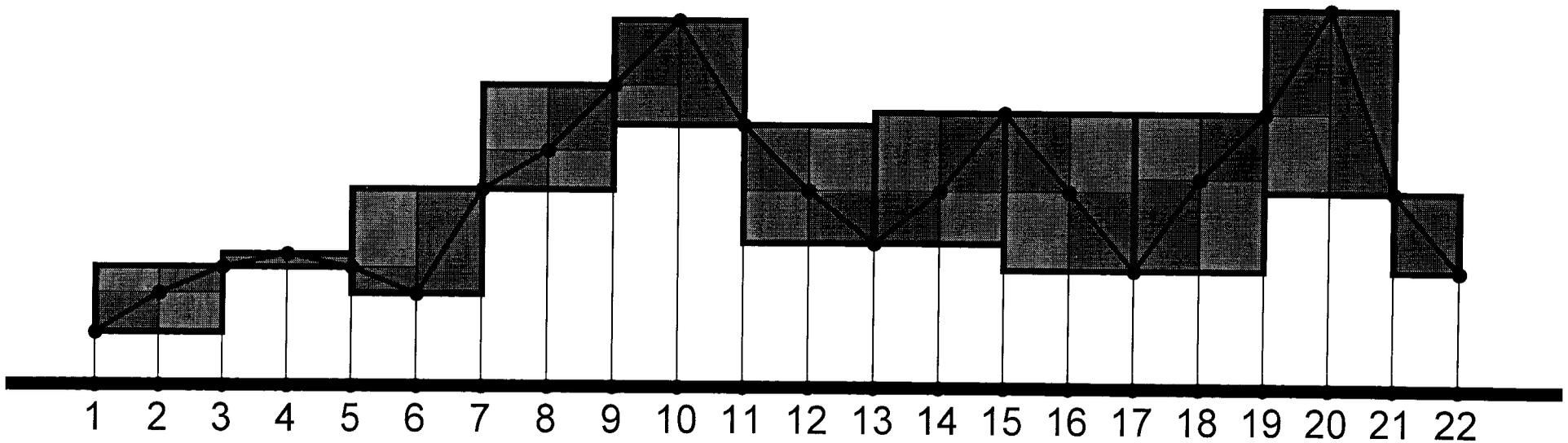
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Make the tree

First, read the elevation data (the DEM)

Drape a skin over the DEM posts

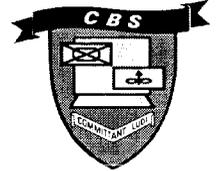
Collect the posts in pairs (instead of quads)





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# A One-Dimensional Illustration looking from the side



## Make the tree

First, read the elevation data (the DEM)

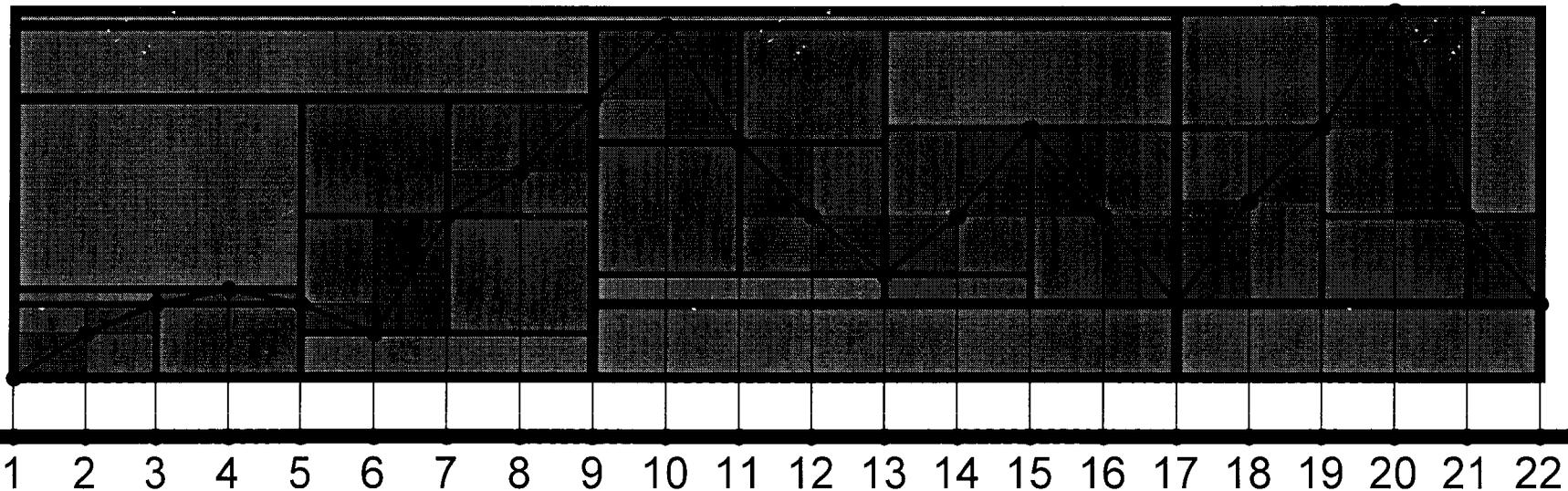
Drape a skin over the DEM posts

Collect the posts in pairs (instead of quads)

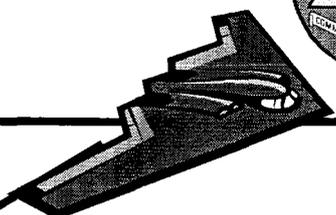
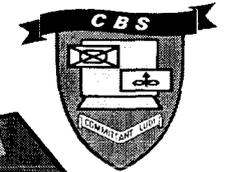
Make pairs of pairs . . . and so on

. . . until done

*Next, an illustration of an LOS assessment*

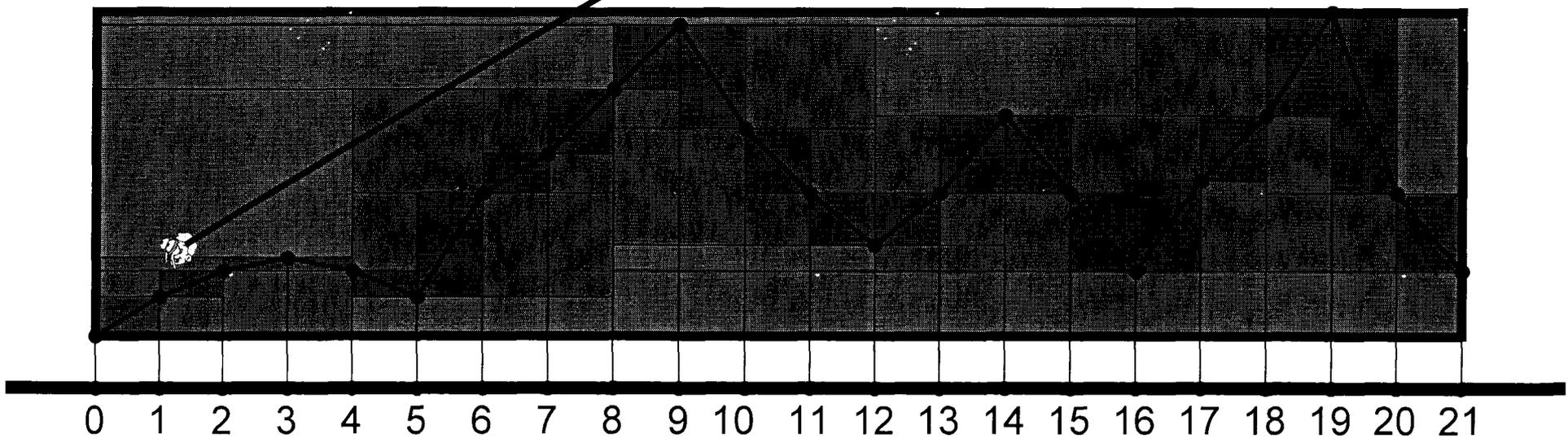


# Now, apply the algorithm



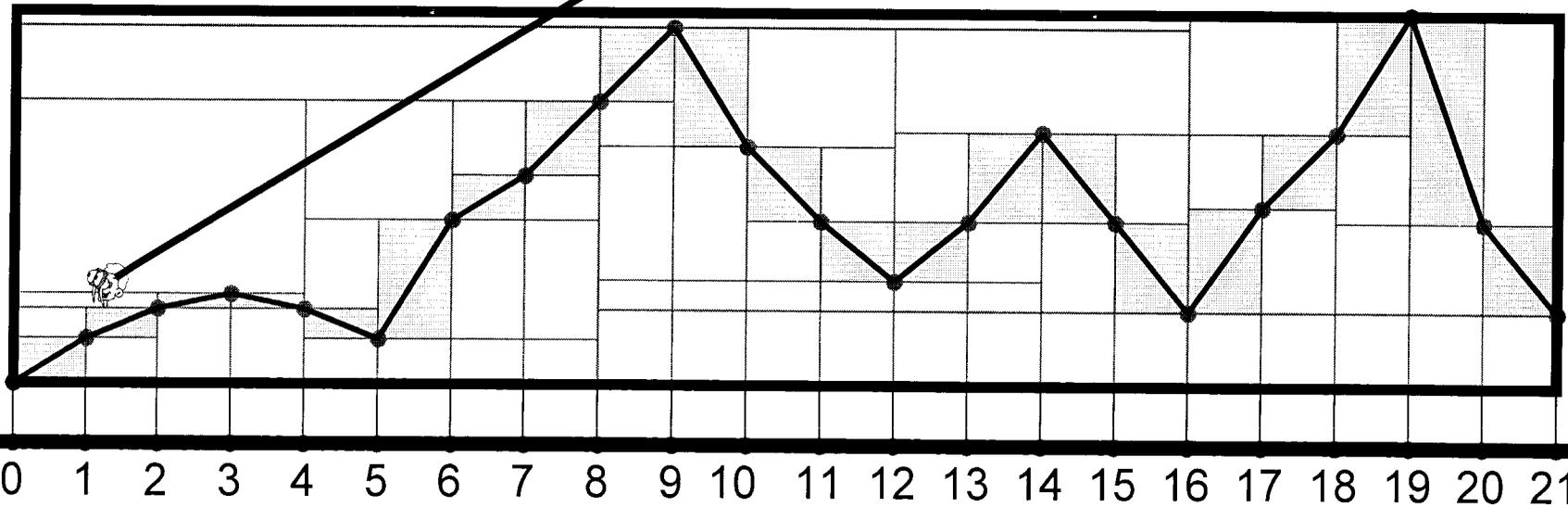
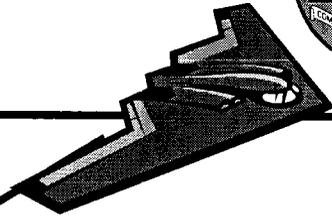
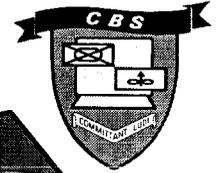
LOS is not obstructed

- This is a relatively difficult case: LOS grazes the ground surface
- 9 box queries at a distance of 20 posts (about 40 edge crossings in 3-D)



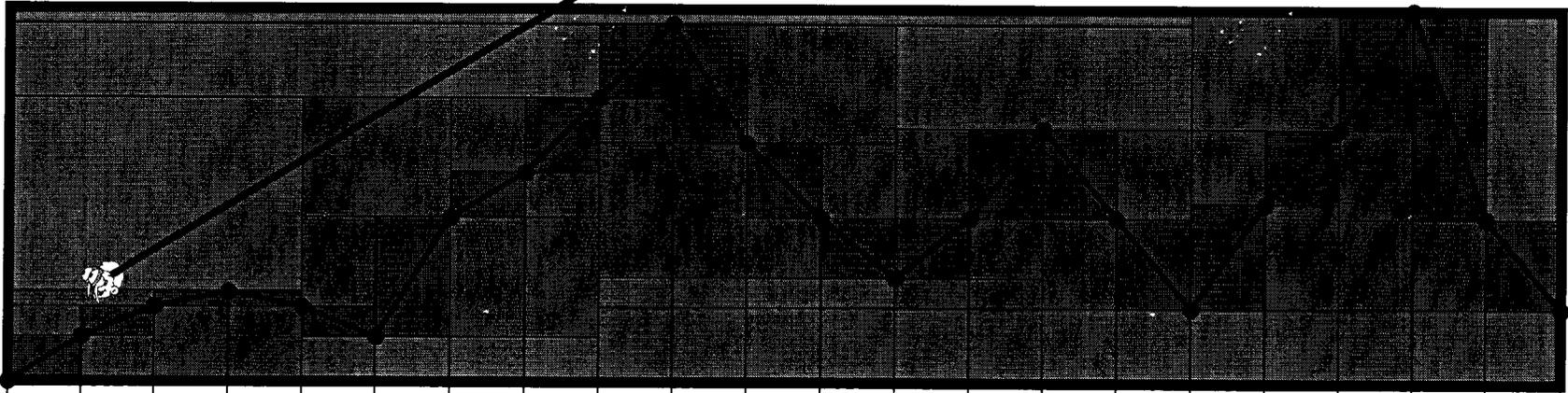
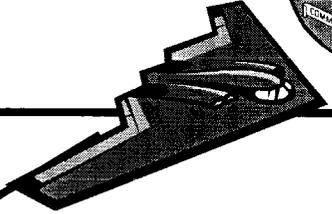
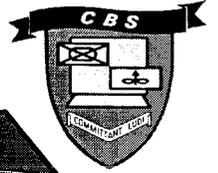


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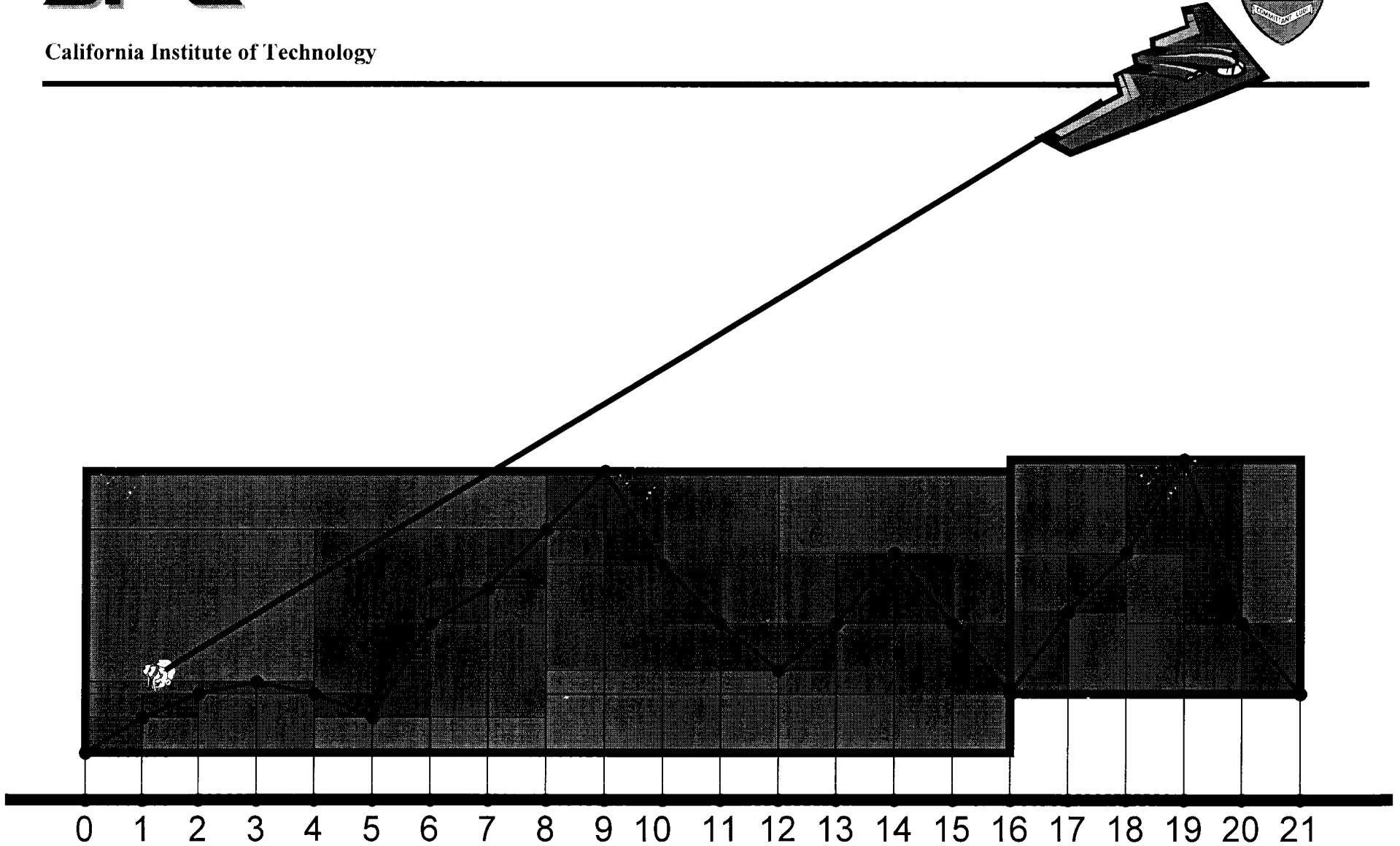
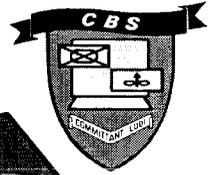
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0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21

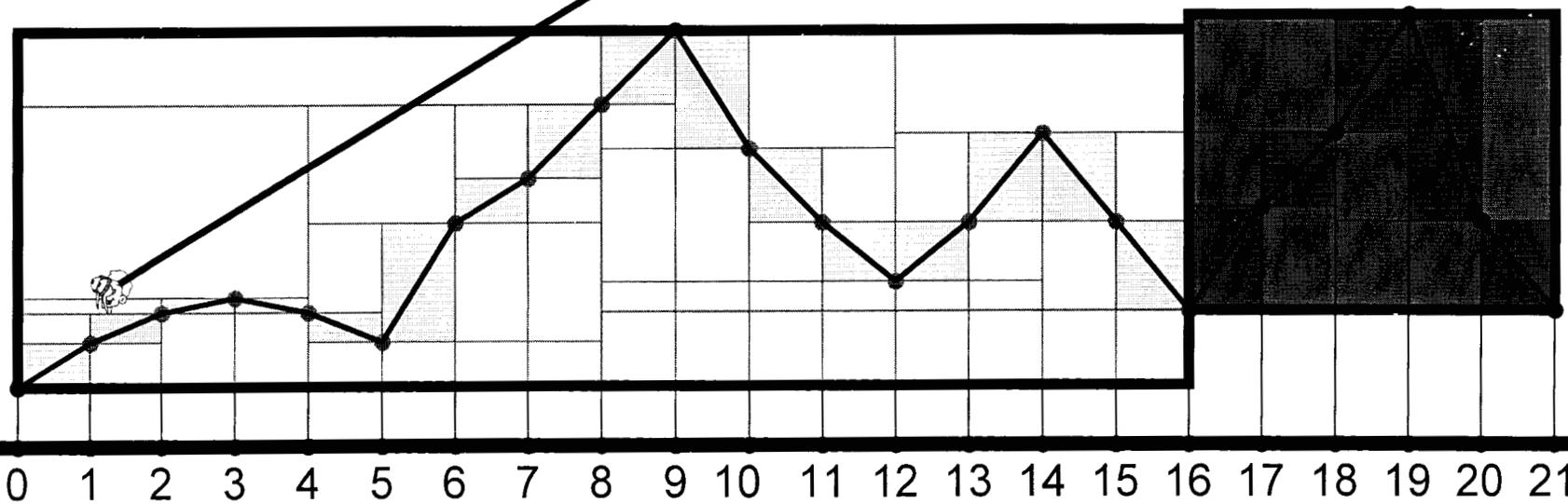
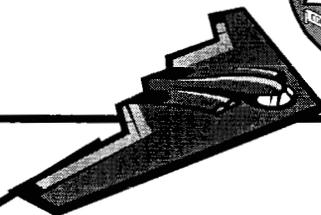
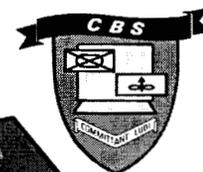


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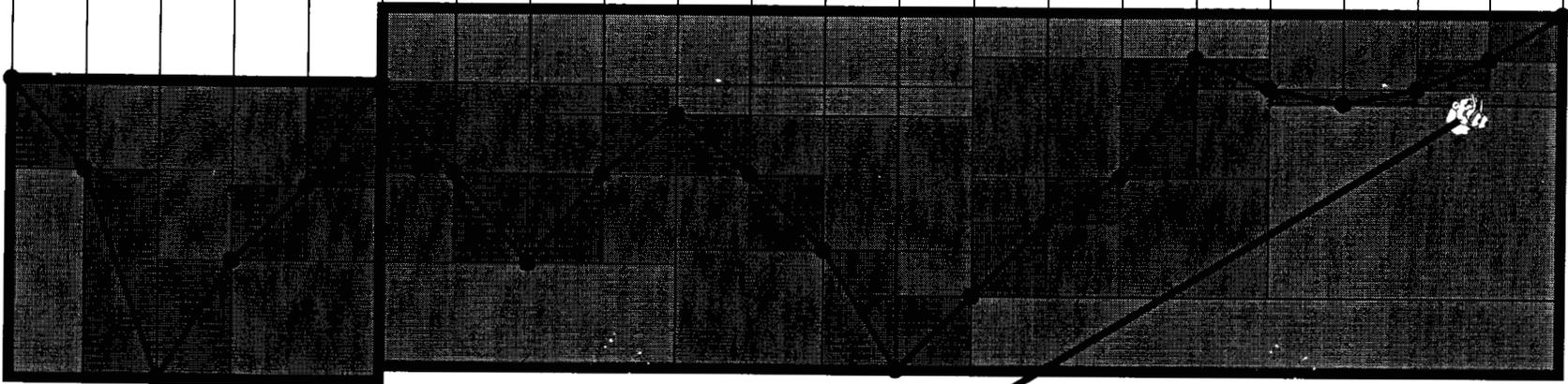




