

Large Aircraft Depaint Manipulator Initiative

Materials and Manufacturing Directorate of the Air Force Research Laboratory

Technology Provider Briefing

Concept Development: Depaint Tools

RoboCrane Platform, Aerial Lift, Micro-Manipulators

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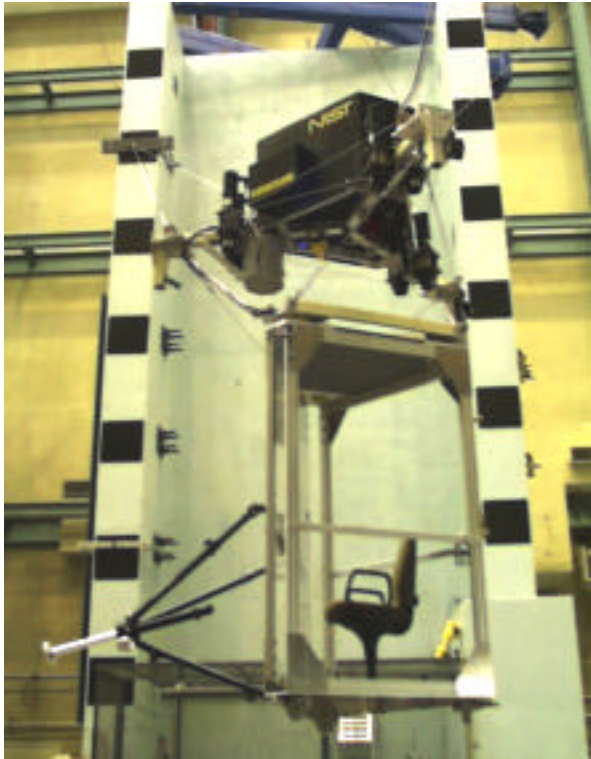


Intelligent Systems Division
National Institute of Standards and Technology



RoboCrane as Personnel Carrier

Macro-Manipulator Concept



See RoboCrane Video

PRO

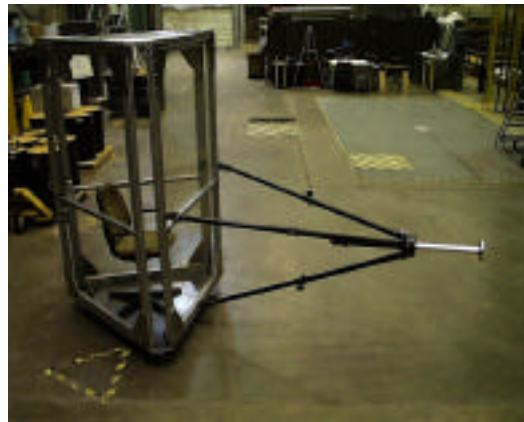
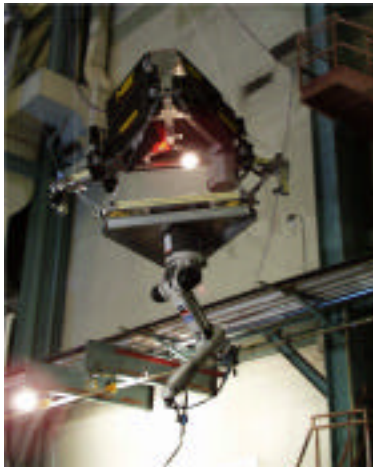
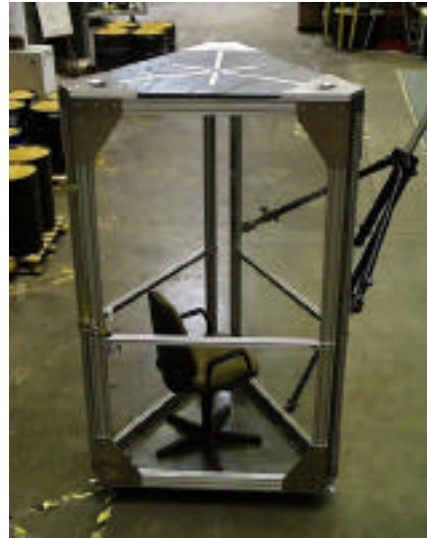
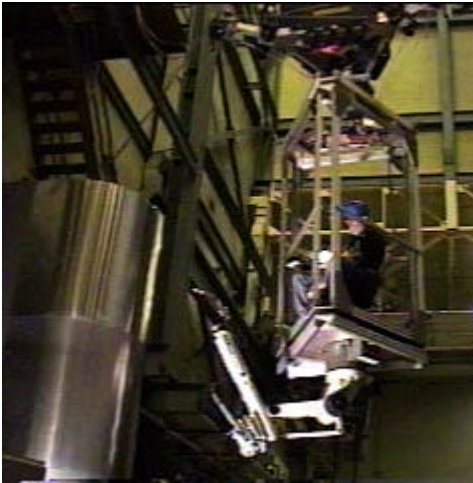
- Modular/Relatively Cheap
- Easily scalable in size, mounting configuration
- High payload/weight ratio
- Full 6 d.o.f. joystick control
- Straight line motion inherent
- Stand-off control and surface following available
- Collision avoidance safeguards available
- Positions personnel without scaffolding or other ground based equipment
- Ideal for masking access to elevated surfaces
- Operator can wield hand tools, wands, inspection equipment, ...
- **Power Failure Mode: No motion**