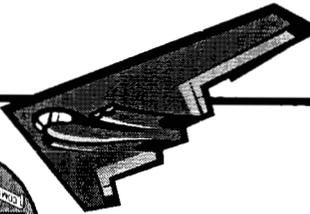
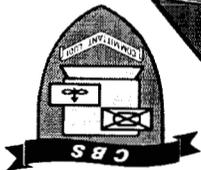
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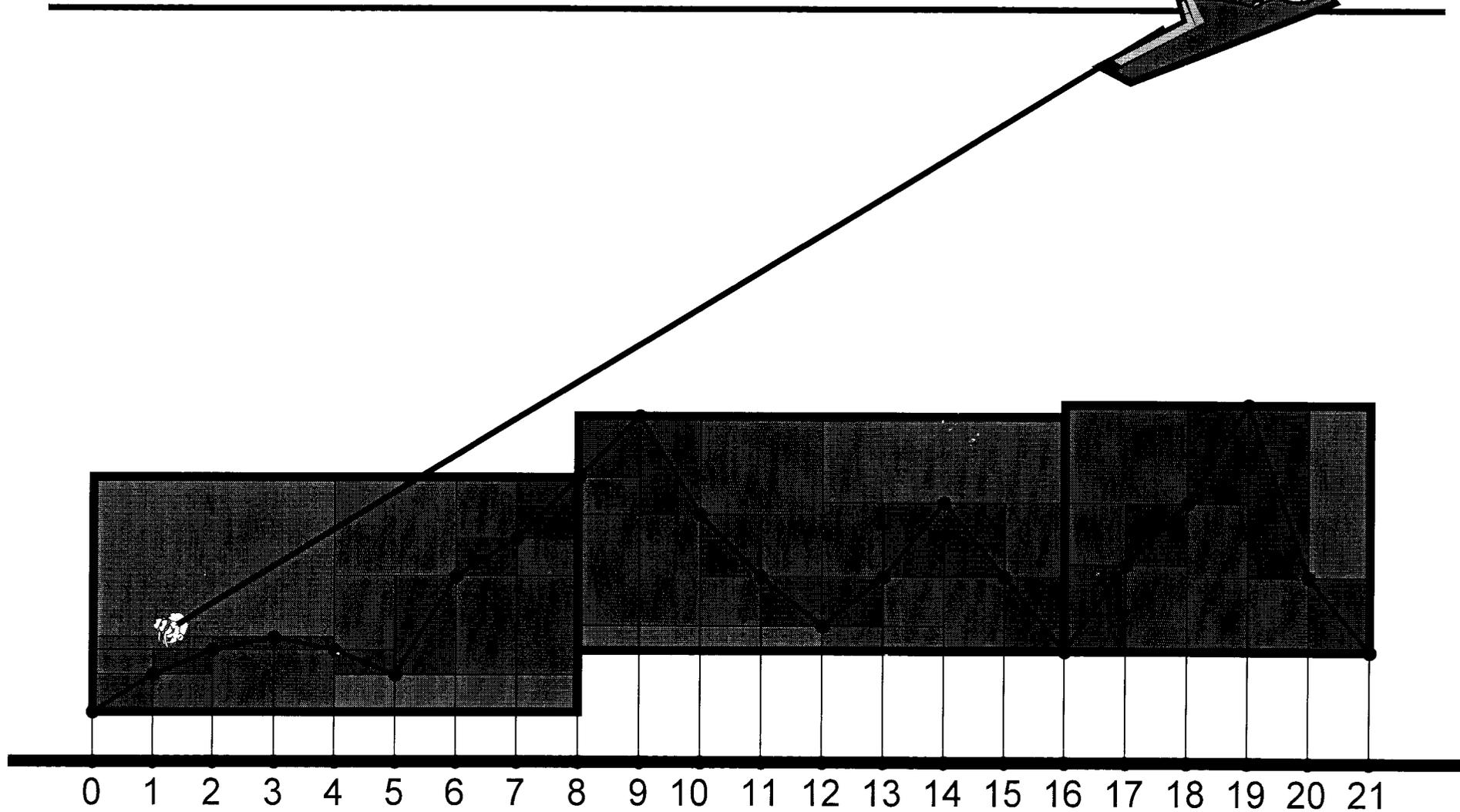


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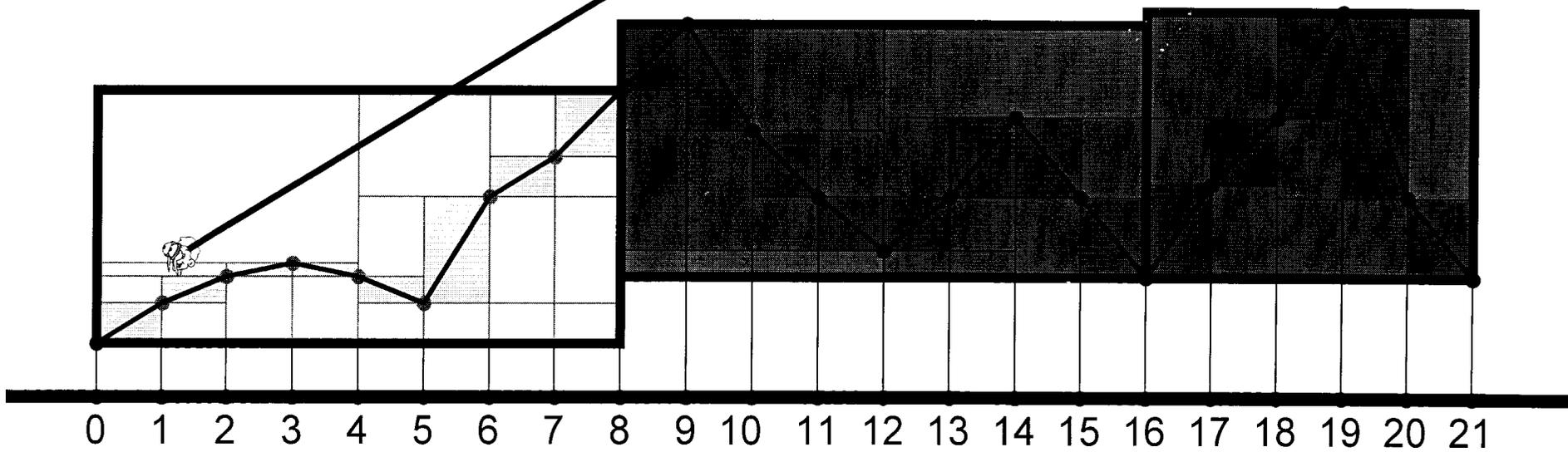
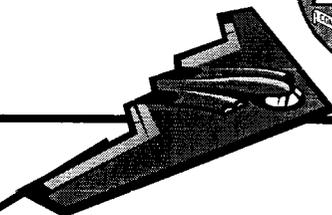
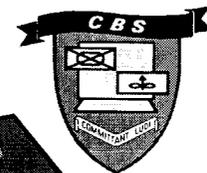
# JPL

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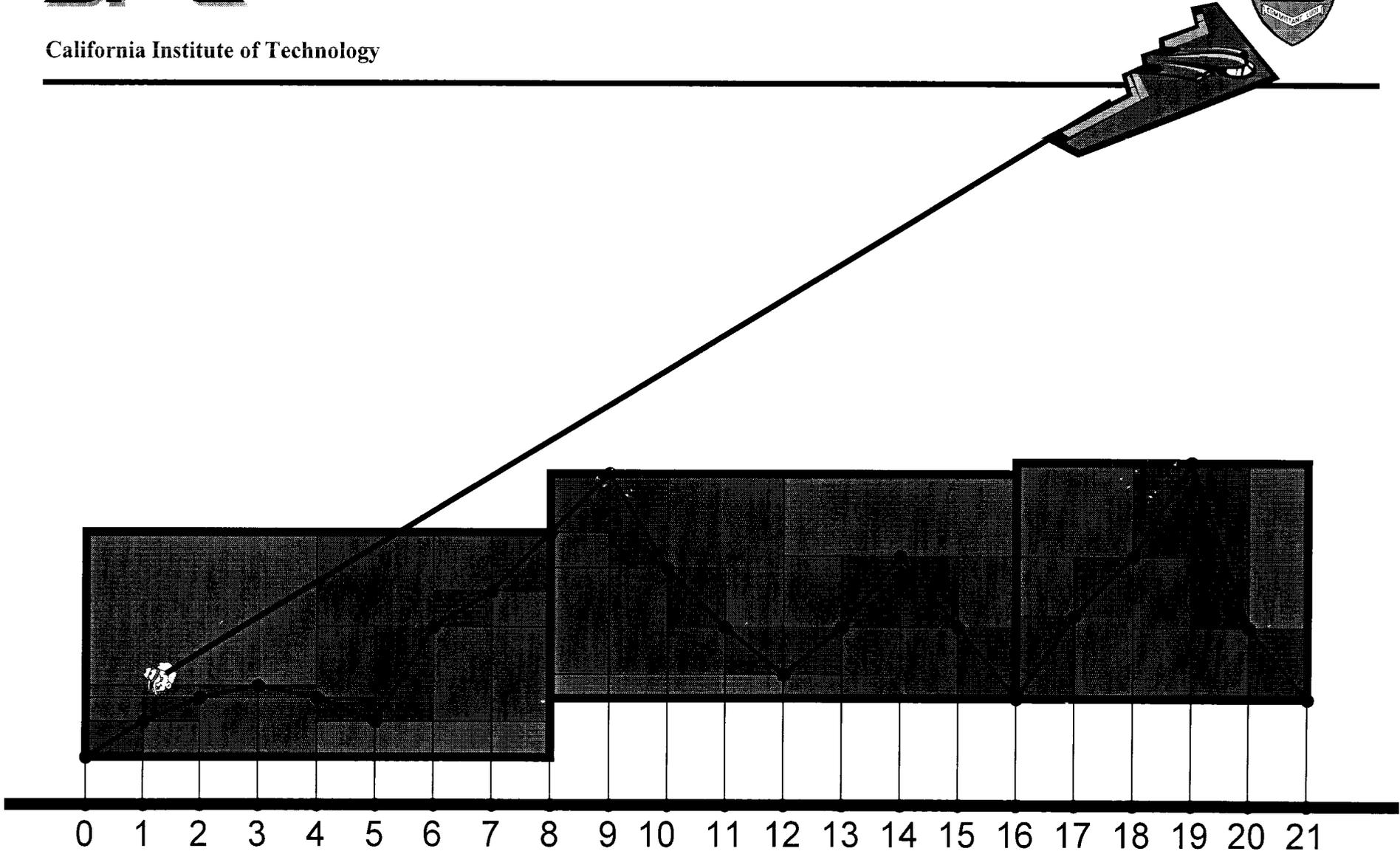
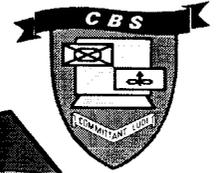


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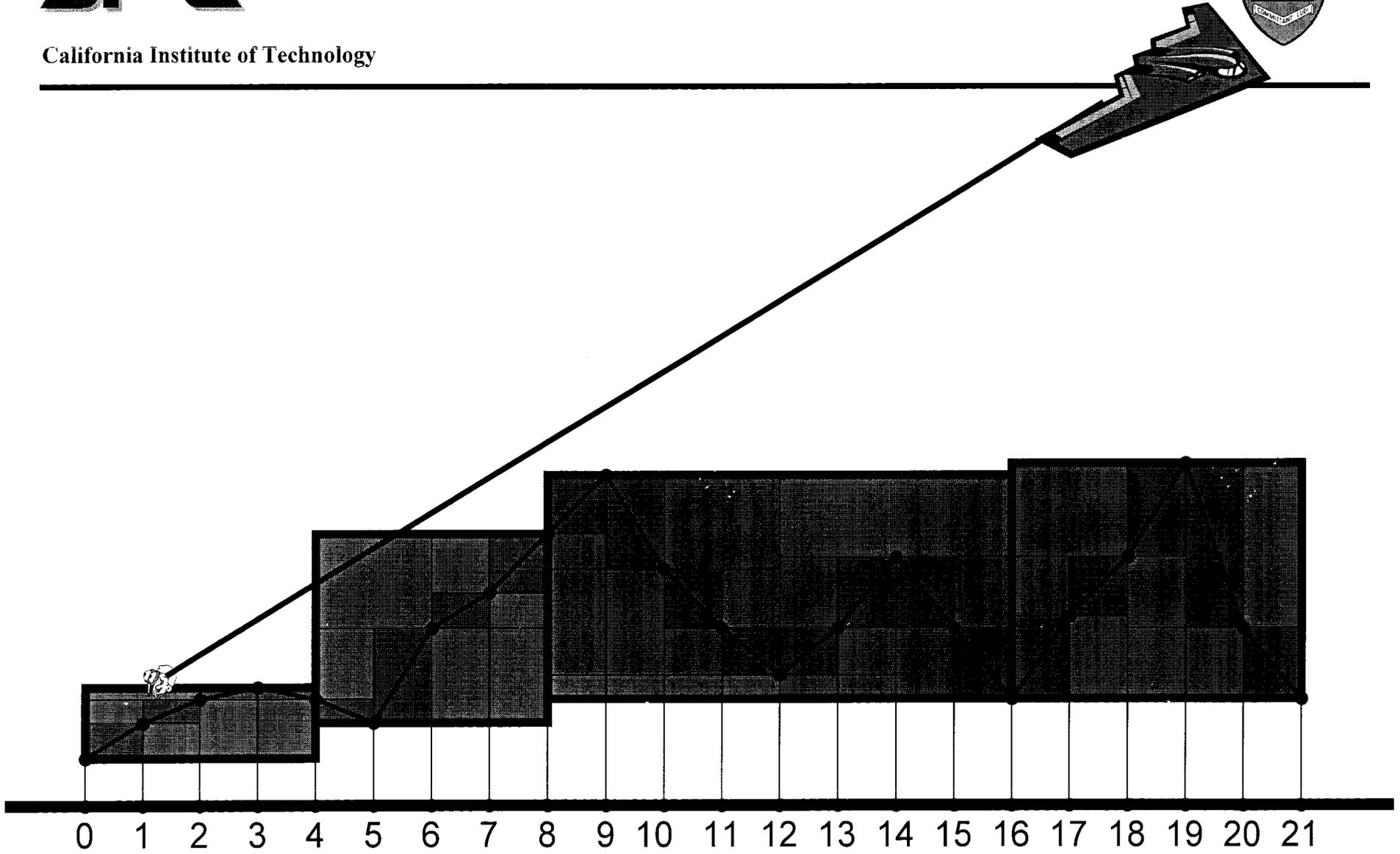
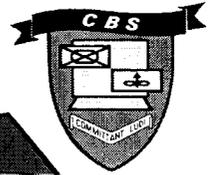
# JPL

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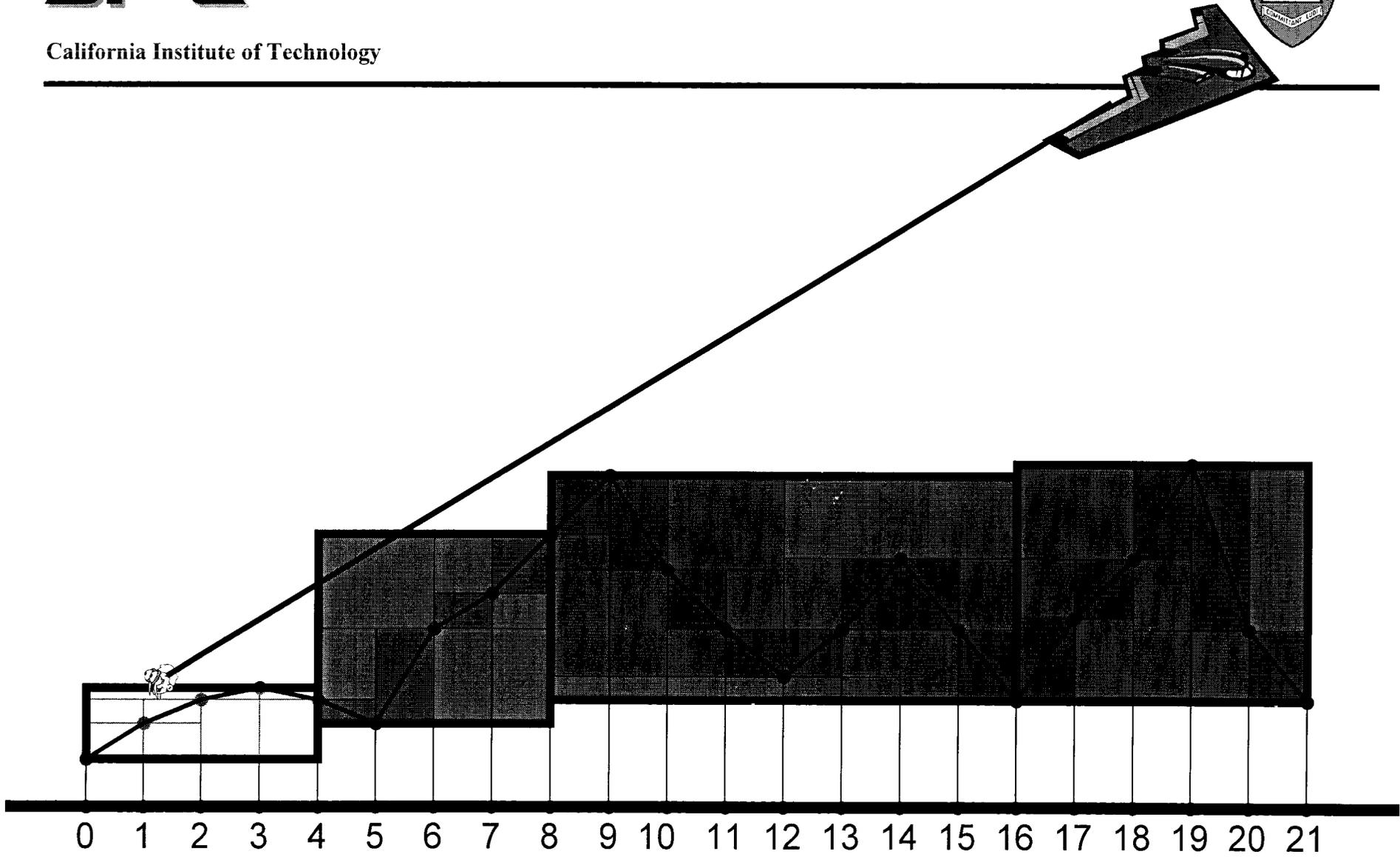
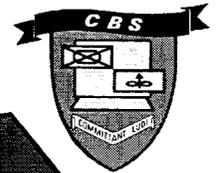


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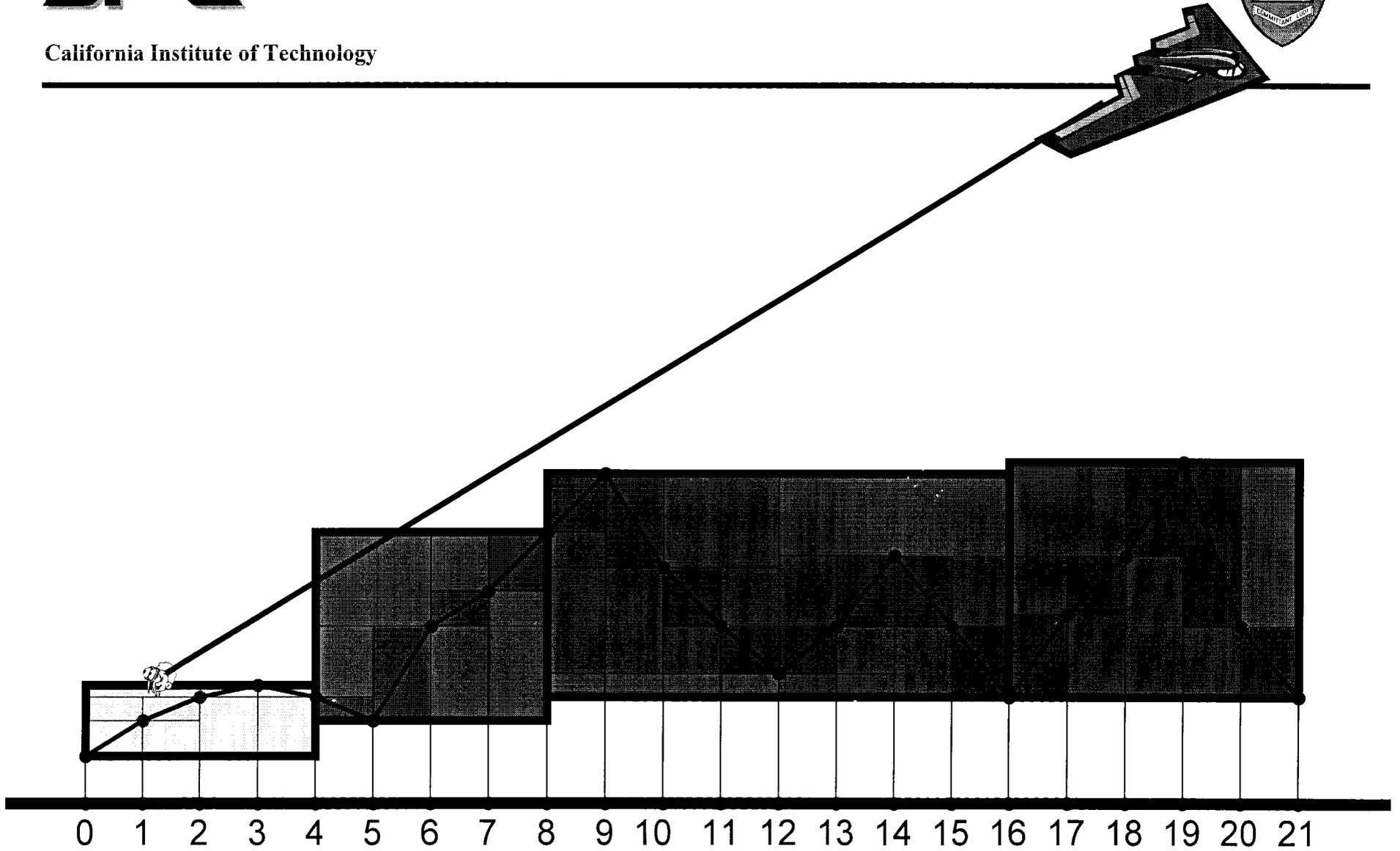


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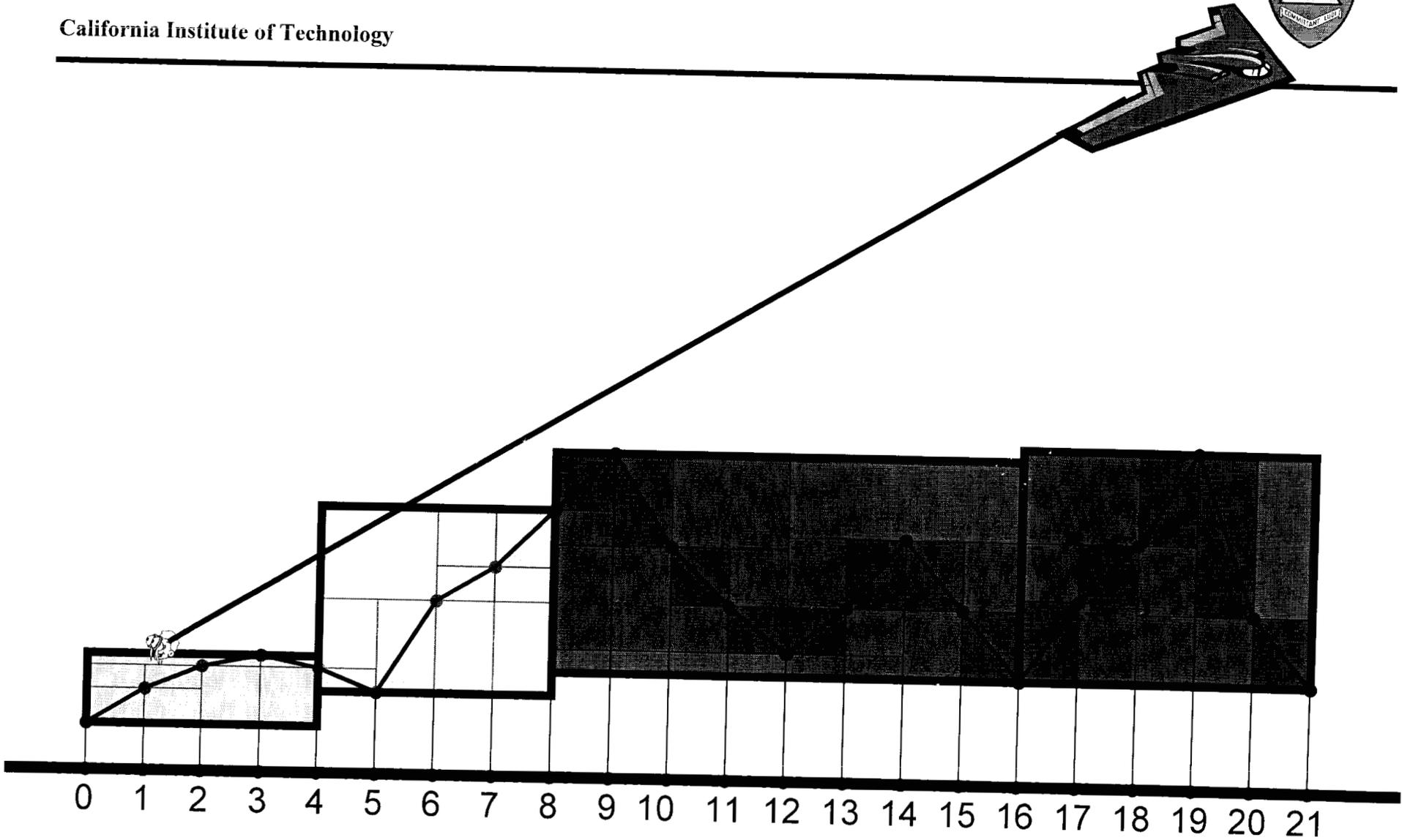
# JPL

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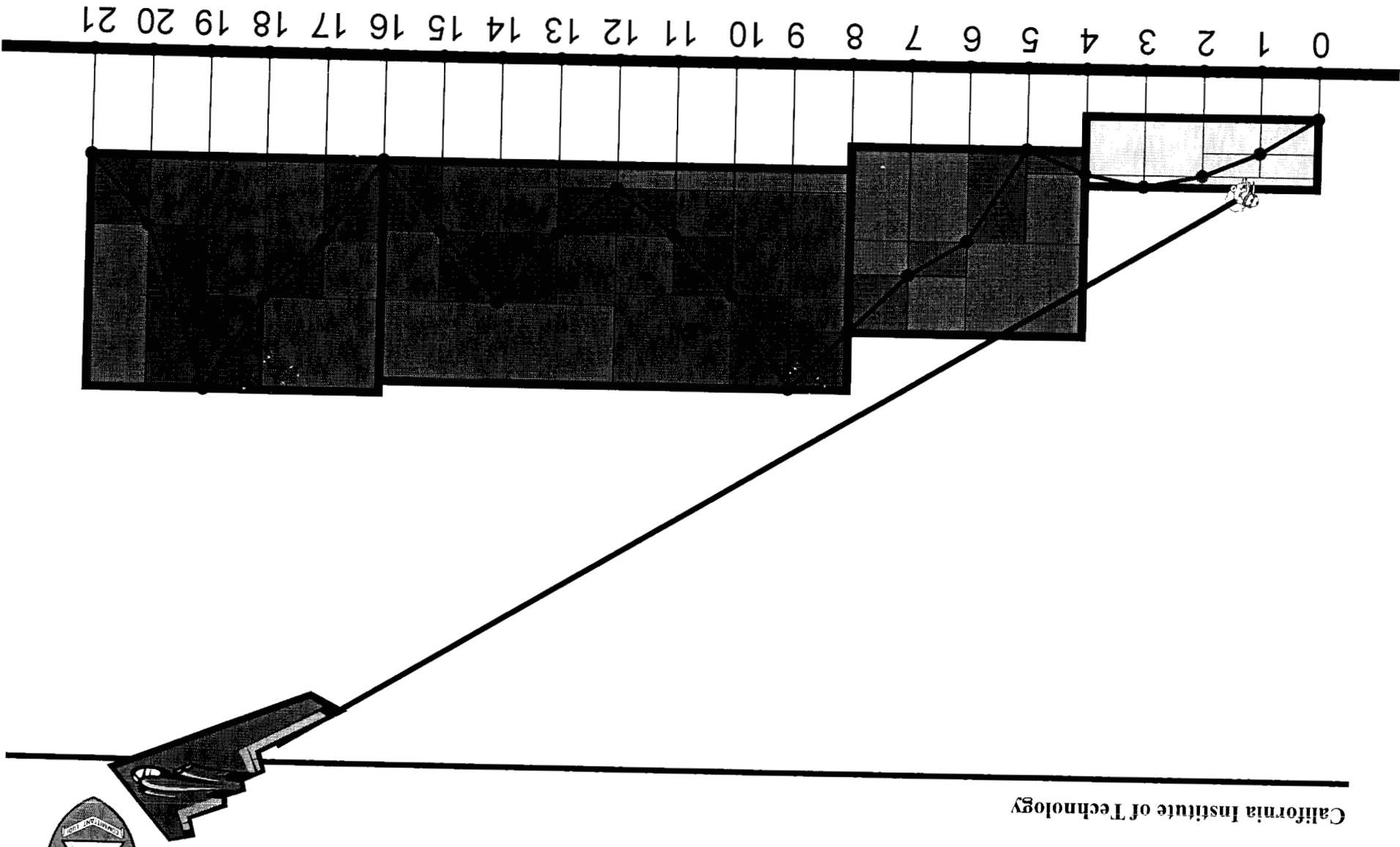
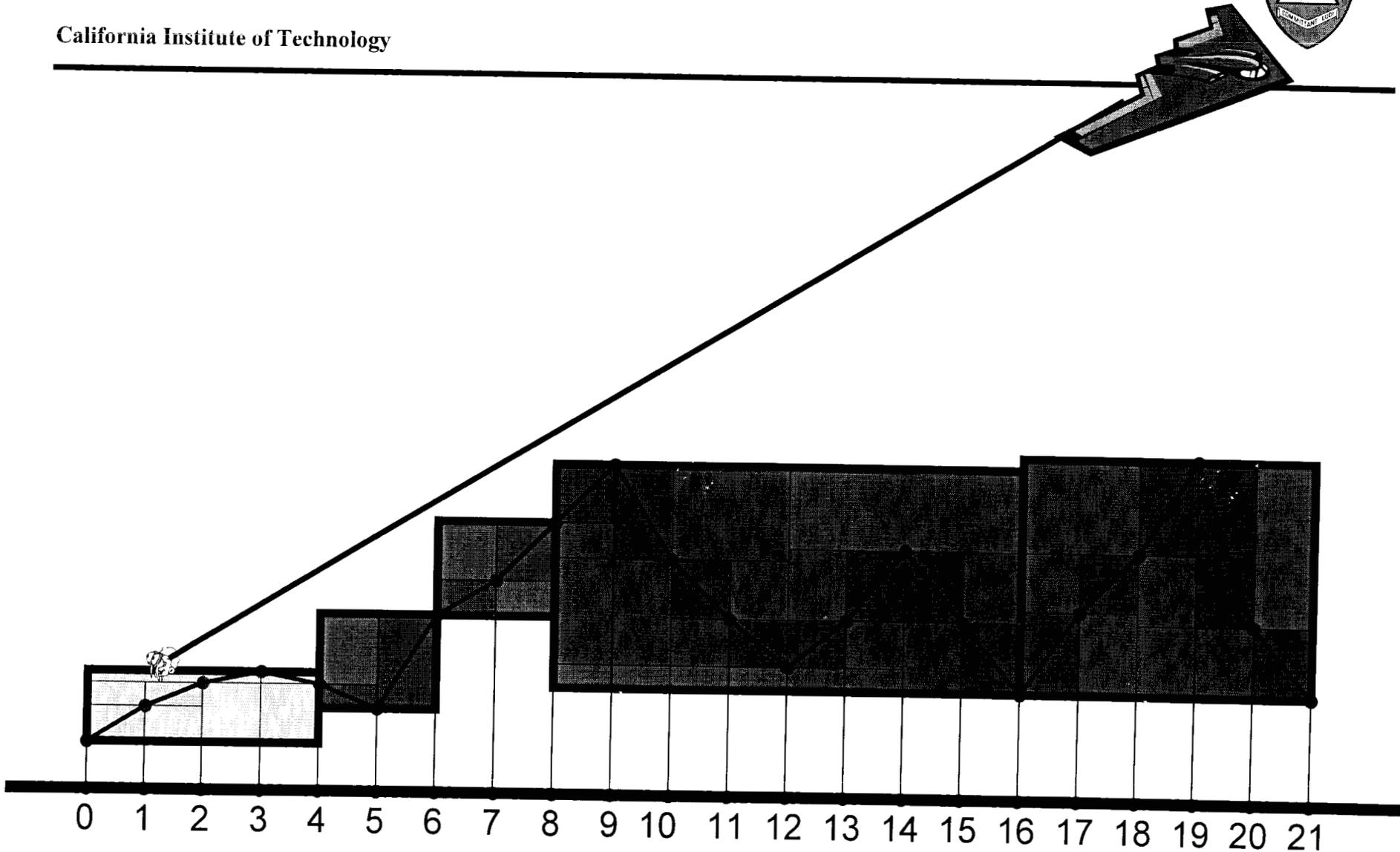


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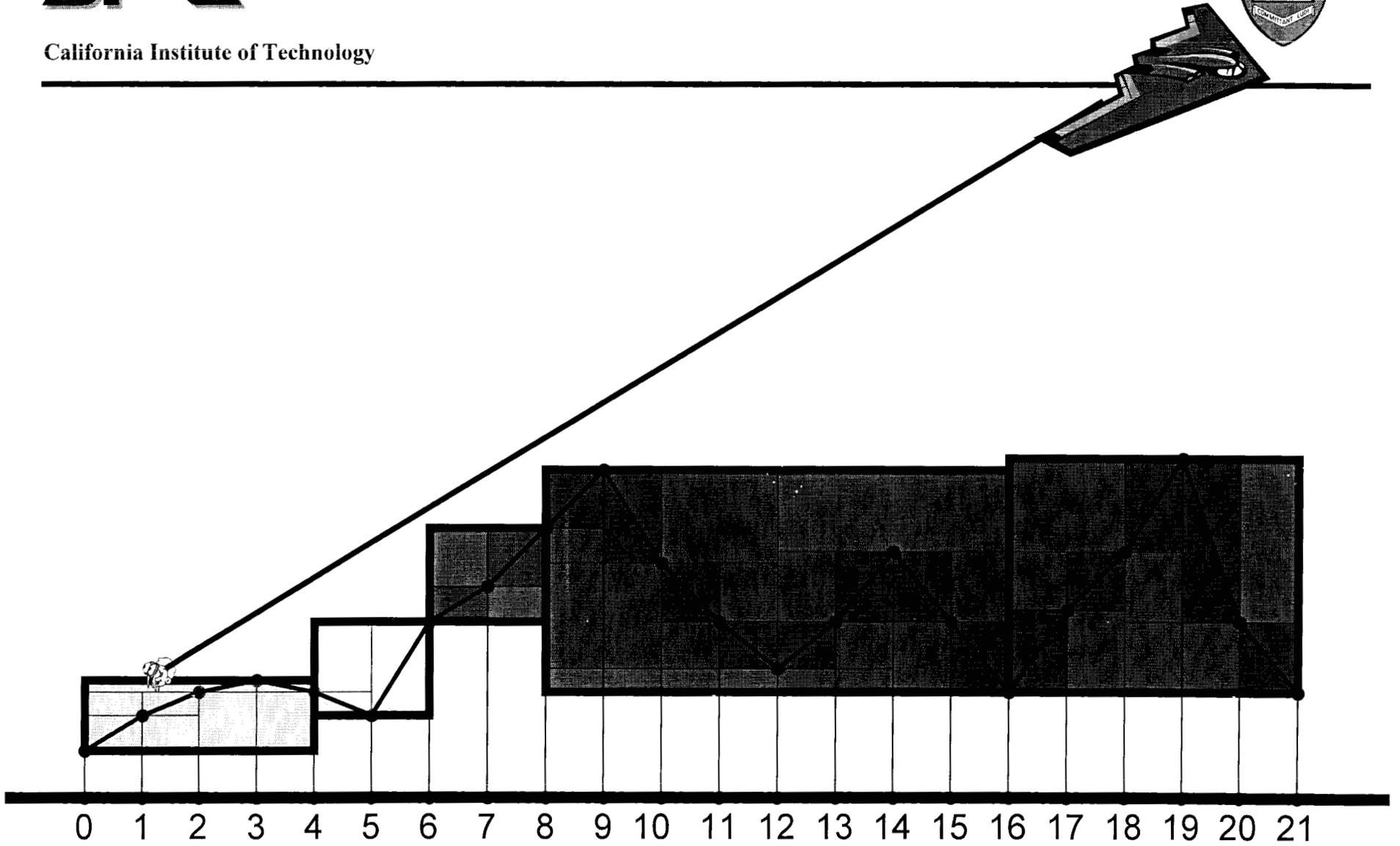


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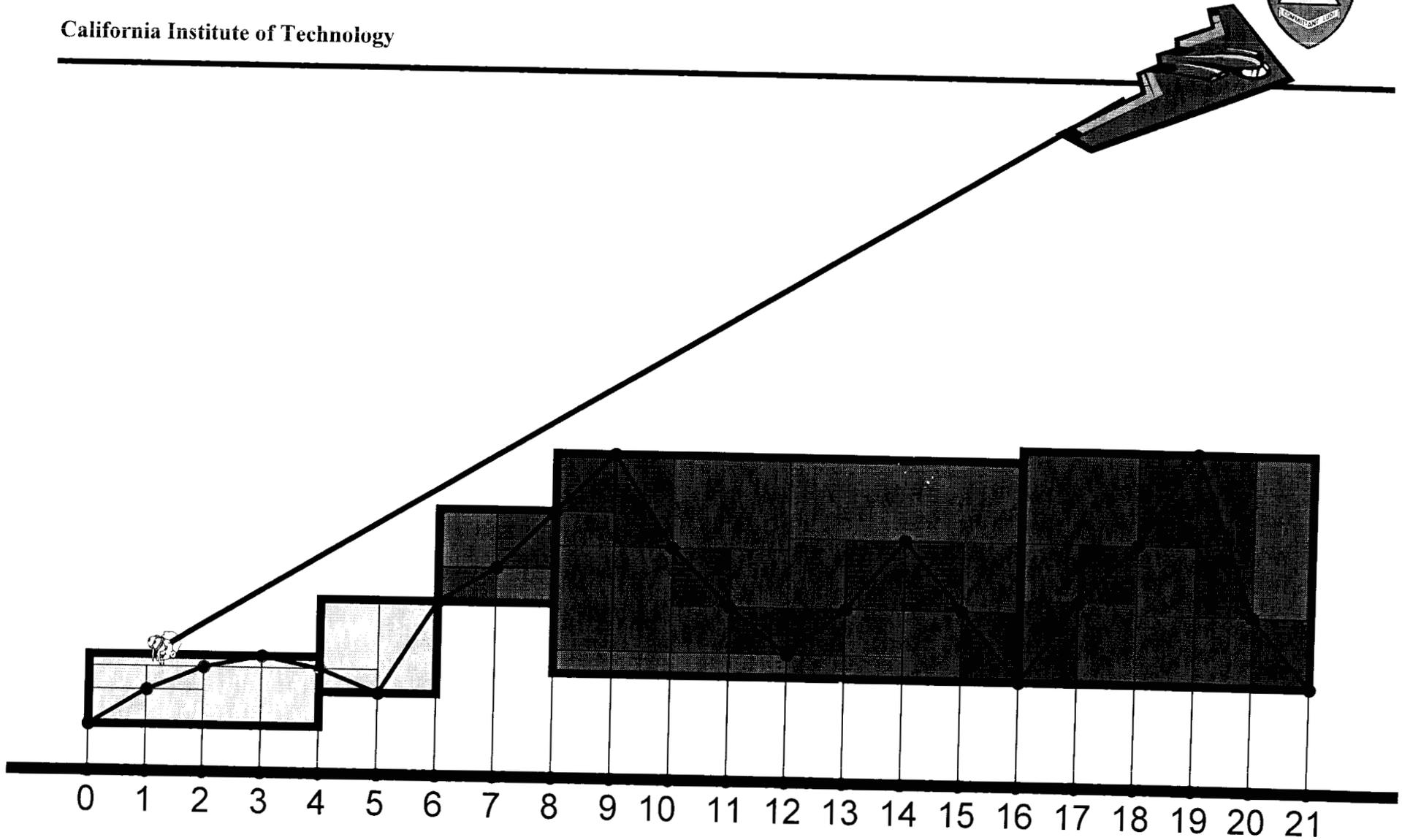


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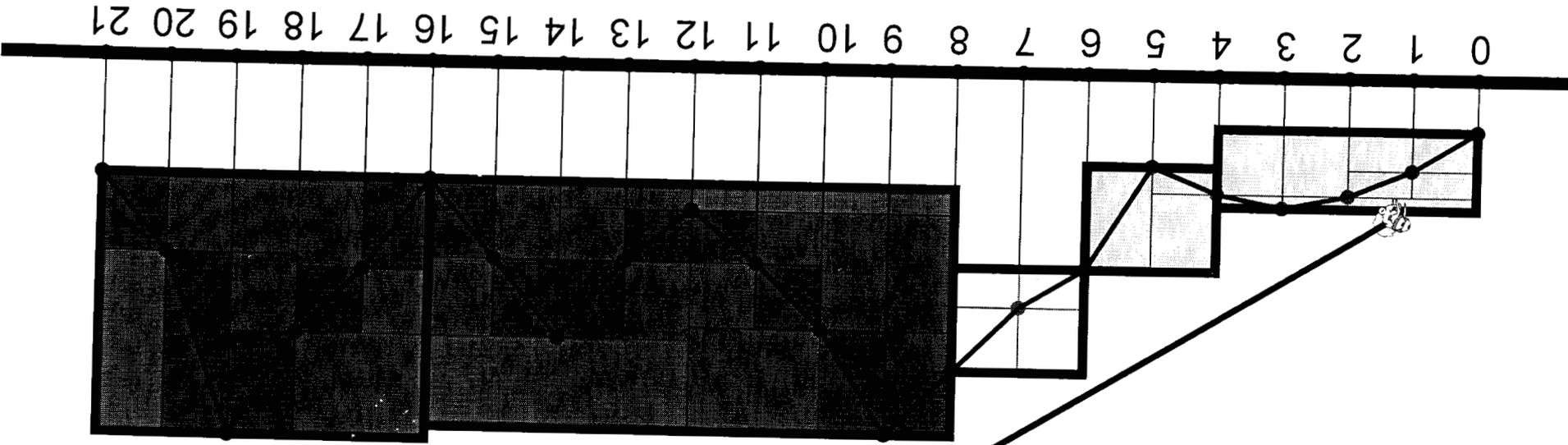


California Institute of Technology



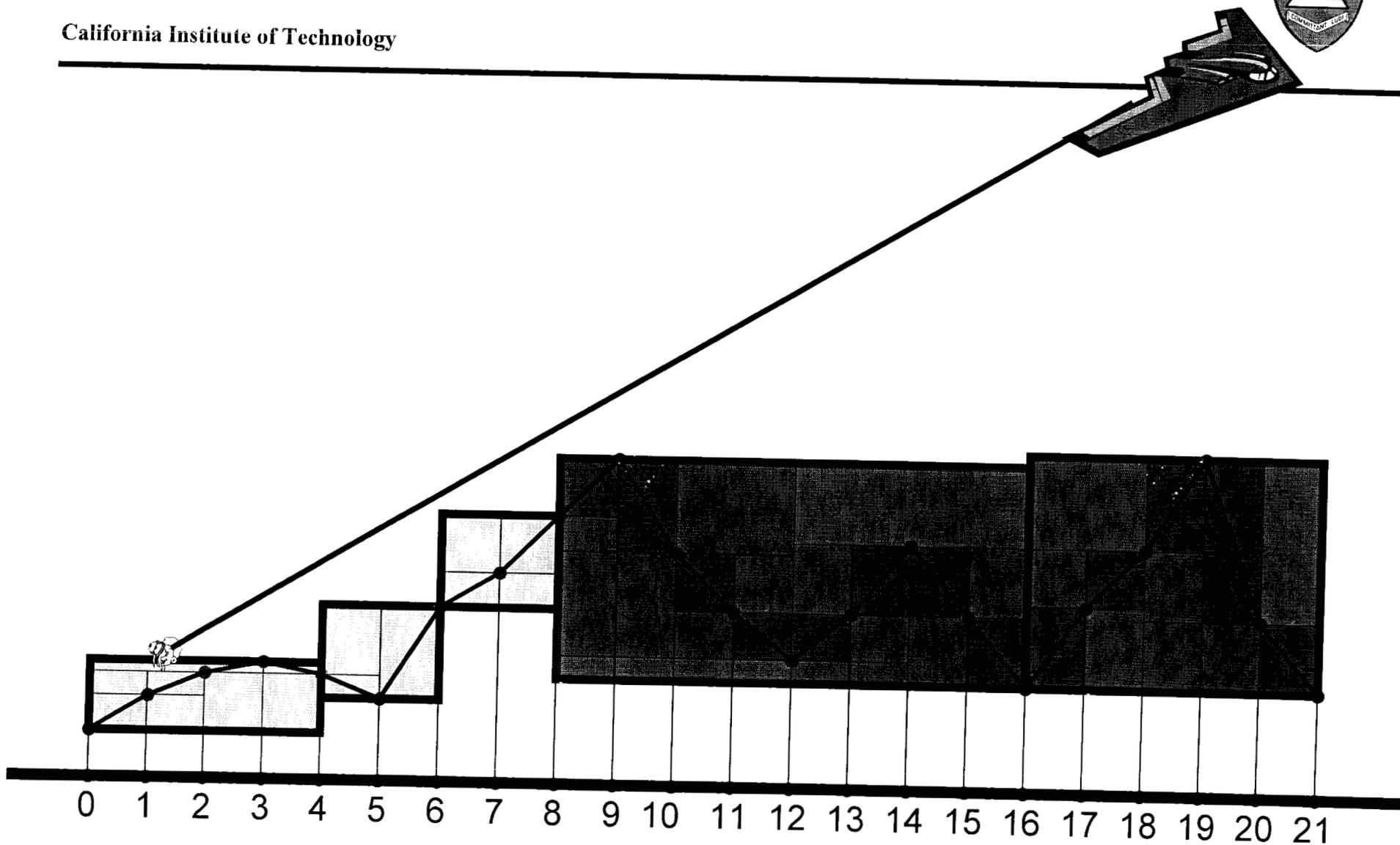
JPL

California Institute of Technology



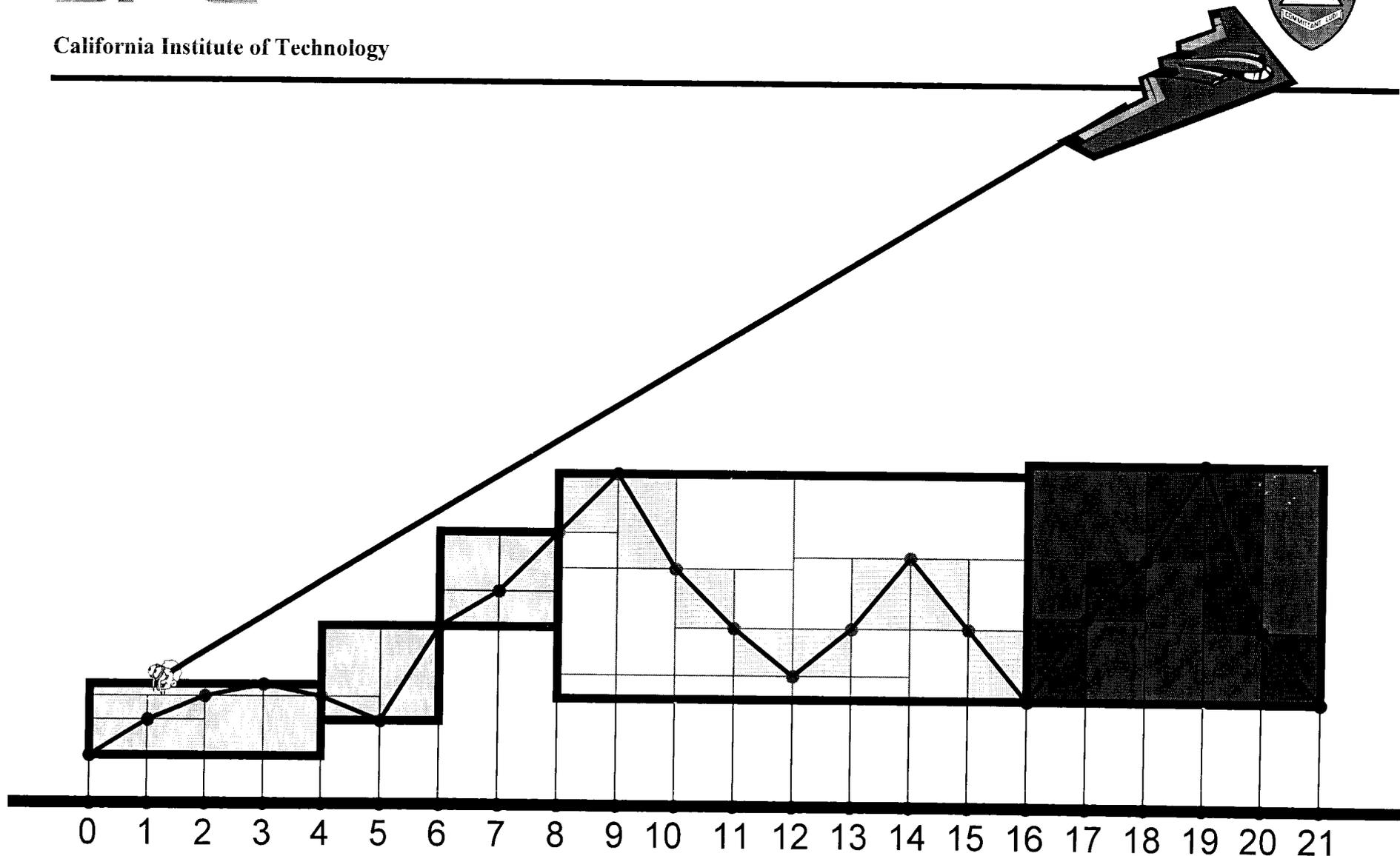
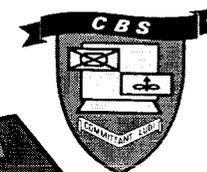
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California Institute of Technology