CON

- Existing technology, but not yet commercially available

RoboCrane with Micro-Manipulator

Macro-Manipulator Concept



PRO

- Same benefits as RoboCrane Personnel Carrier
- Allows ganging of depaint nozzles for more efficient operations (patches or continuous)
- Improves depaint process quality with better control of process parameters (speed, stand-off,...)
- Improved operator ergonomics increase depaint process throughput
- Operator fatigue and repetitive stress injuries vastly reduced
- Can have semi-sealed personnel cab to further improve operator working conditions (visibility, comfort, safety, ...)
- **Power Failure Mode: No motion**

CON

- Existing technology, but not yet commercially available

Aerial Lift as Personnel Carrier

Macro-Manipulator Concept



See NIST/Navy Aerial Lift Video

PRO

- Proven commercial equipment
- Operator familiarity
- Advanced control system coordinates joints
- Intuitive single joystick operation means less reliance on base vehicle to reposition operator
- Cartesian, cylindrical and surface following modes available
- Computer enforced operating limits
- Collision avoidance available
- Leverages Navy sponsored tech development
- Existing demos available
- **Power Failure Mode: No motion**

CON

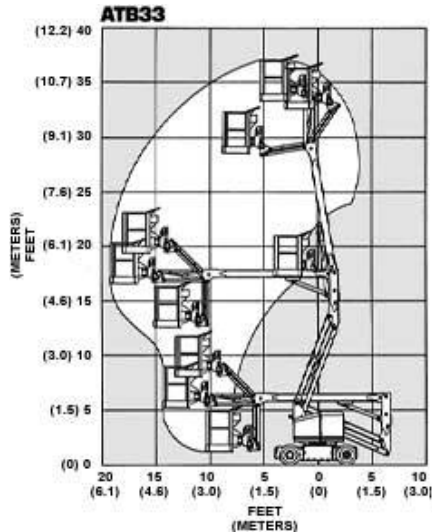
- Bouncy at long reaches
- Must navigate around ground obstacles
- Not designed to be media proof