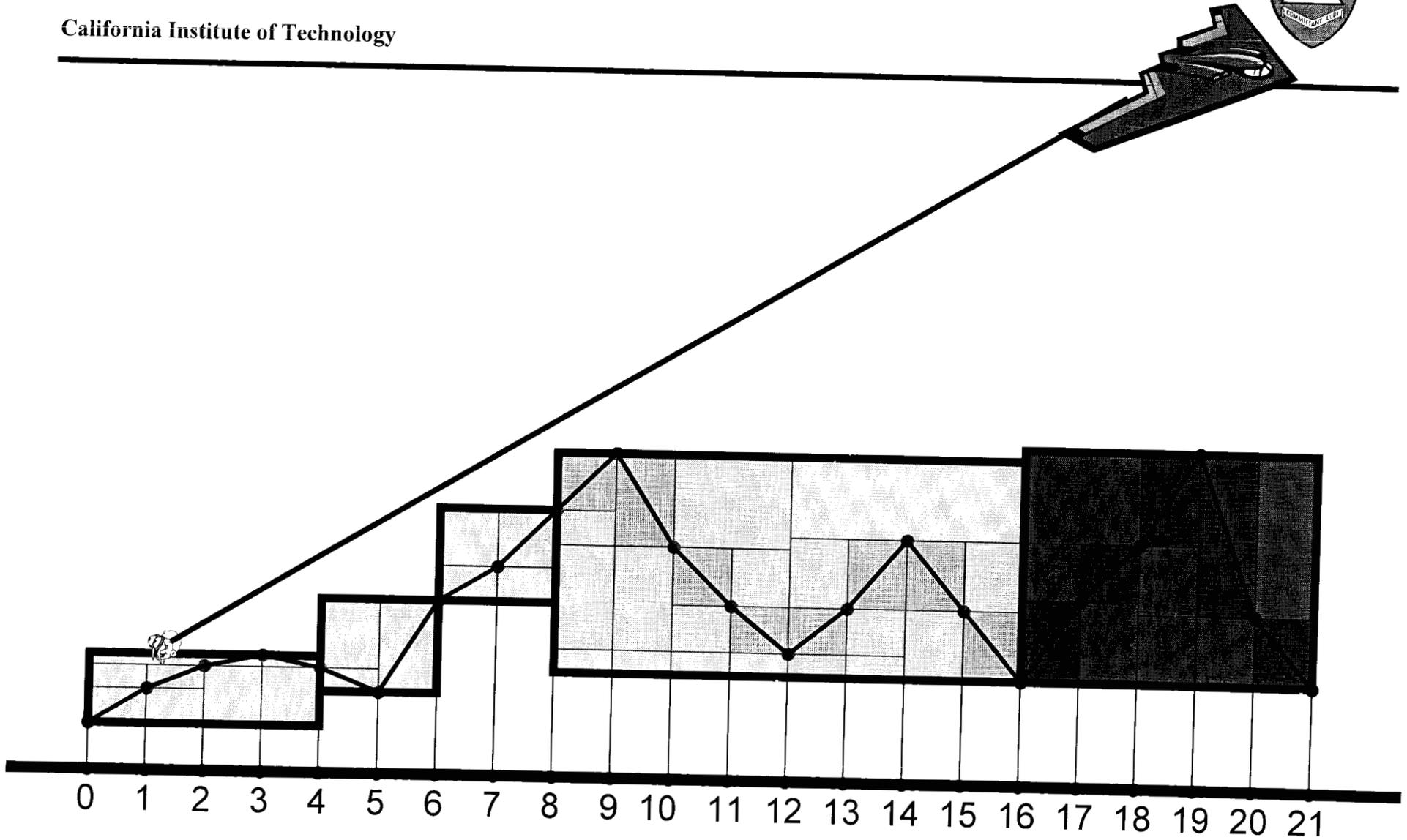
# JPL

California Institute of Technology



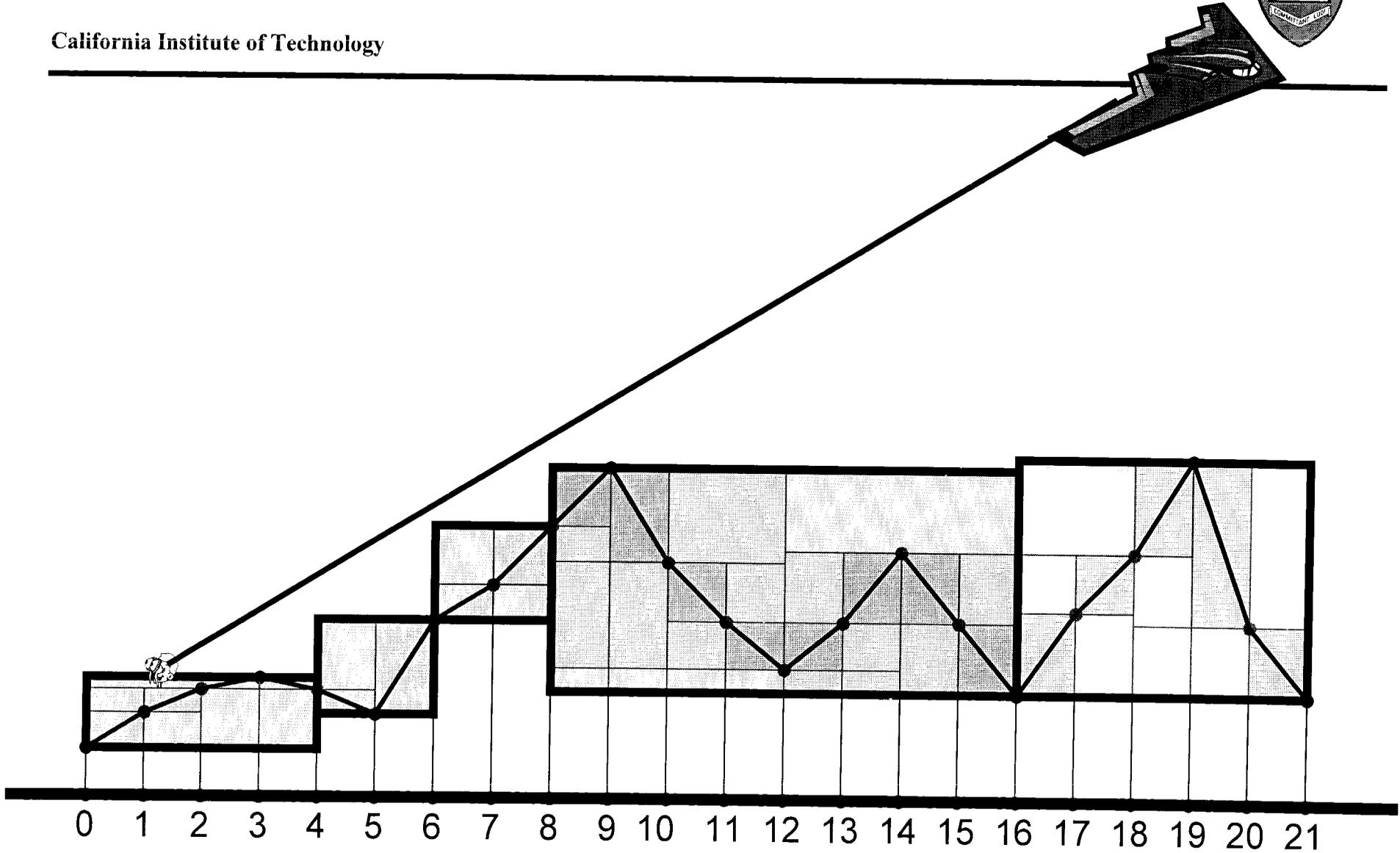
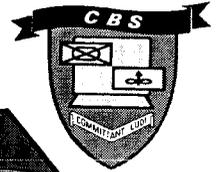
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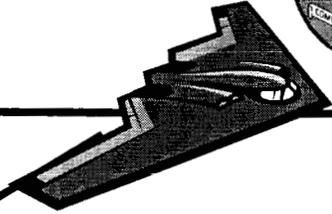
California Institute of Technology





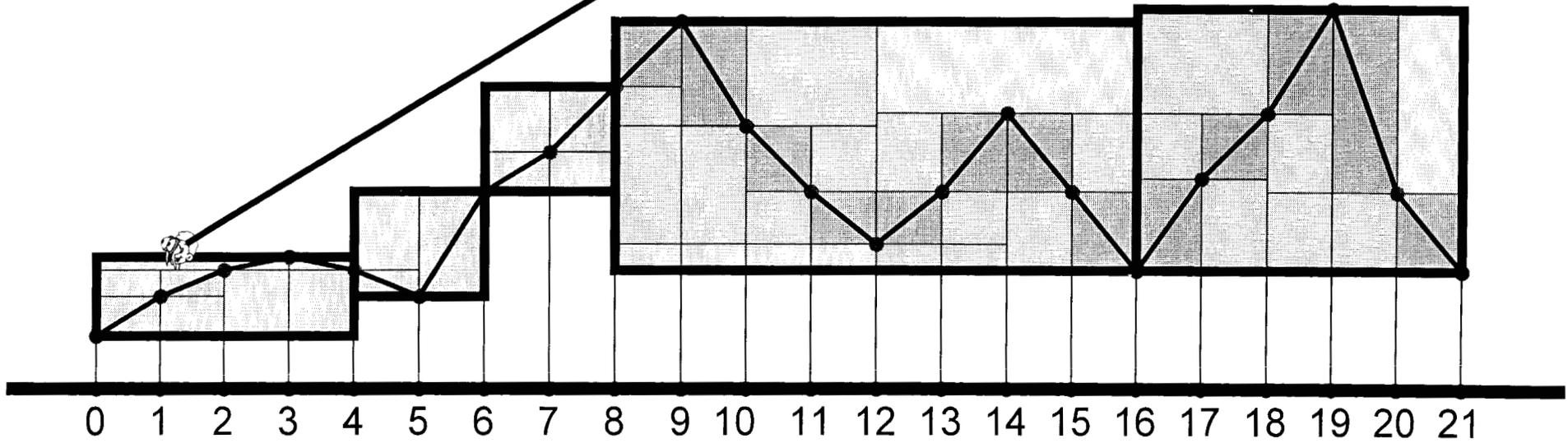
California Institute of Technology



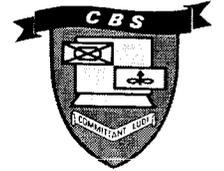


LOS is unobstructed

*Next, an obstructed case*

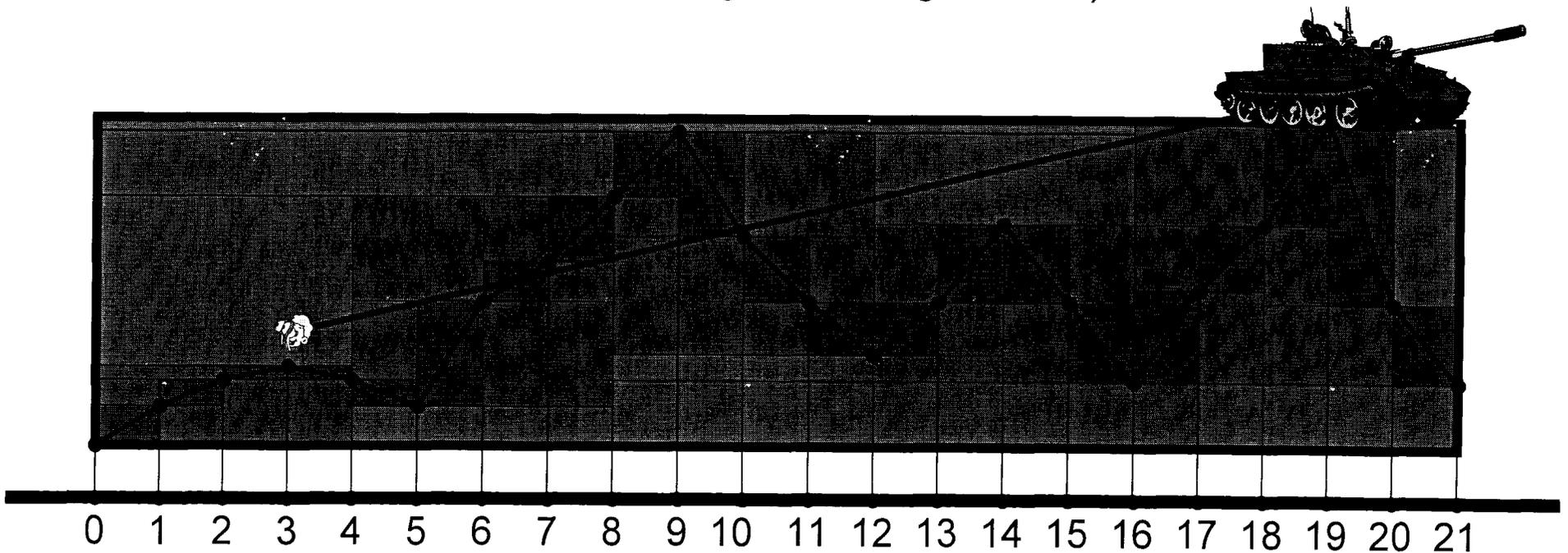


# An Illustration of an Obstructed LOS



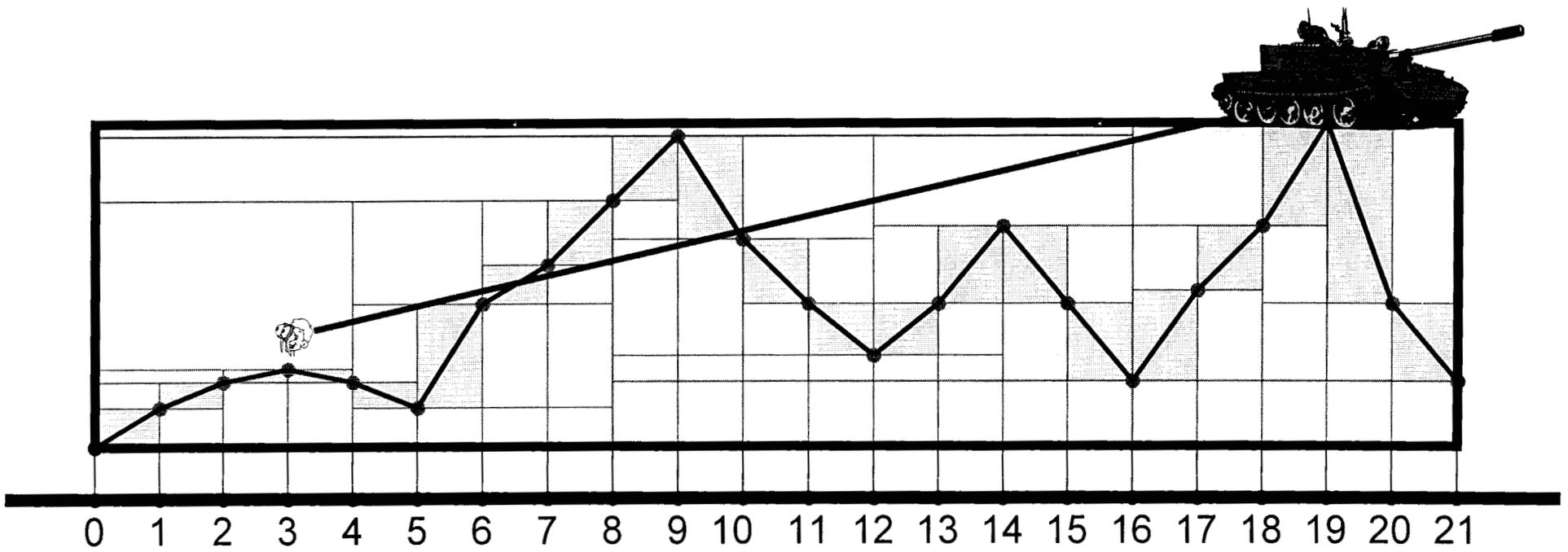
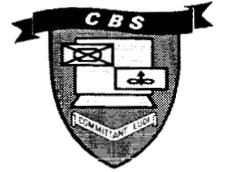
On the same terrain: LOS is obstructed

- LOS still close to grazing
- Also 9 box queries, plus two sets of leaf queries, at a distance of 20 posts (about 40 edge crossings in 3-D)



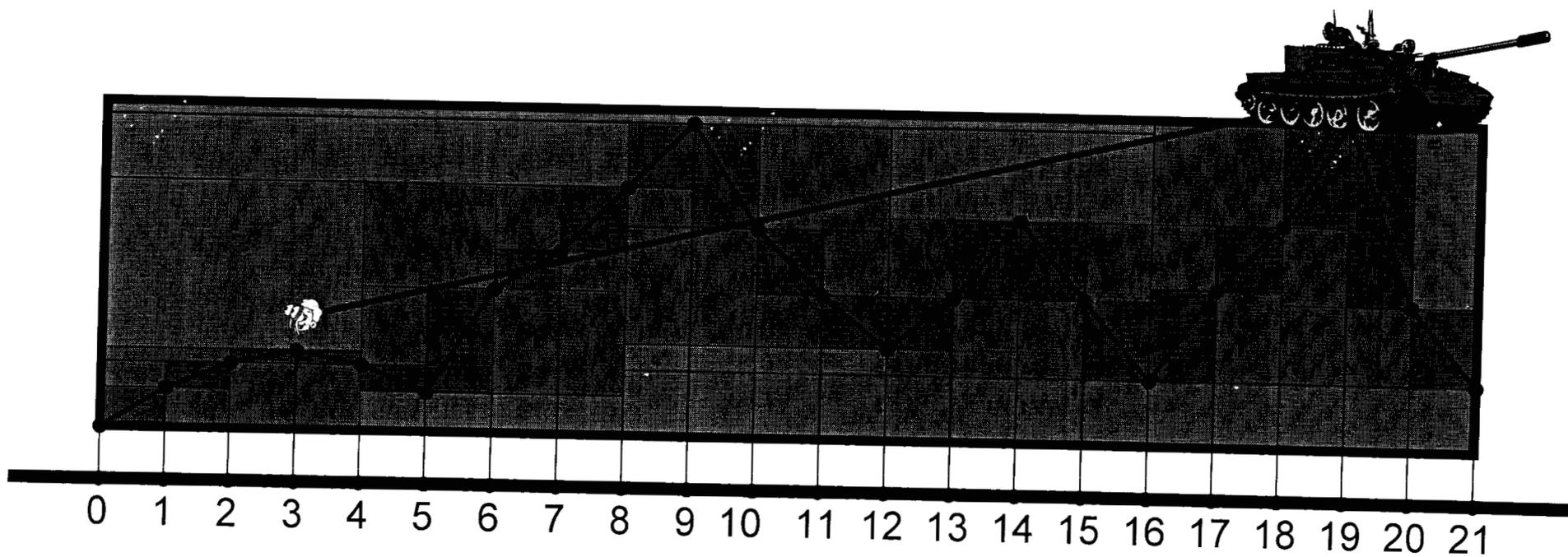
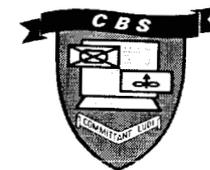


California Institute of Technology



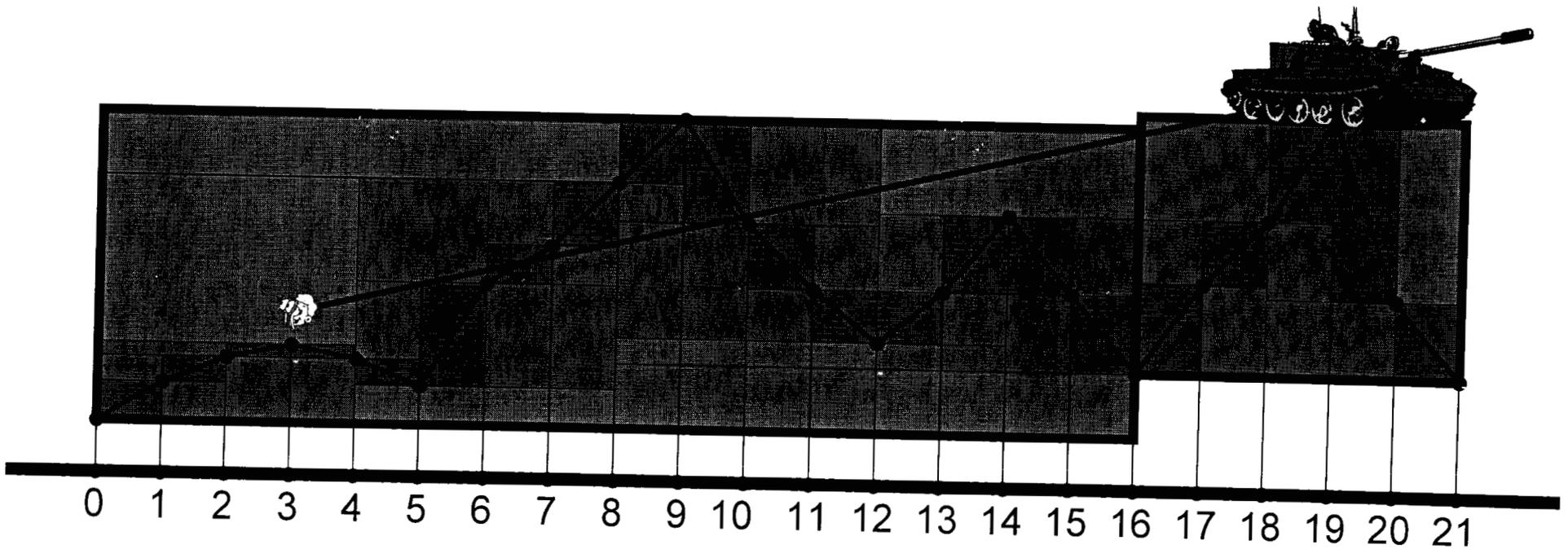


California Institute of Technology



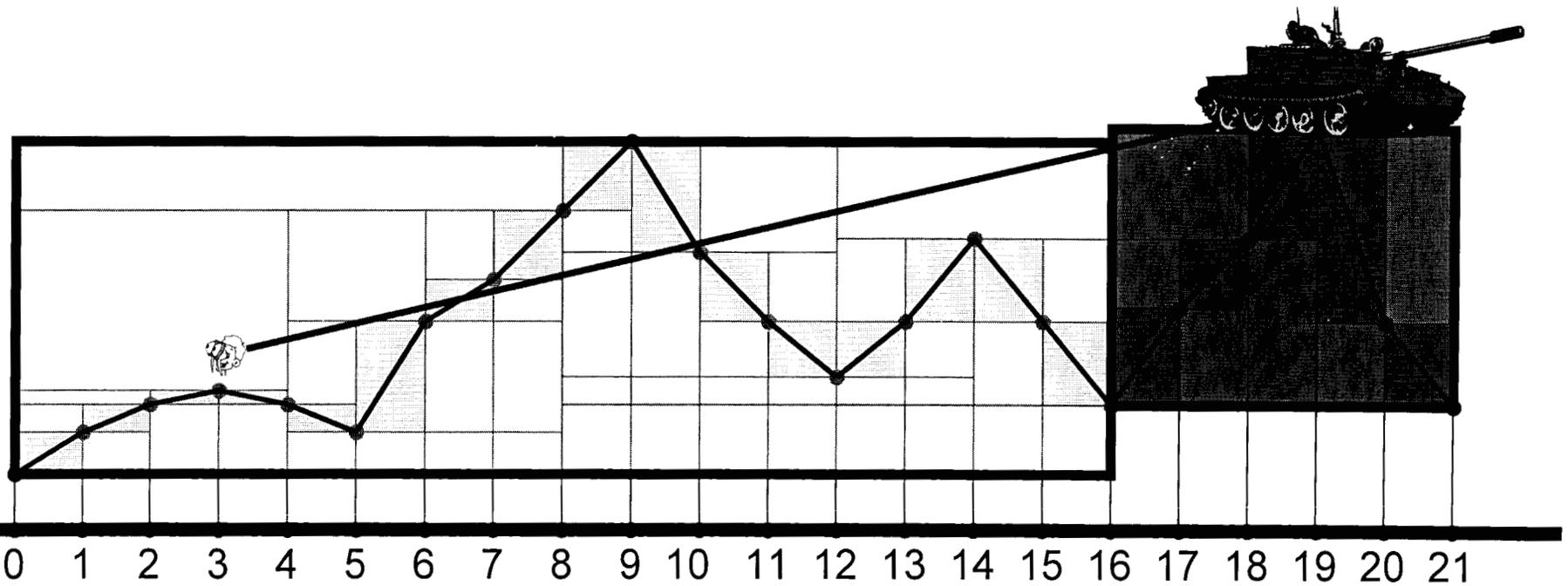
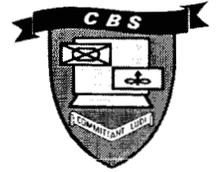


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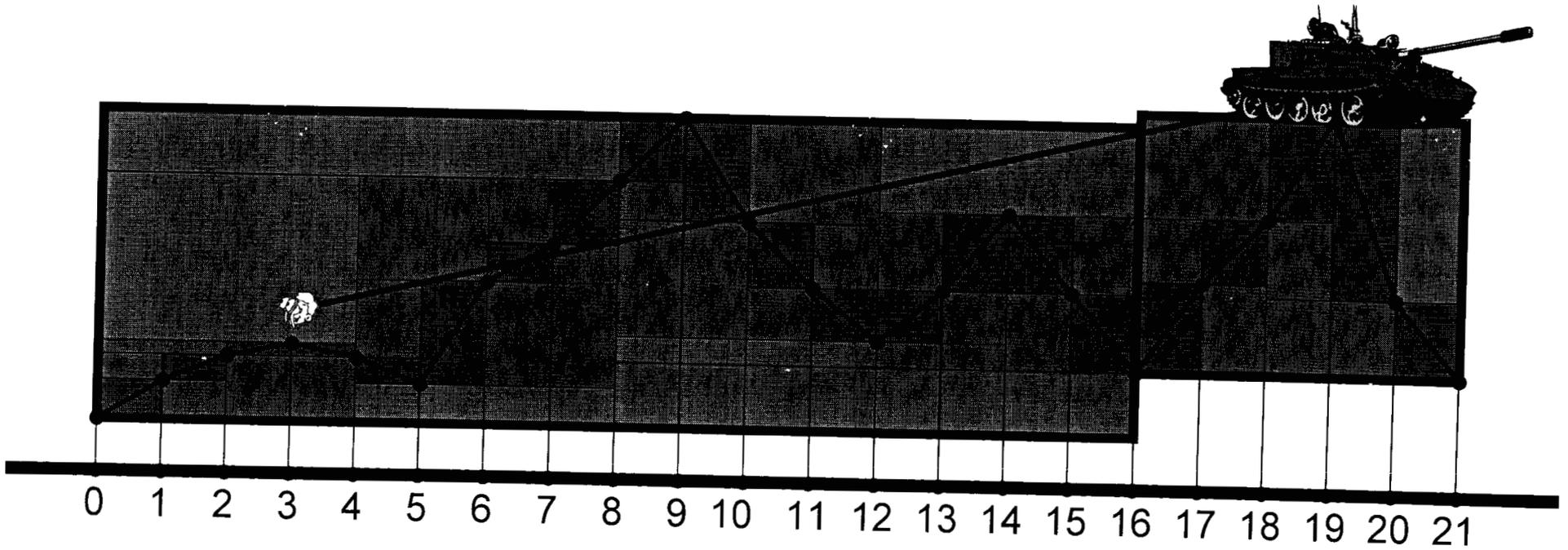
California Institute of Technology





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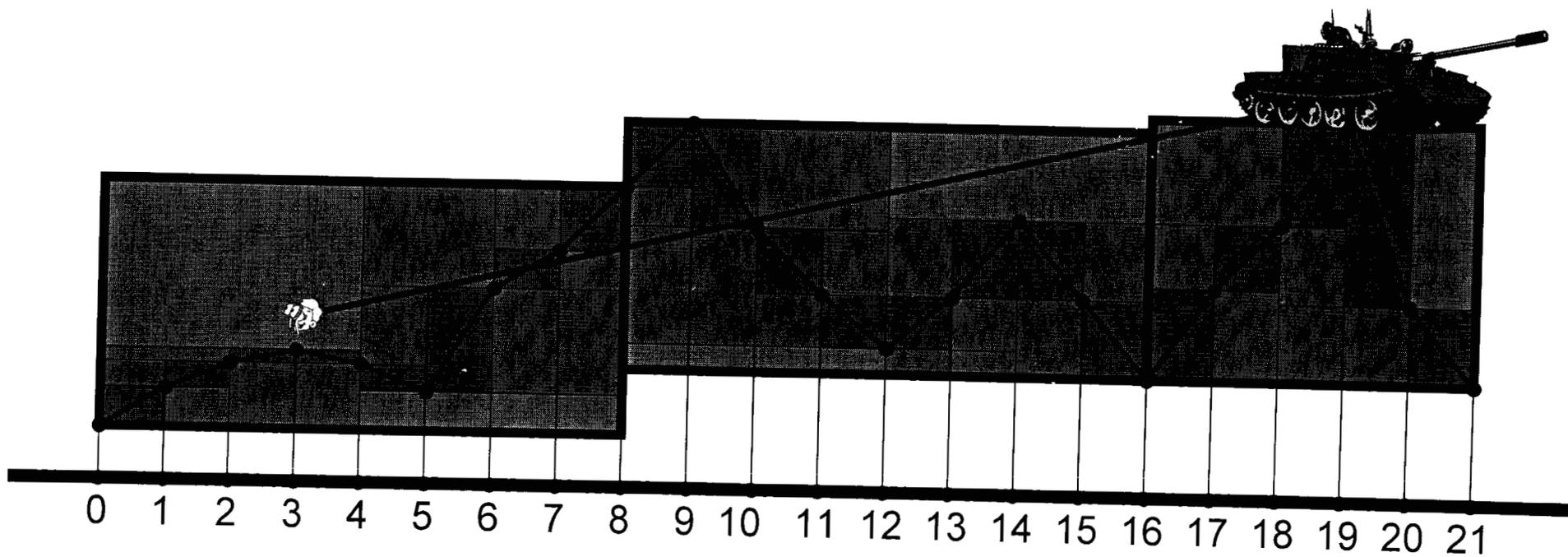
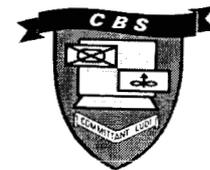
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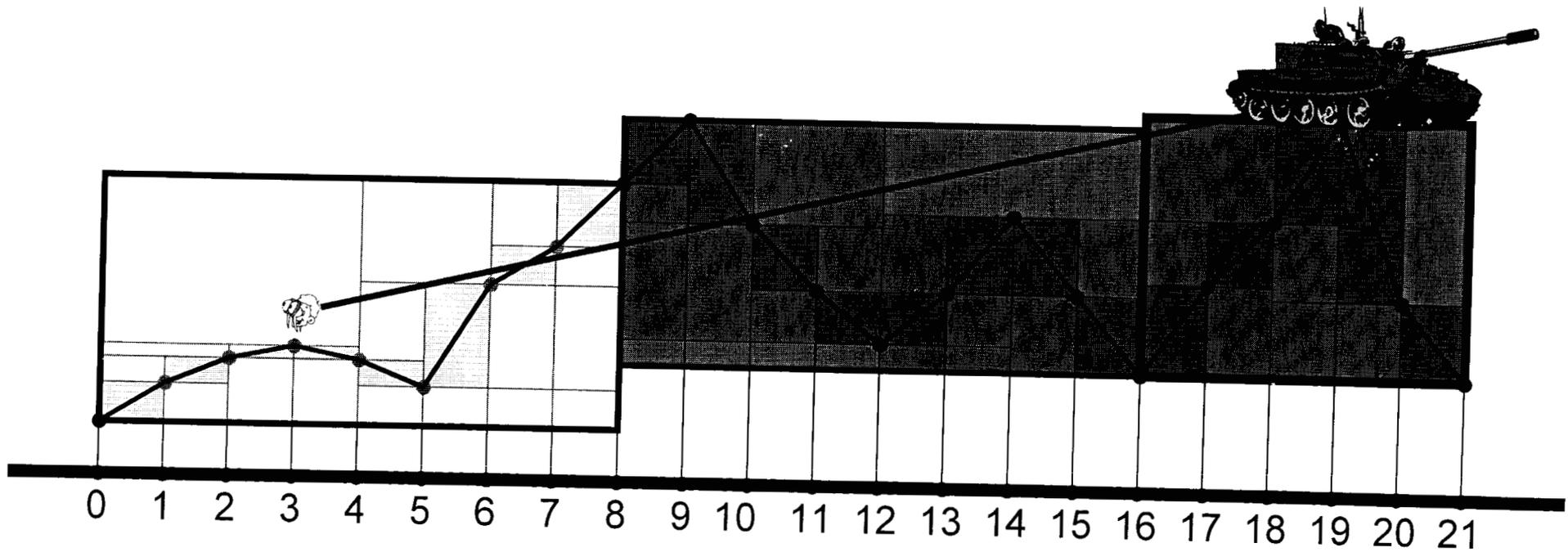


# JPL

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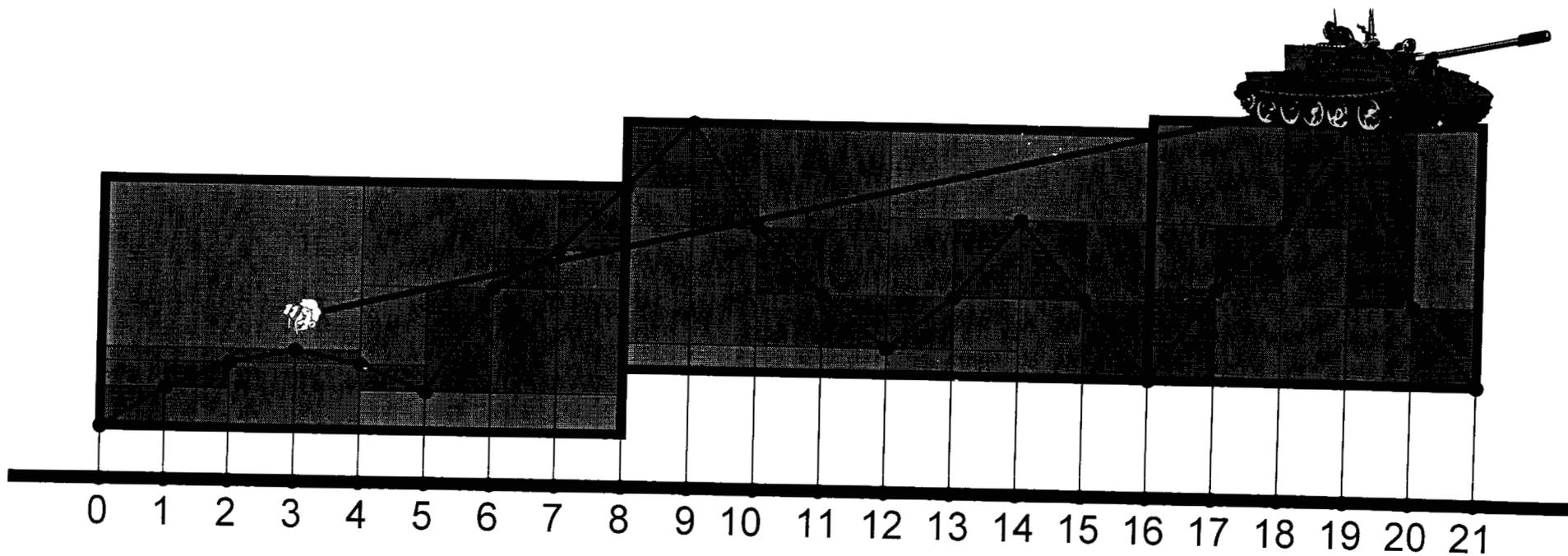
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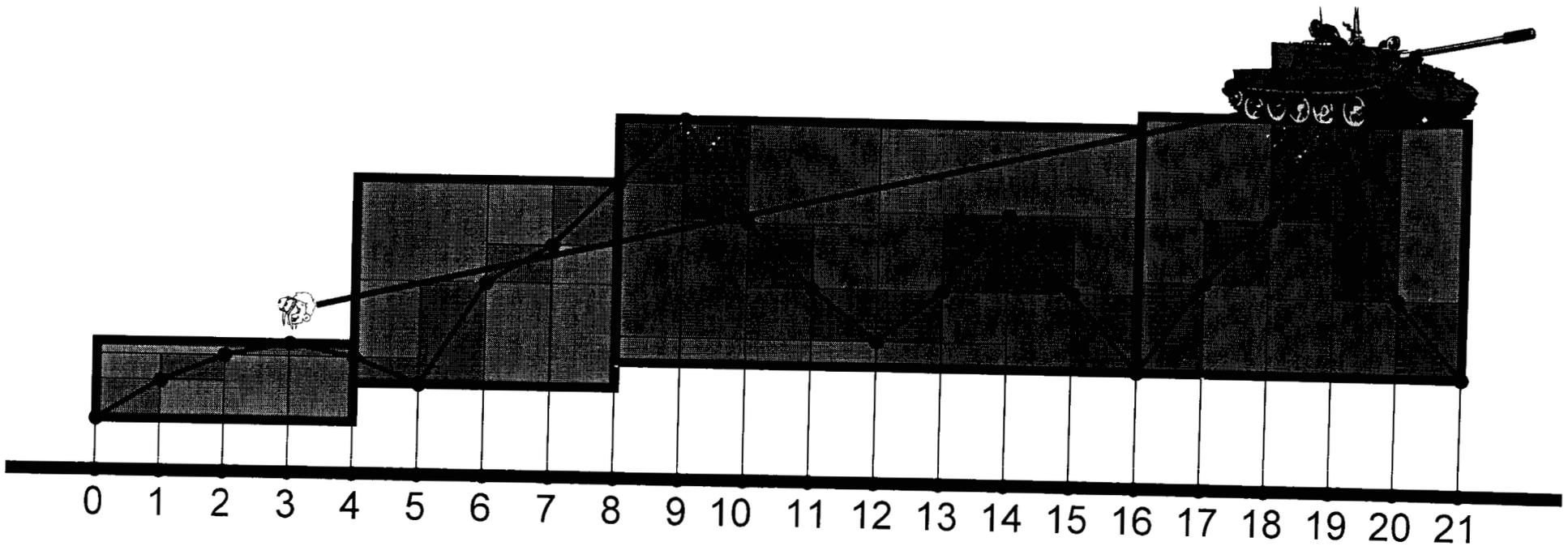


California Institute of Technology



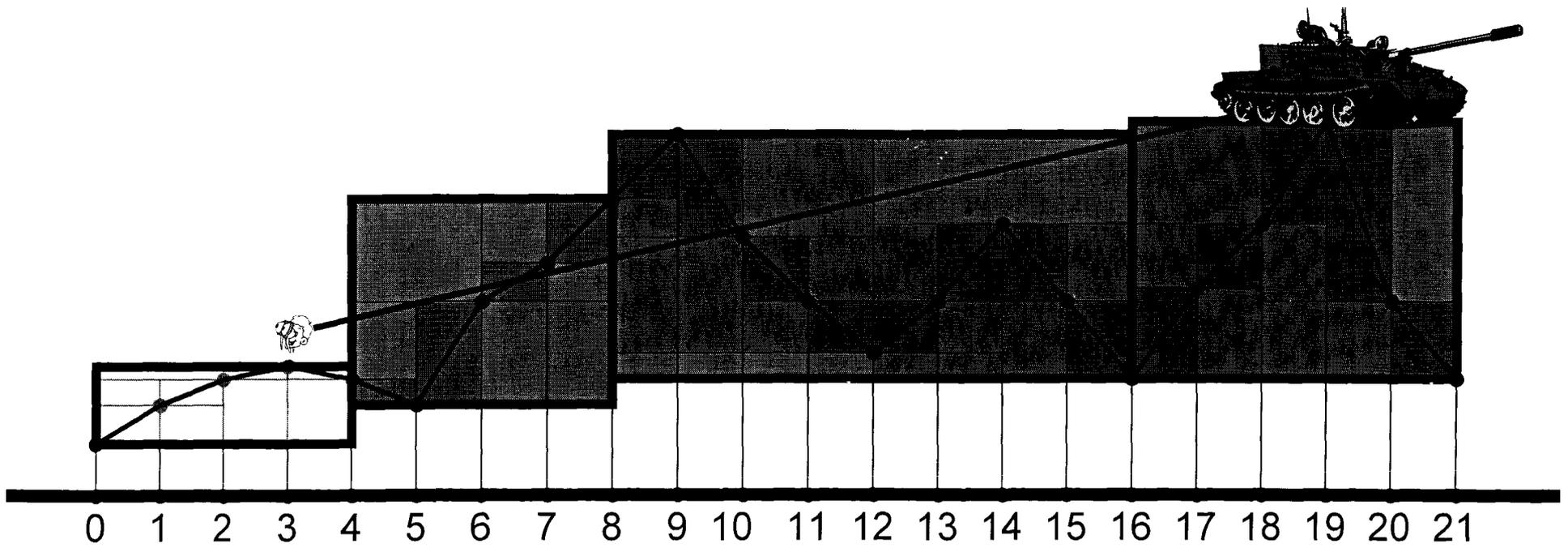
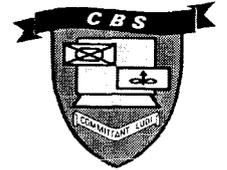


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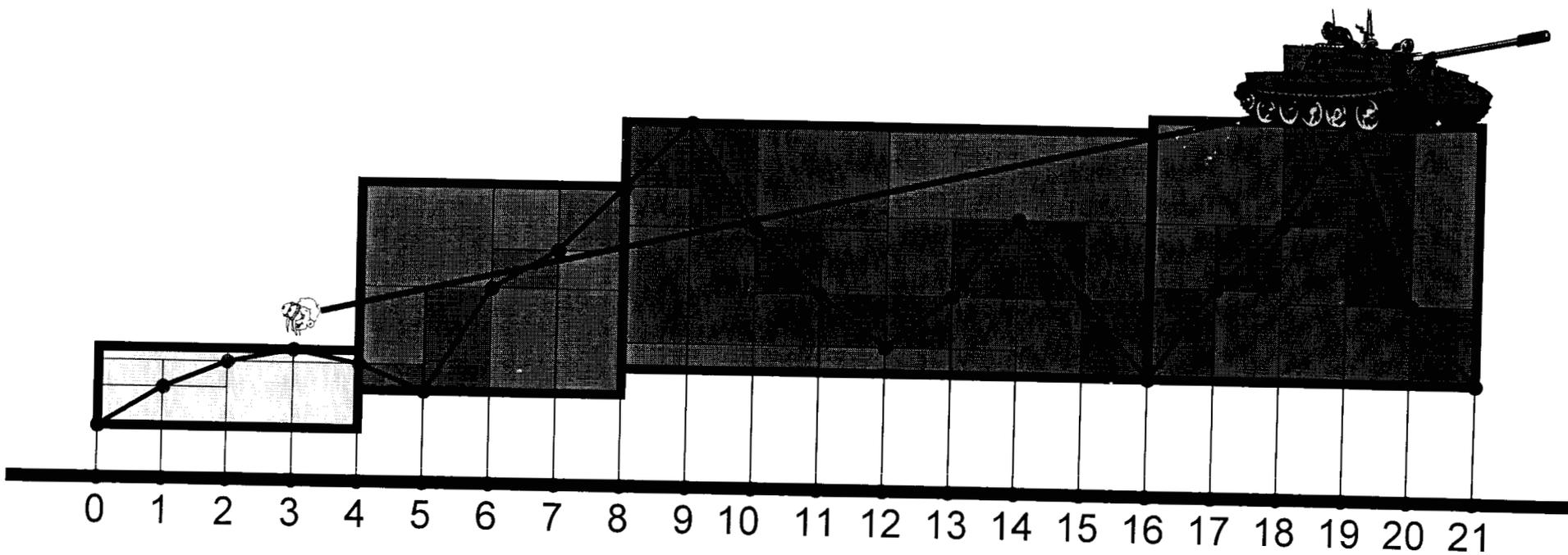


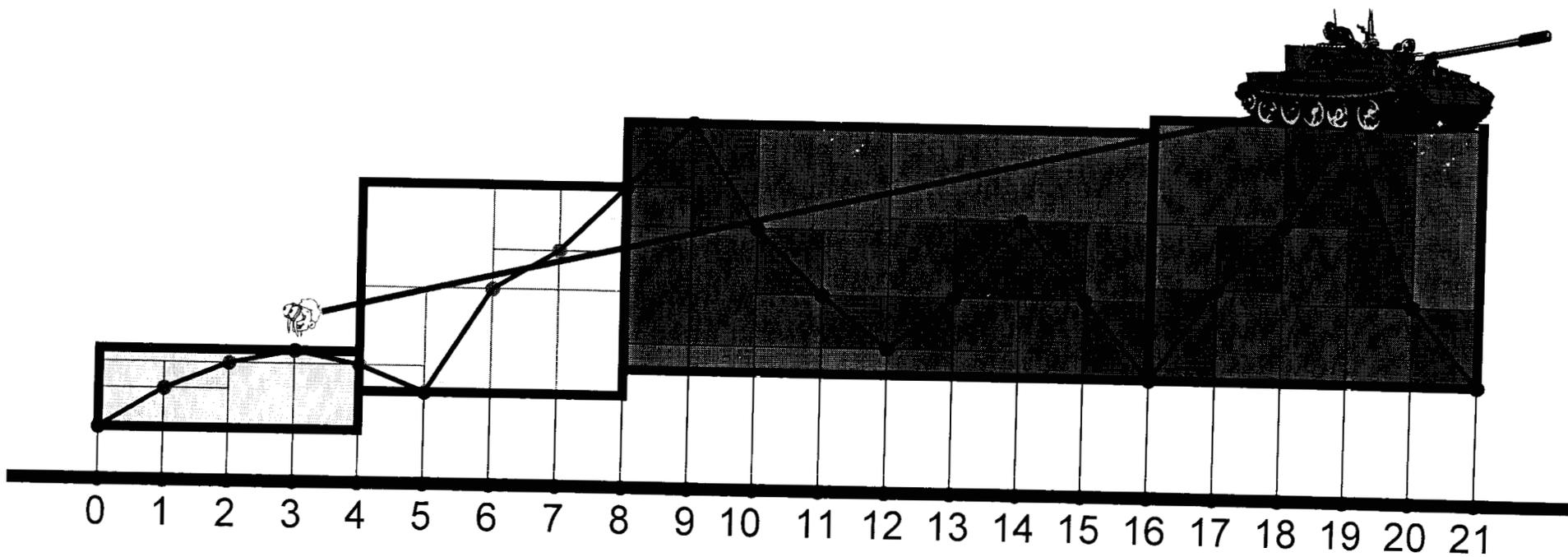
California Institute of Technology





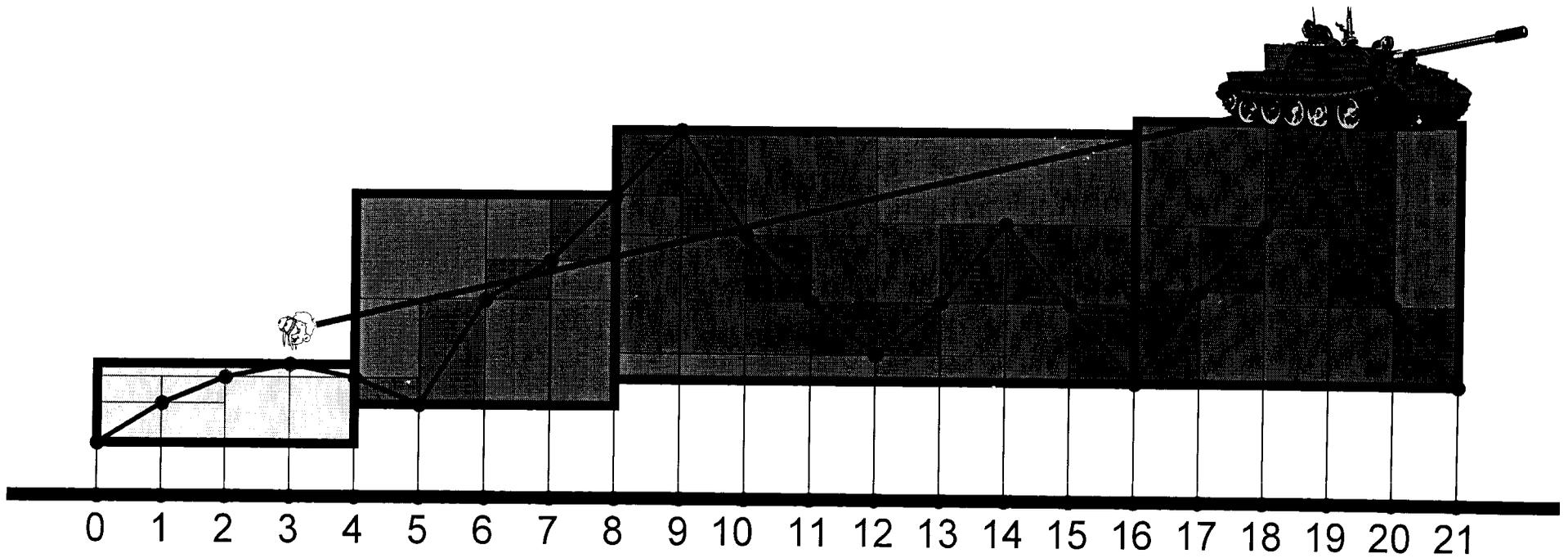
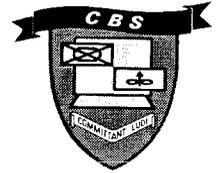
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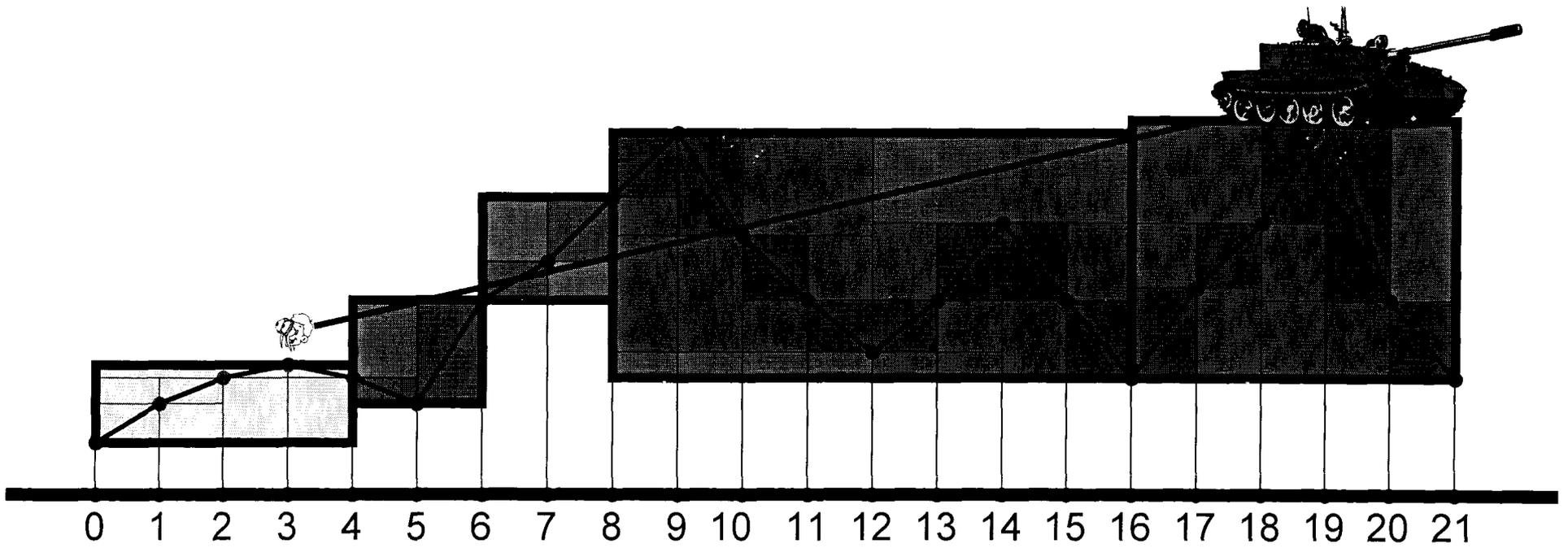
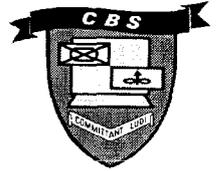


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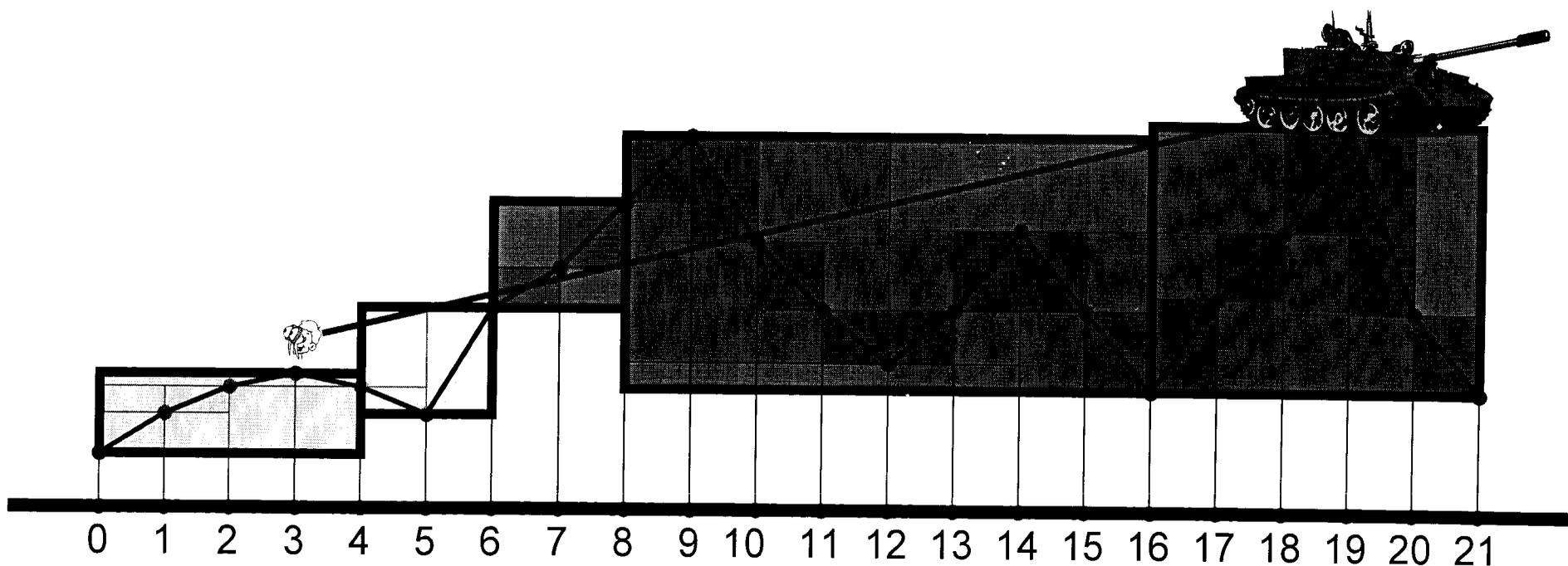
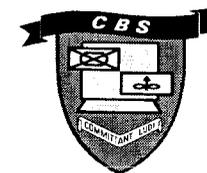


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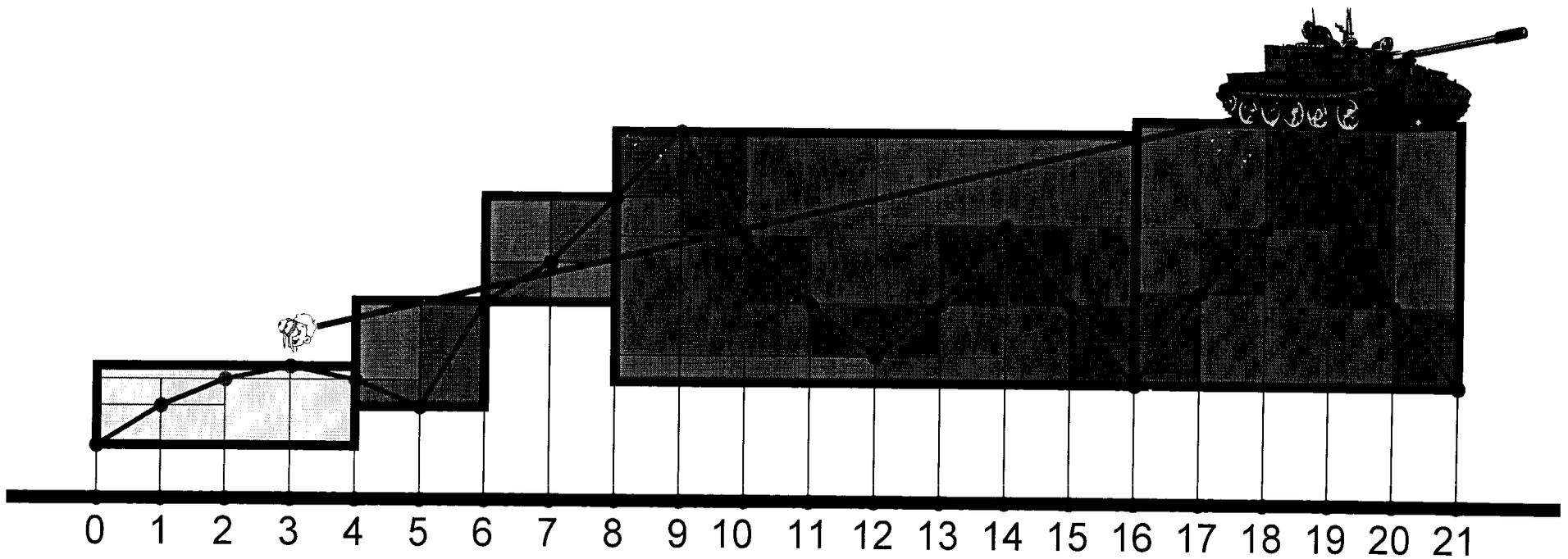
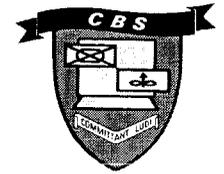
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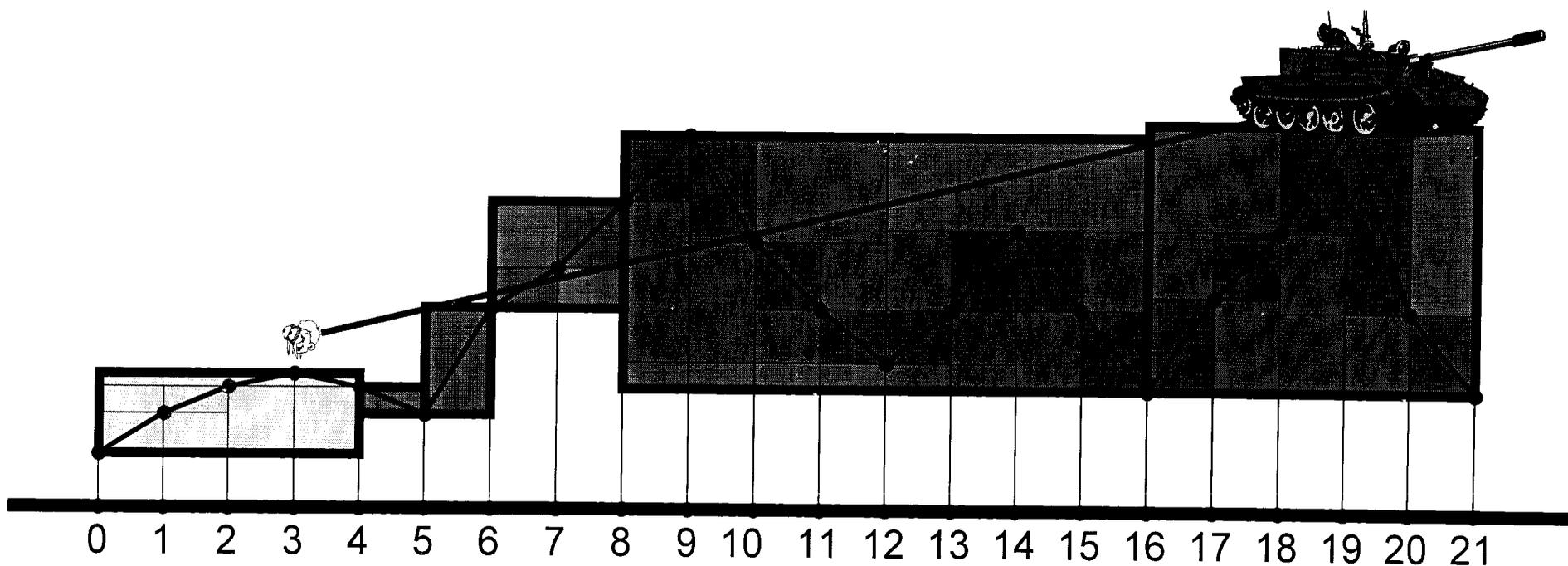
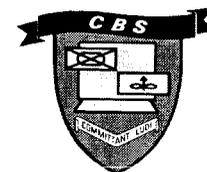
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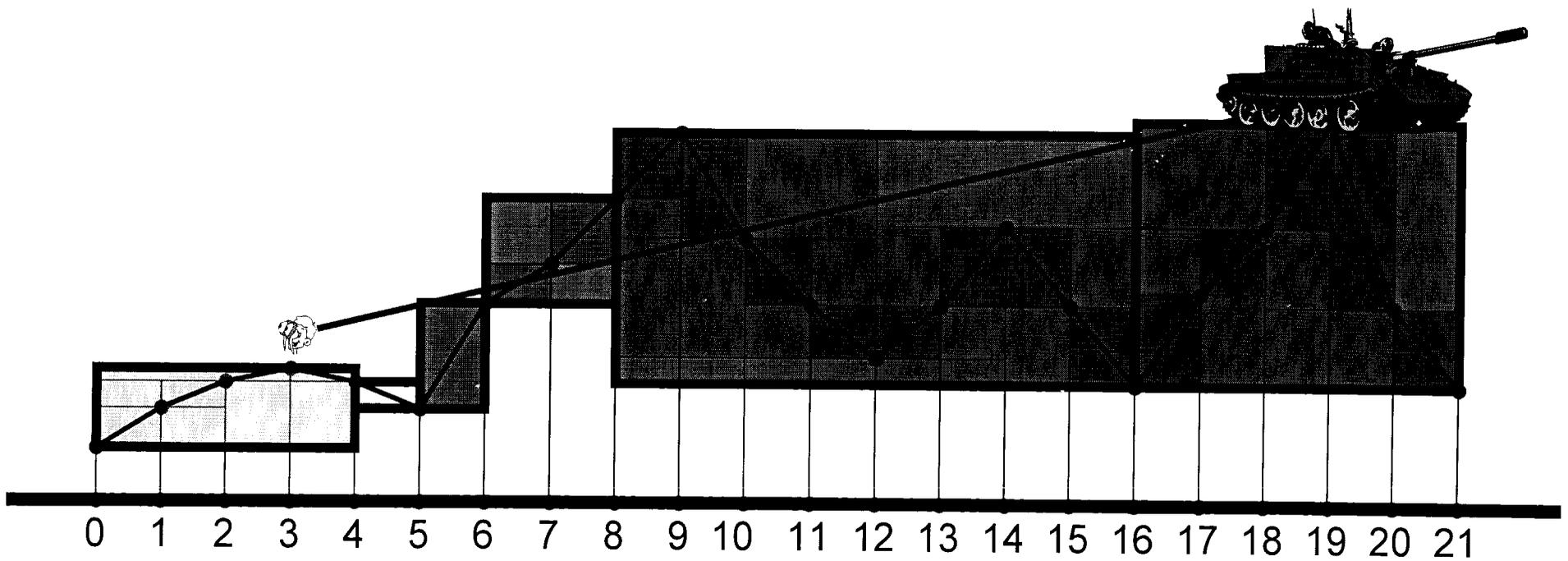
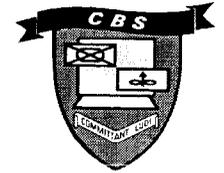
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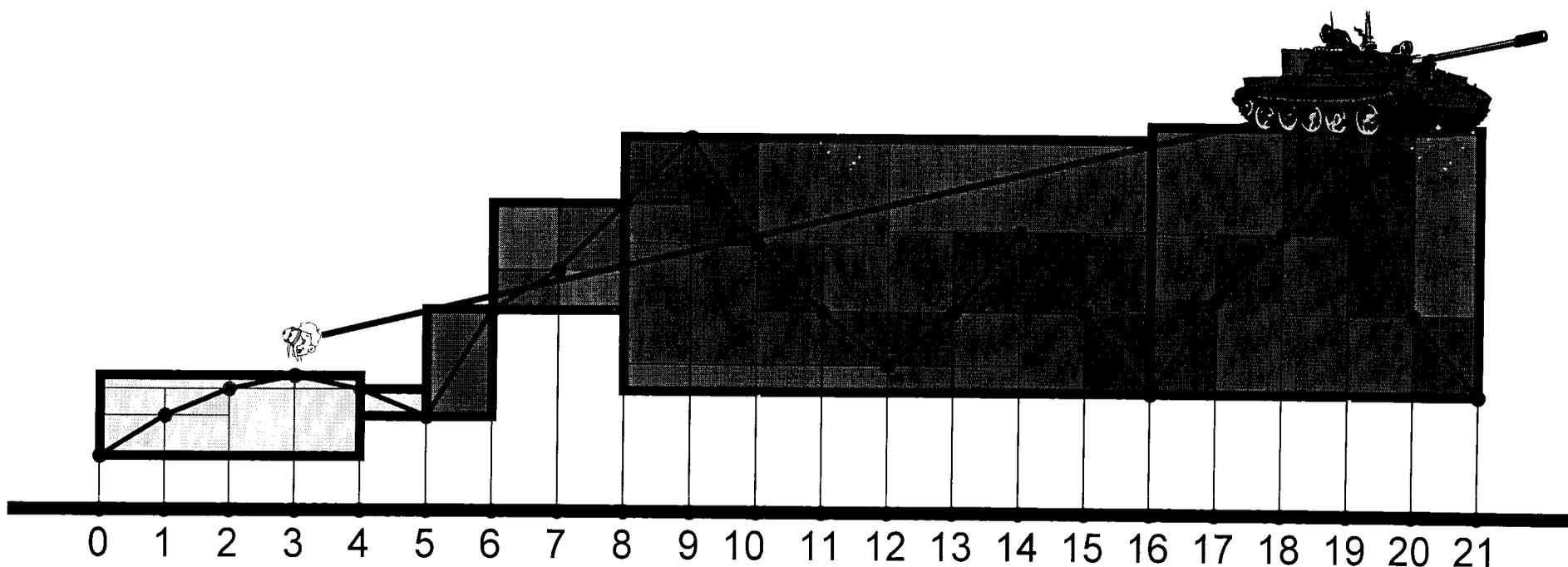
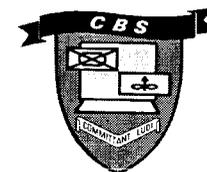


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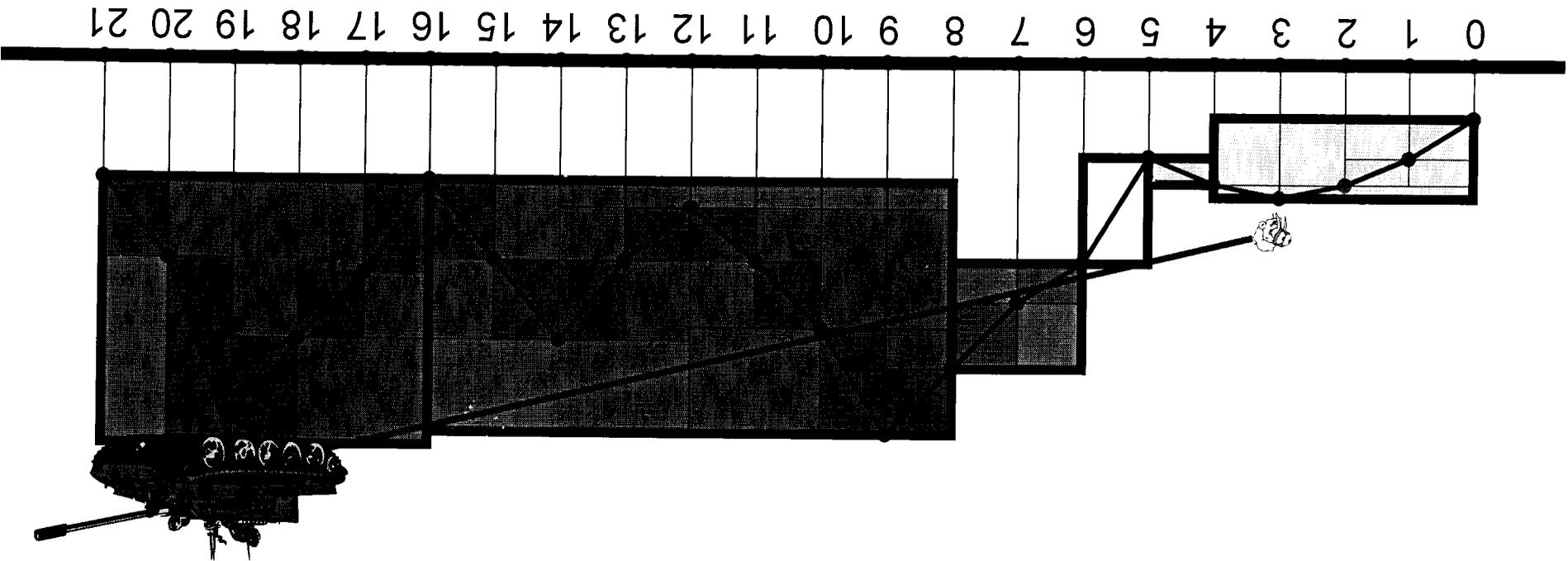
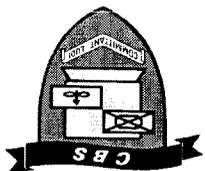


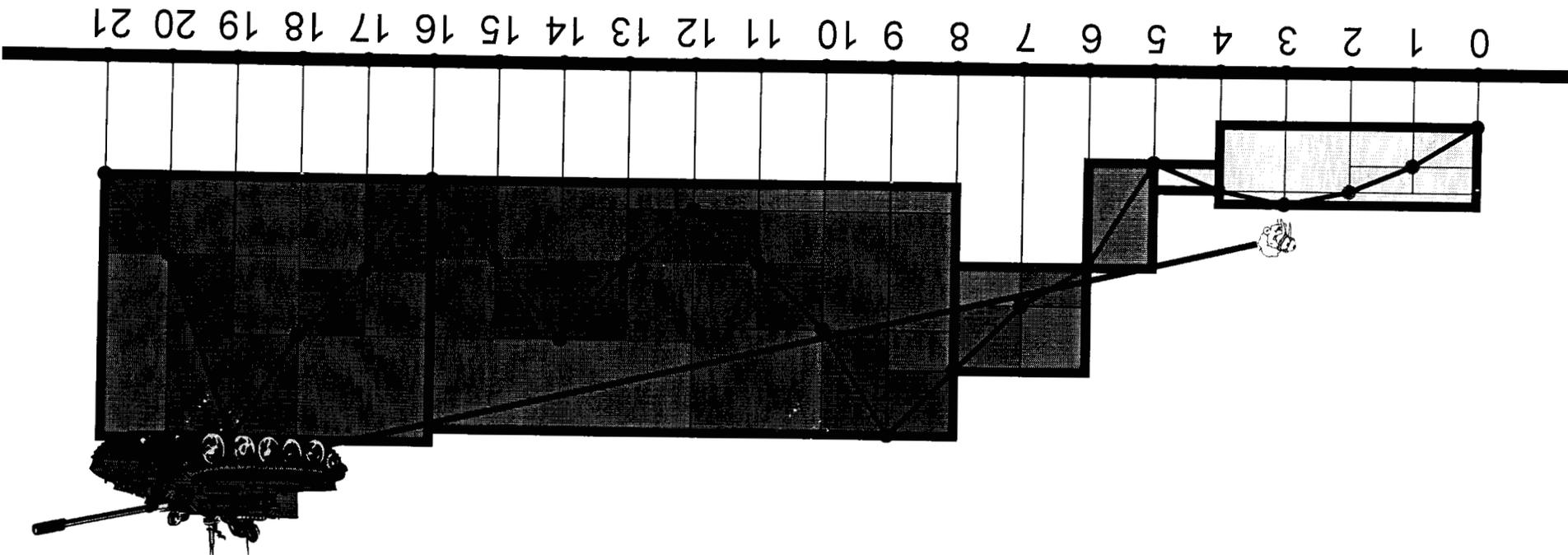
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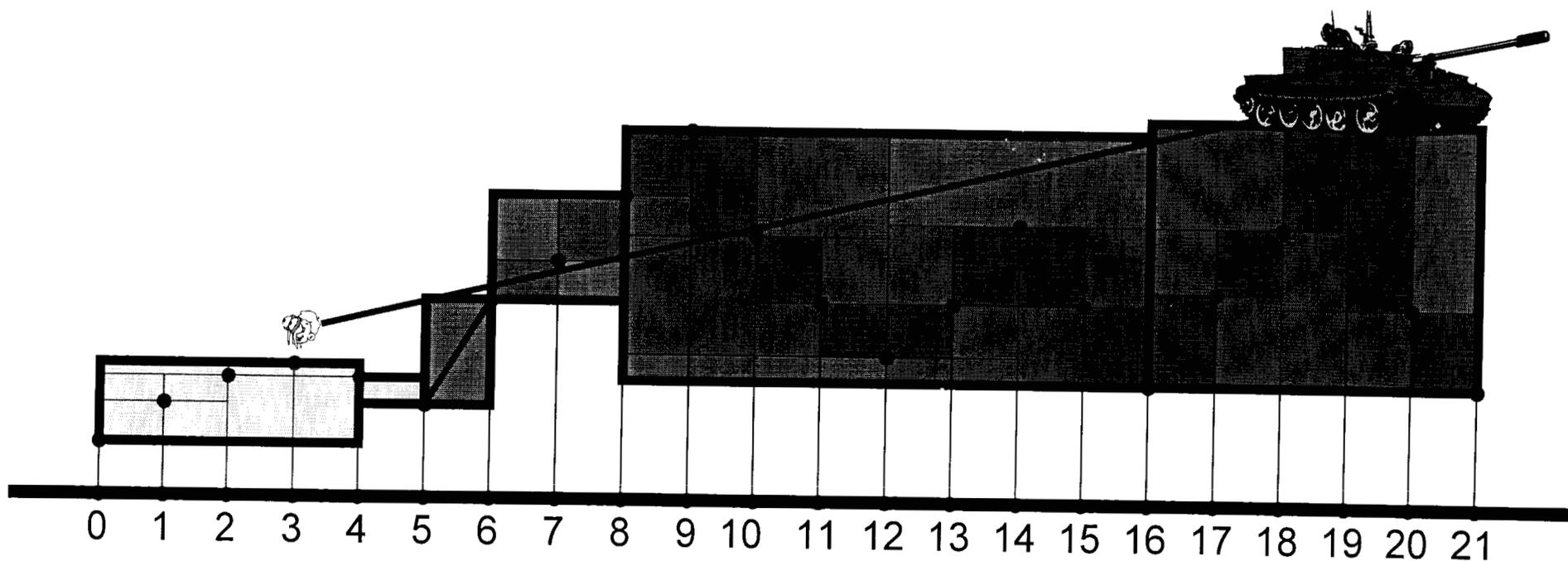
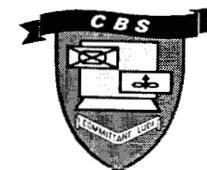


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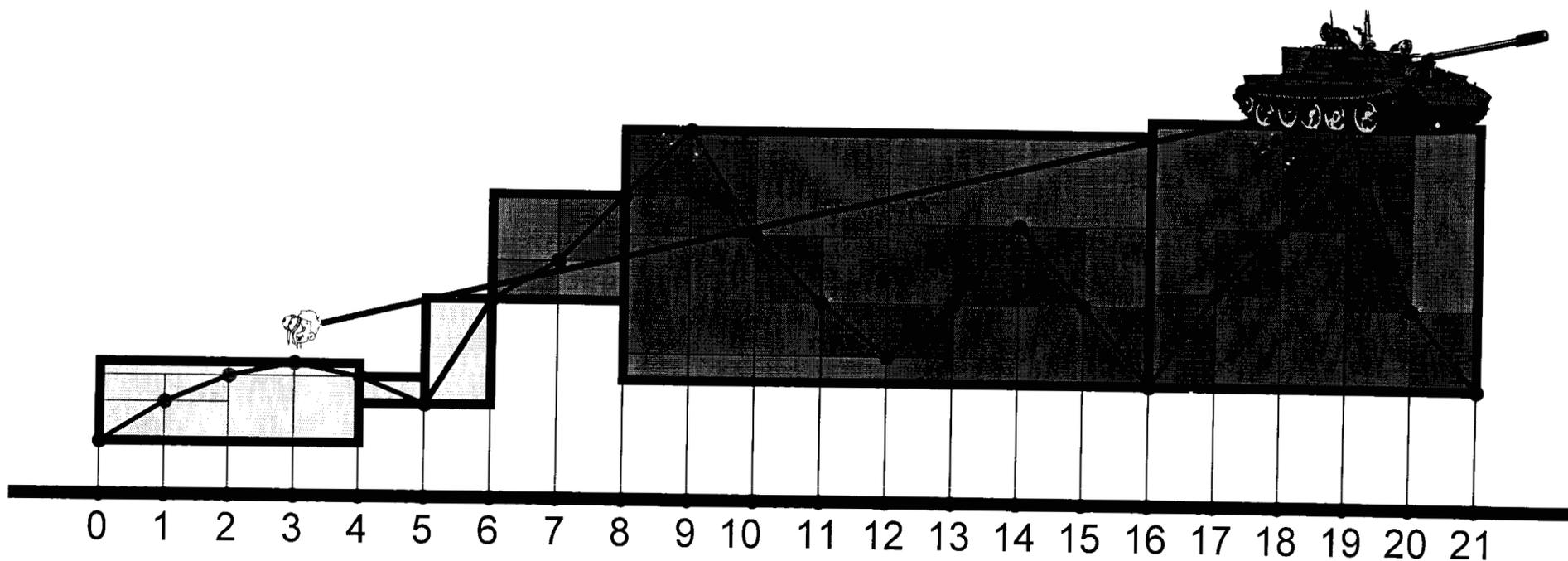
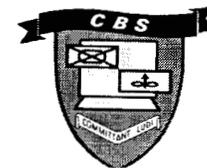


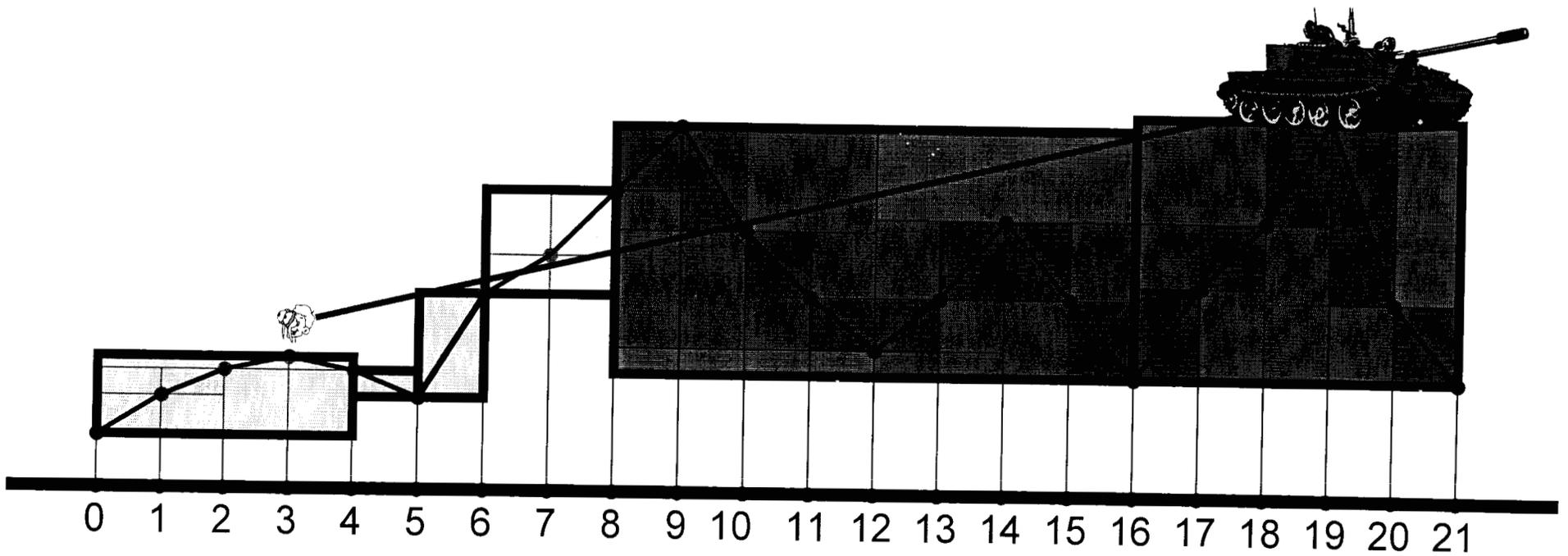
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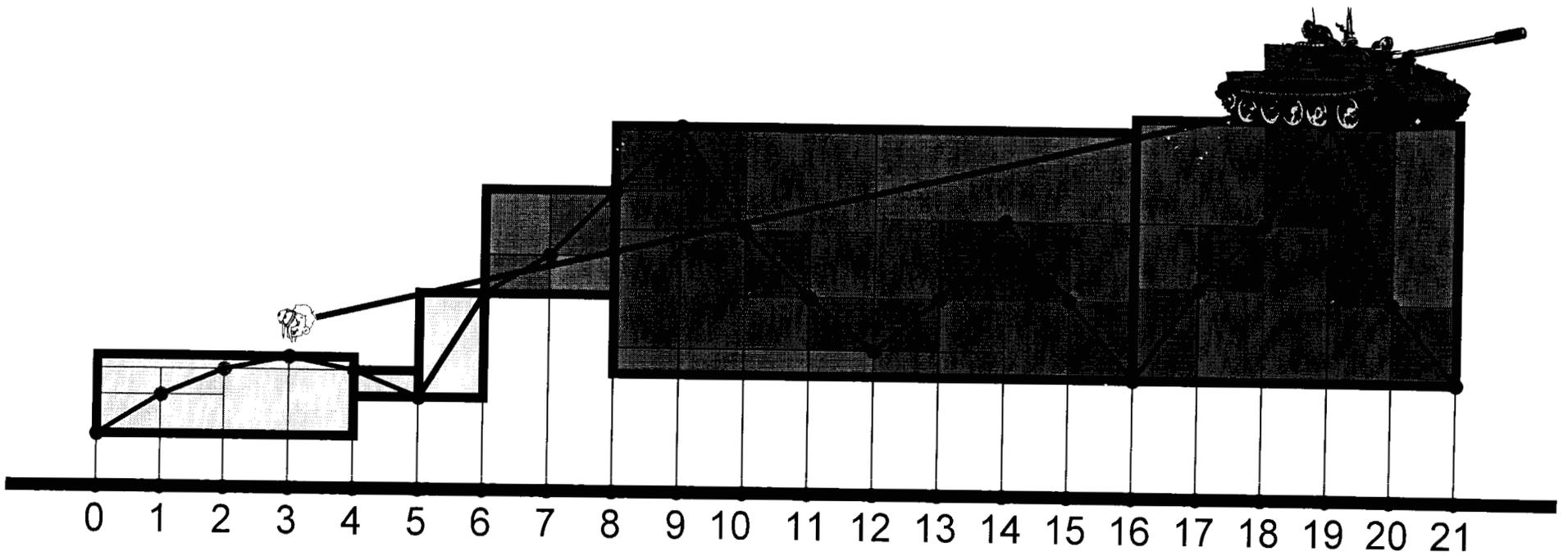
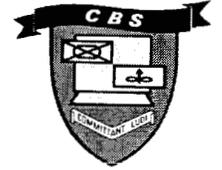
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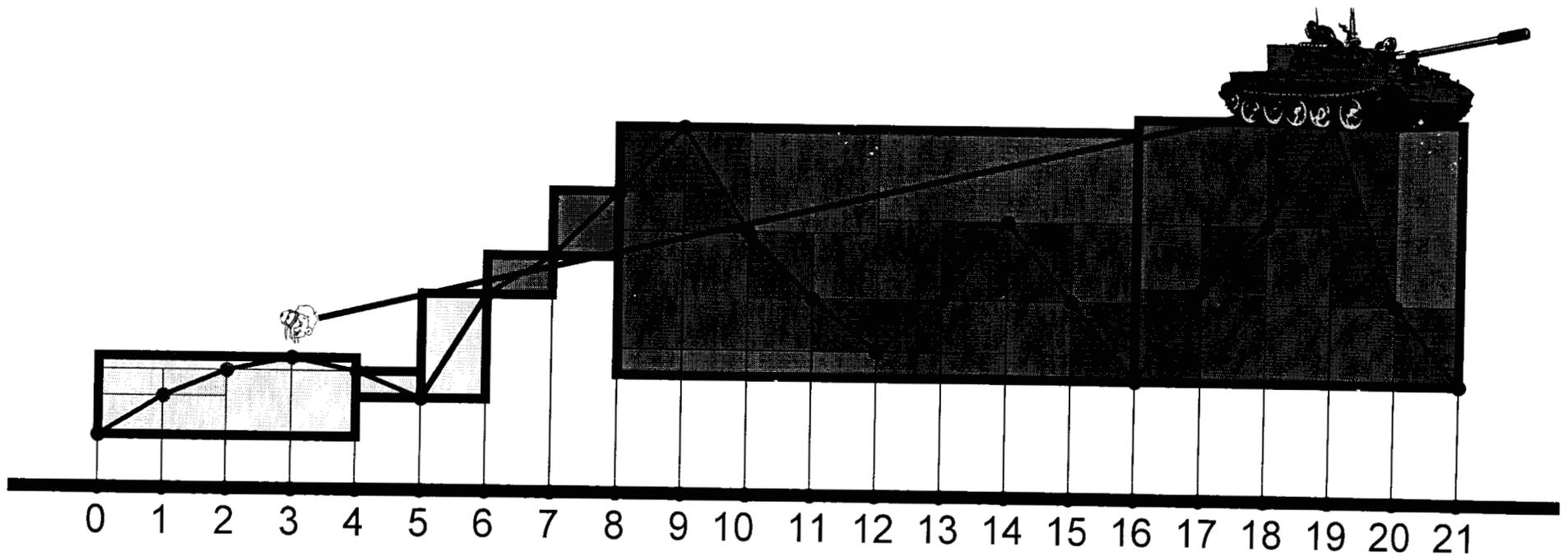


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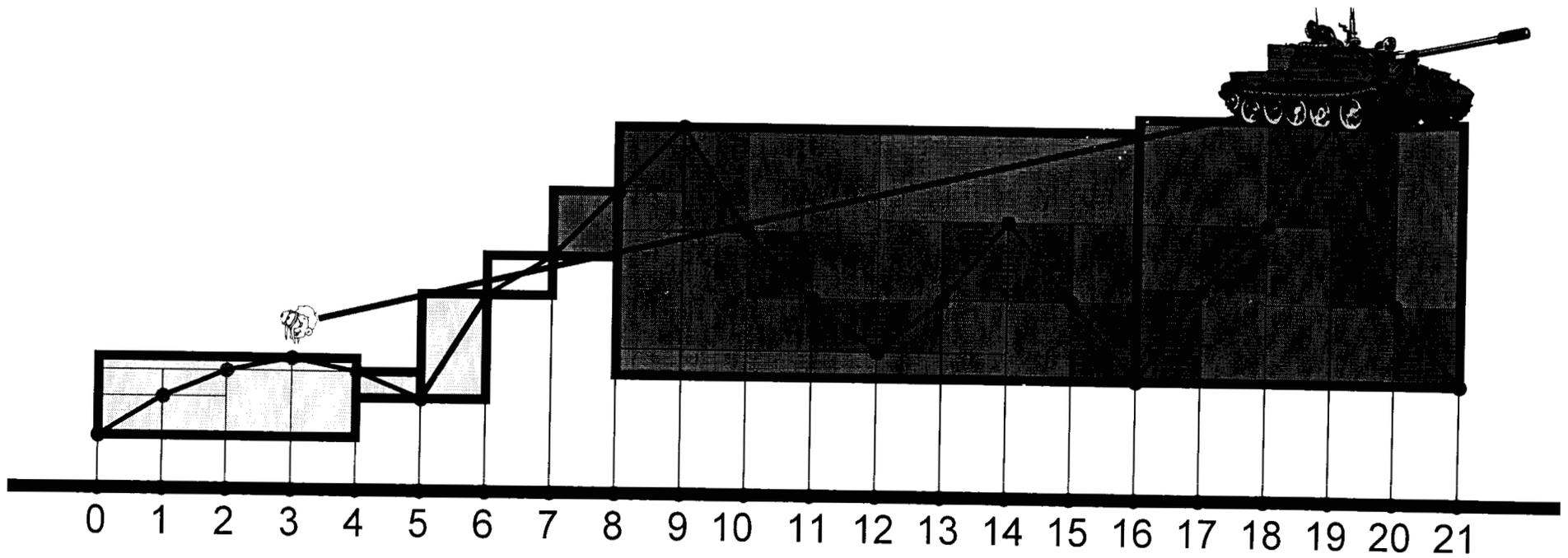
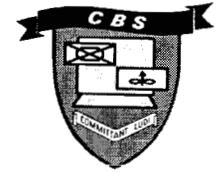


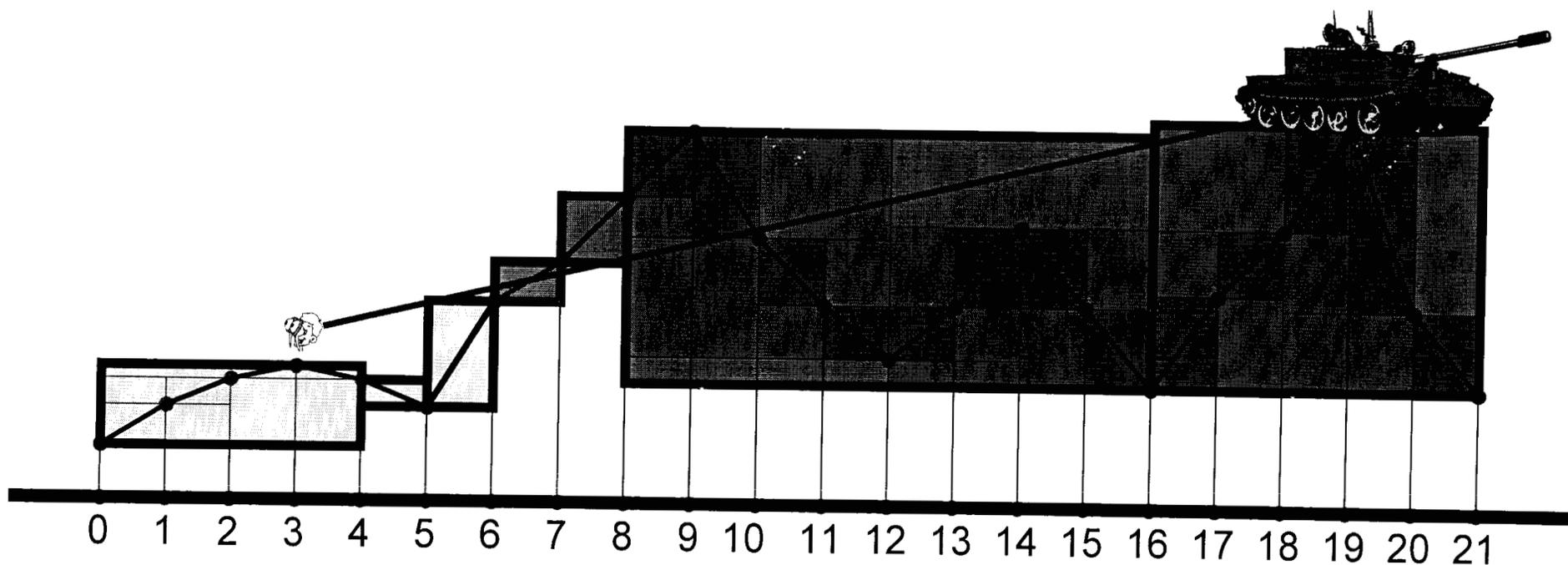
California Institute of Technology





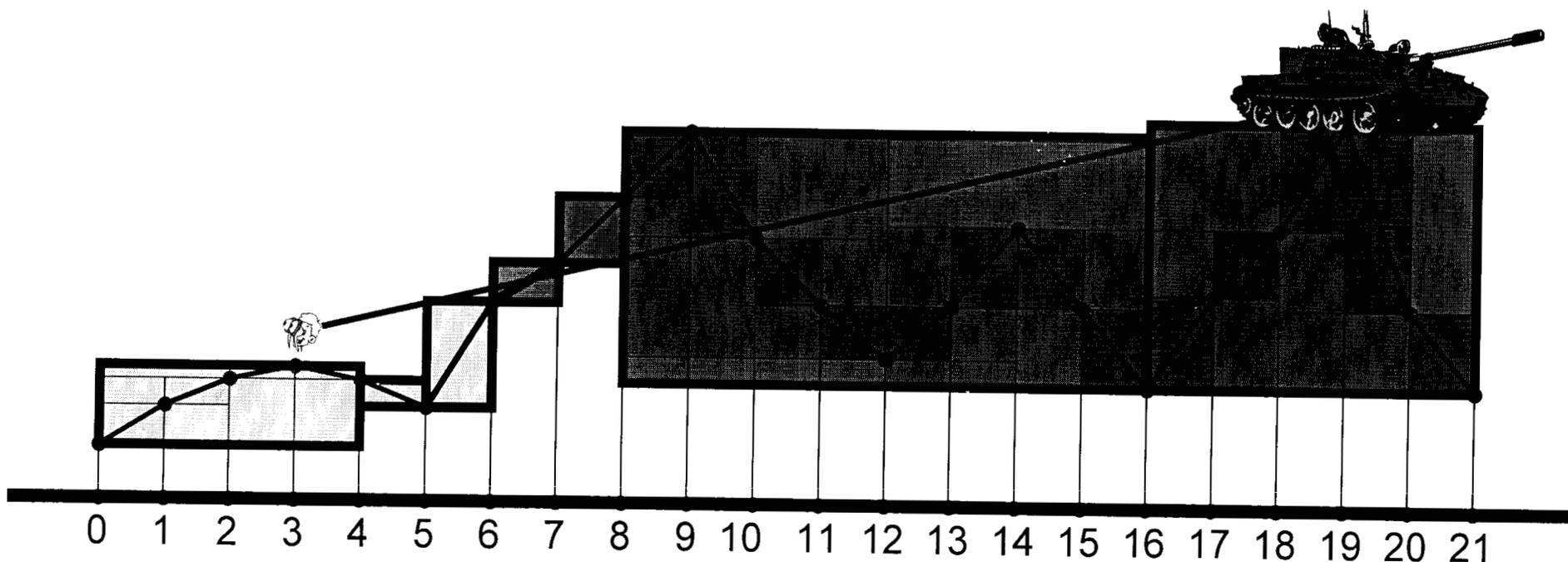
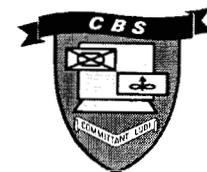
California Institute of Technology





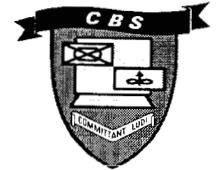


California Institute of Technology

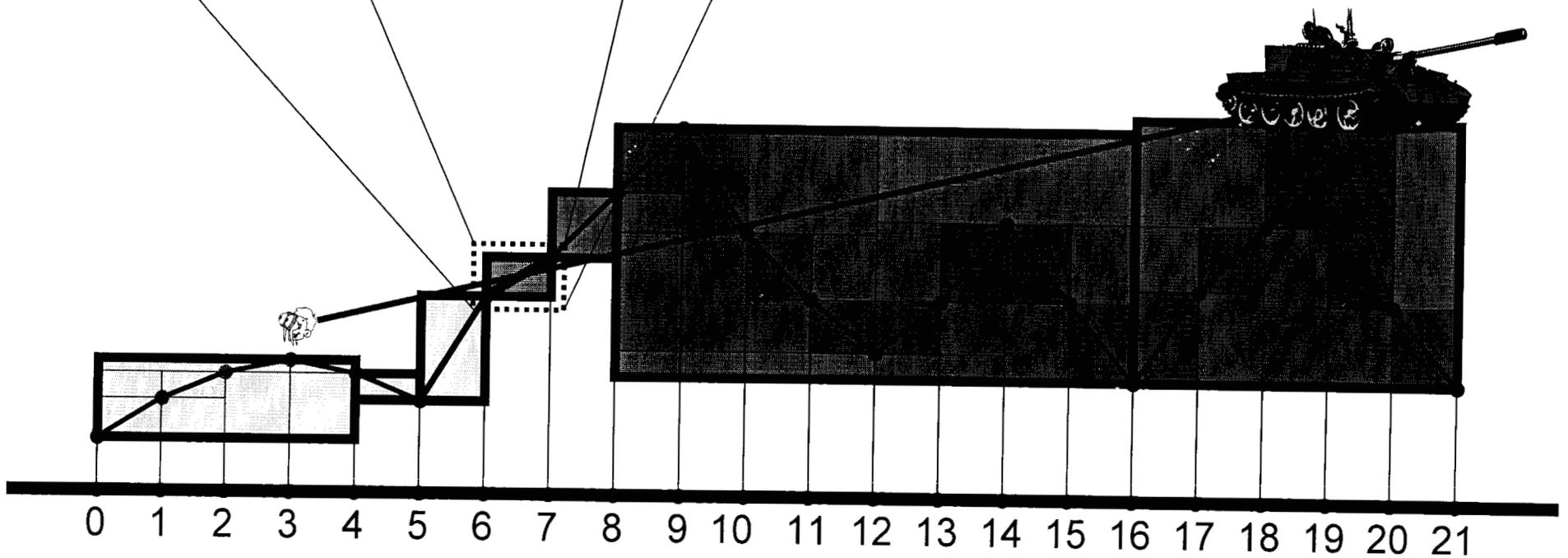


**JPL**

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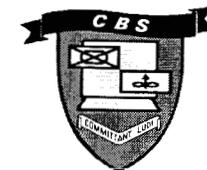
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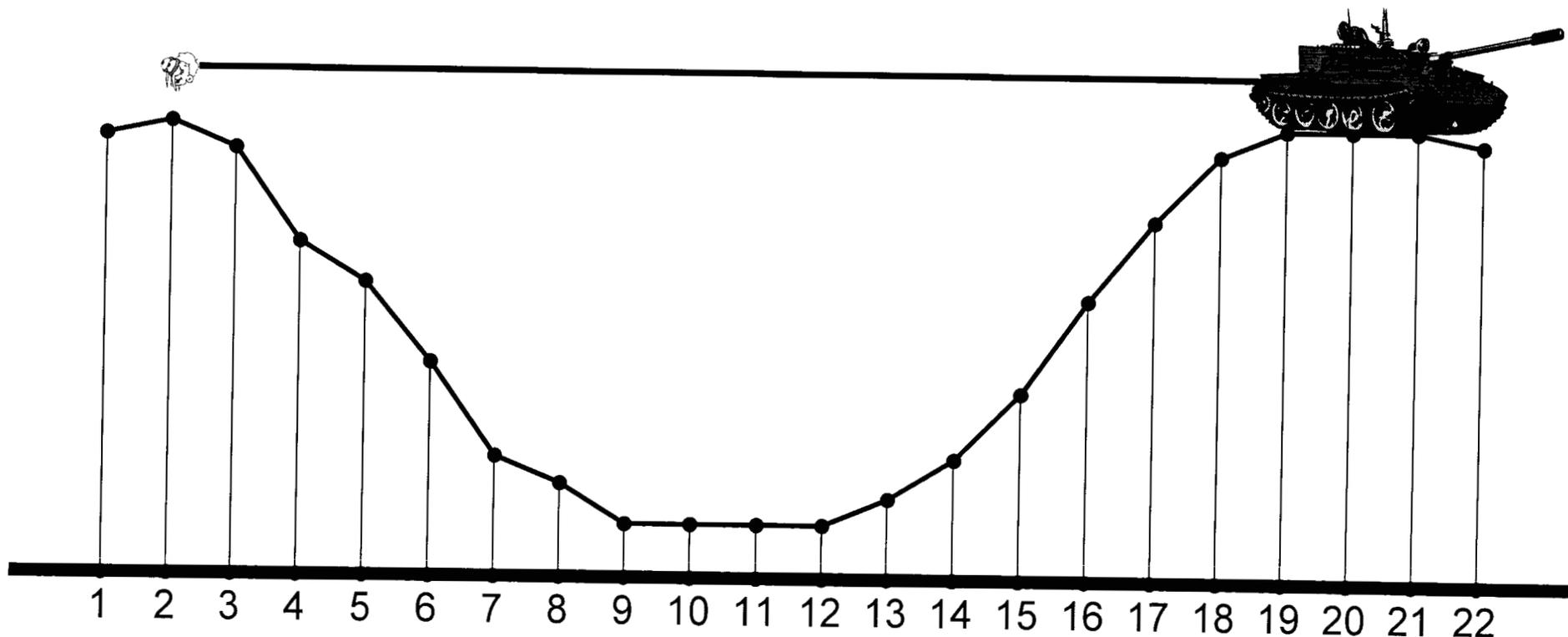


California Institute of Technology

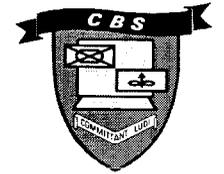
# Consider the following... An Easy Case



Different terrain: LOS is unobstructed

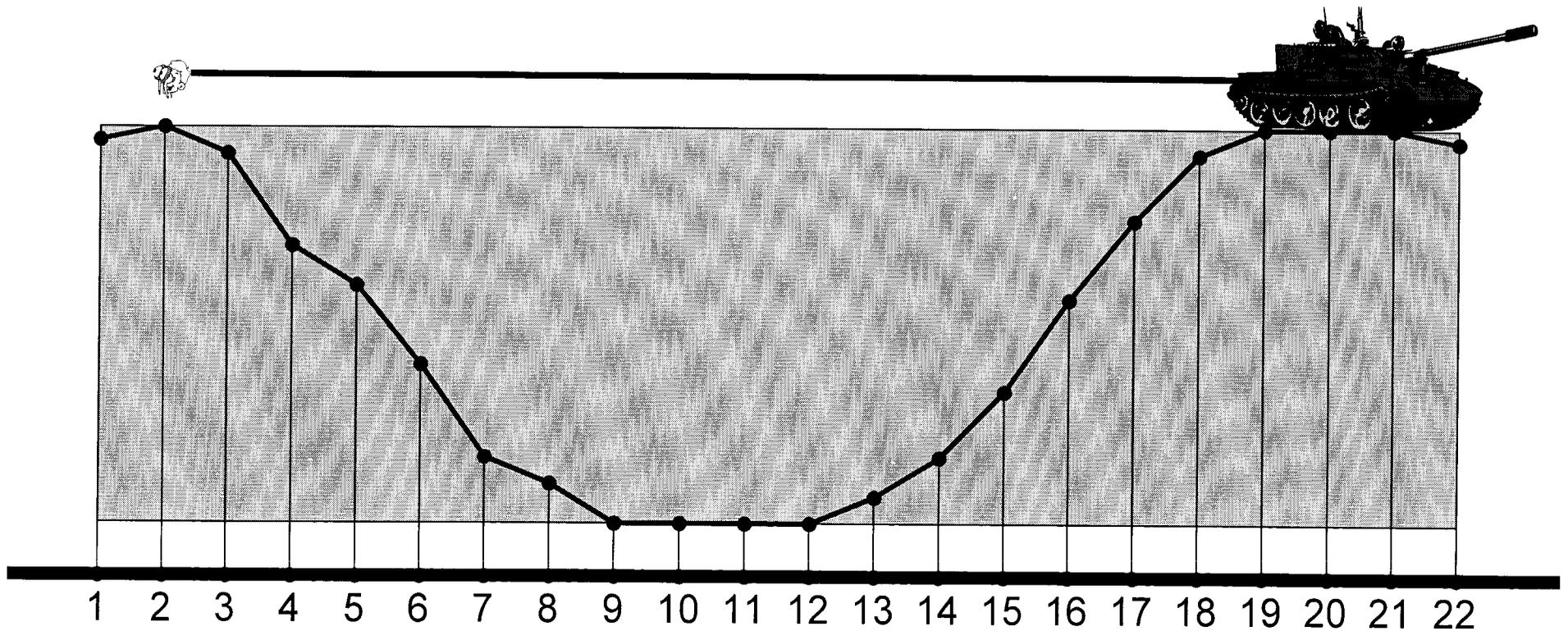


# Consider the following... An Easy Case

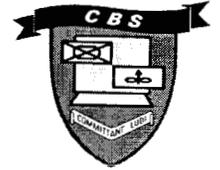


Different terrain: LOS is unobstructed

- 1 box query, still at a distance of 20 posts (about 40 edges)

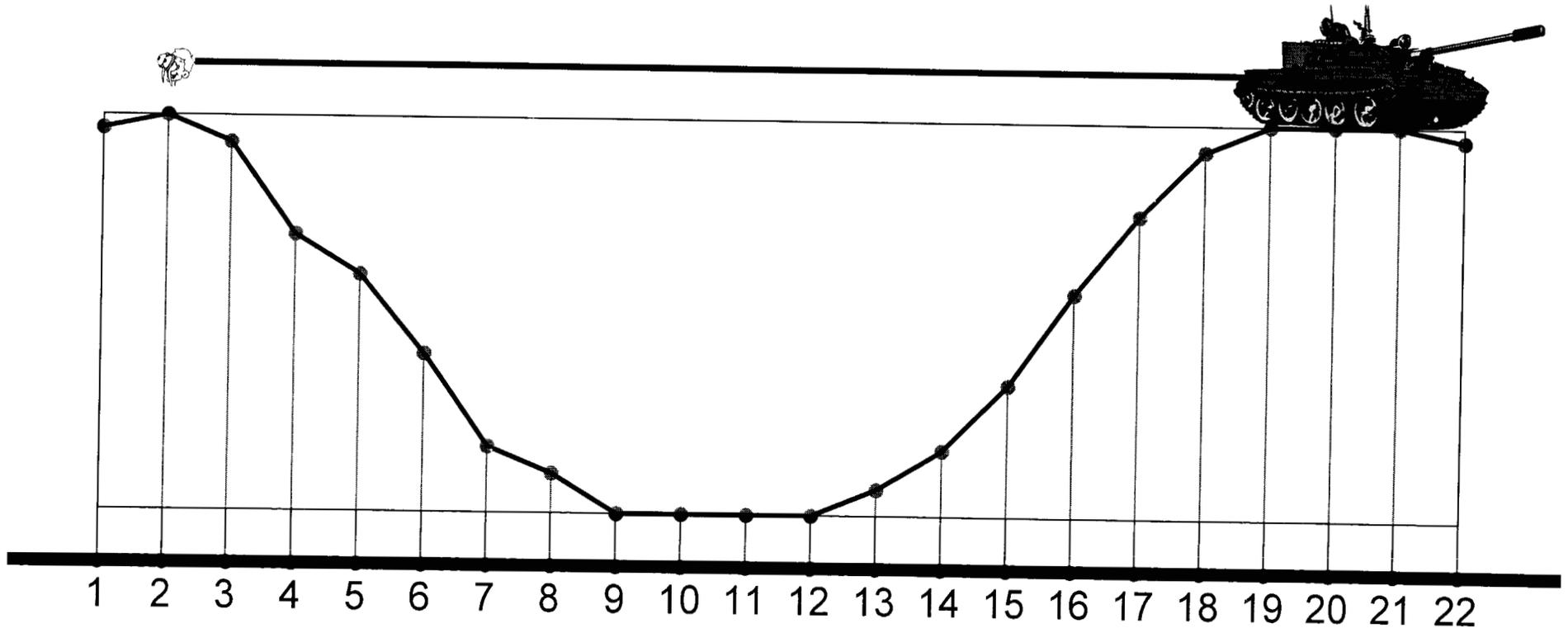


## An Easy Case

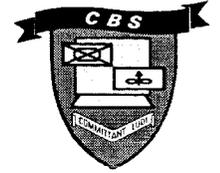


Different terrain: LOS is unobstructed

- 1 box query, still at a distance of 20 posts (about 40 edges)



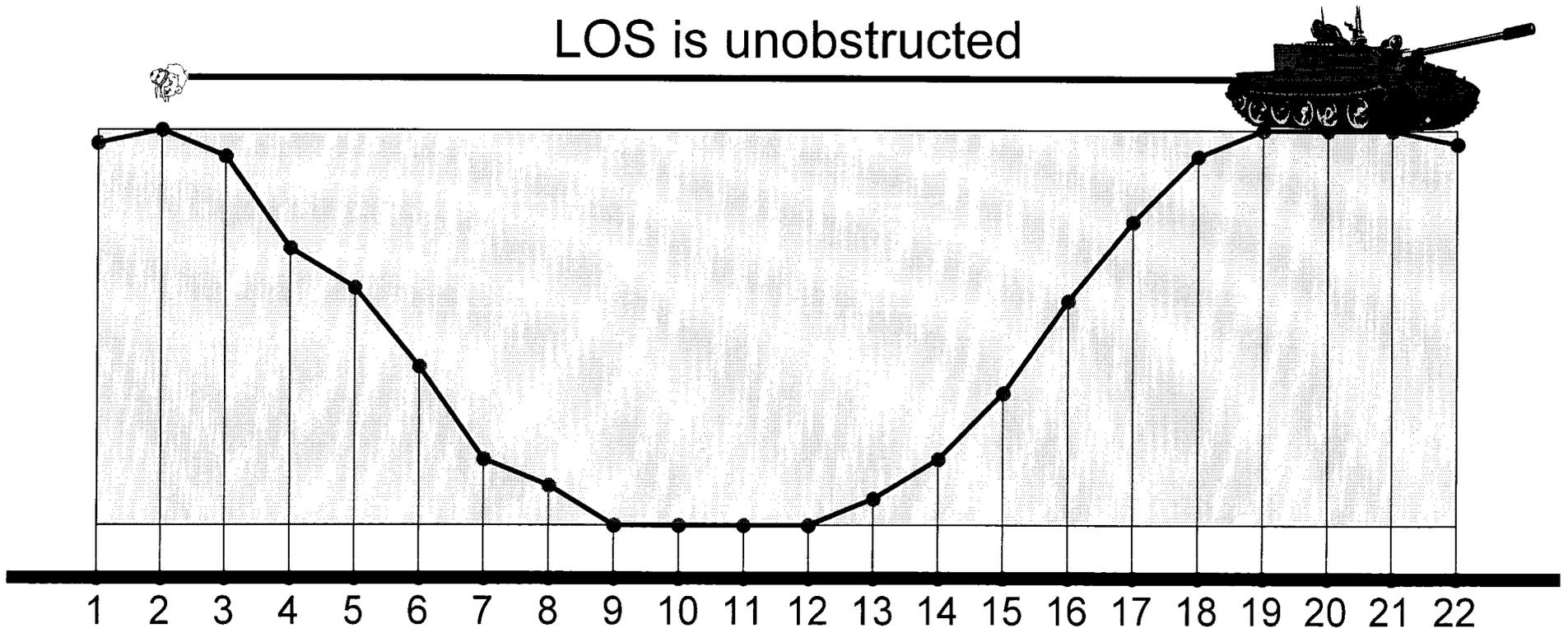
# An Easy Case



Different terrain: LOS is unobstructed

- 1 box query, still at a distance of 20 posts (about 40 edges)

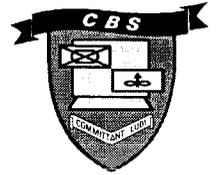
LOS is unobstructed





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**SURF'S UP!**