Aerial Lift with Micro-Manipulator

Macro-Manipulator Concept



**TRIPOD
MANIPULATOR
WITH GANGED
NOZZLES**



PRO

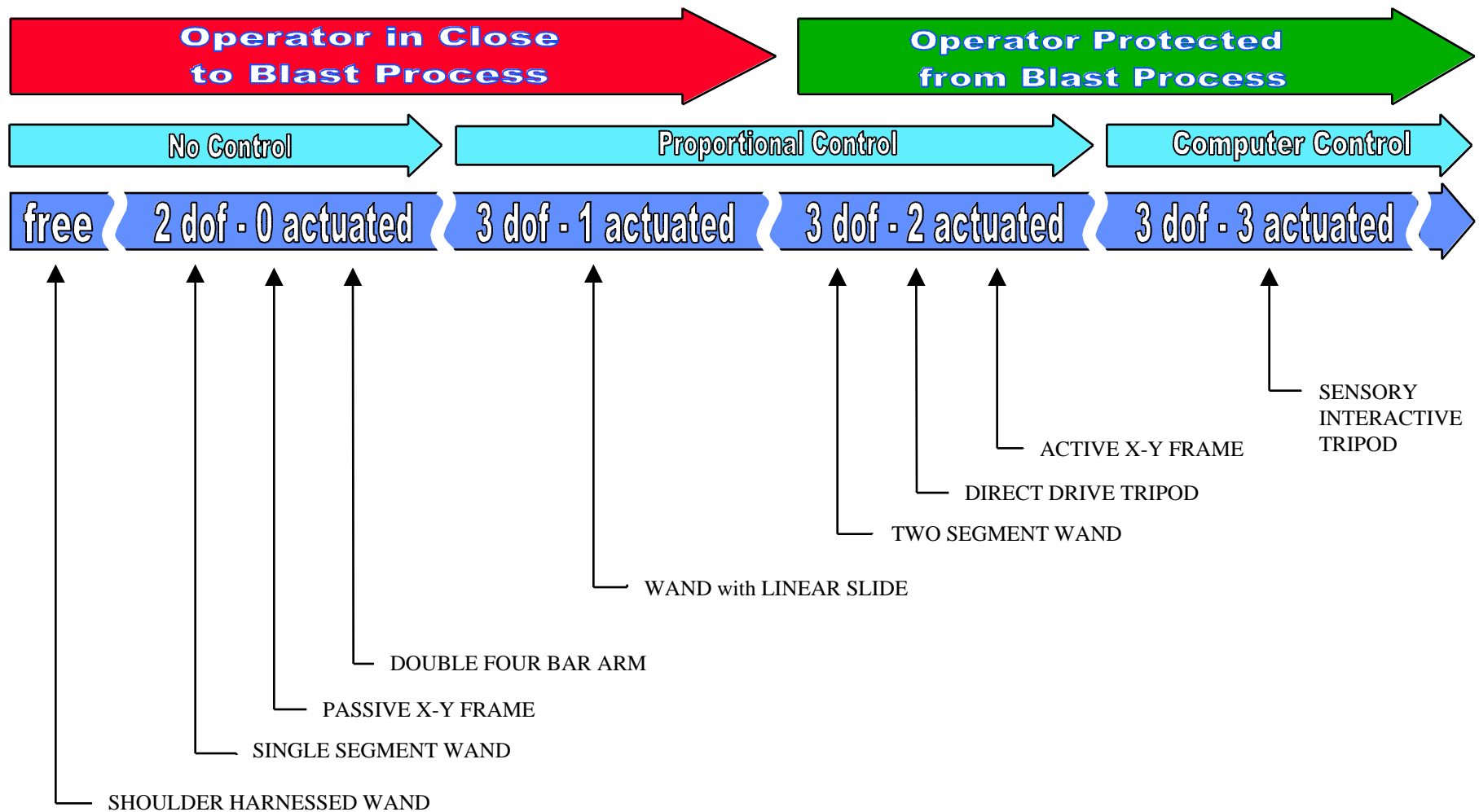
- Same benefits as Aerial Lift as Personnel Carrier
- Allows ganging of depaint nozzles for more efficient operations (patches or continuous)
- Improves depaint process quality with better control of process parameters (speed, stand-off,...)
- Improved operator ergonomics increase depaint process throughput
- Operator fatigue and repetitive stress injuries vastly reduced
- Can have semi-sealed personnel cab integrated into existing bucket to further improve operator working conditions (visibility, comfort, safety, ...)
- **Power Failure Mode: No motion**

CON

- Bouncy at long reaches
- Must navigate around ground obstacles
- Not designed to be media proof
- System complexity

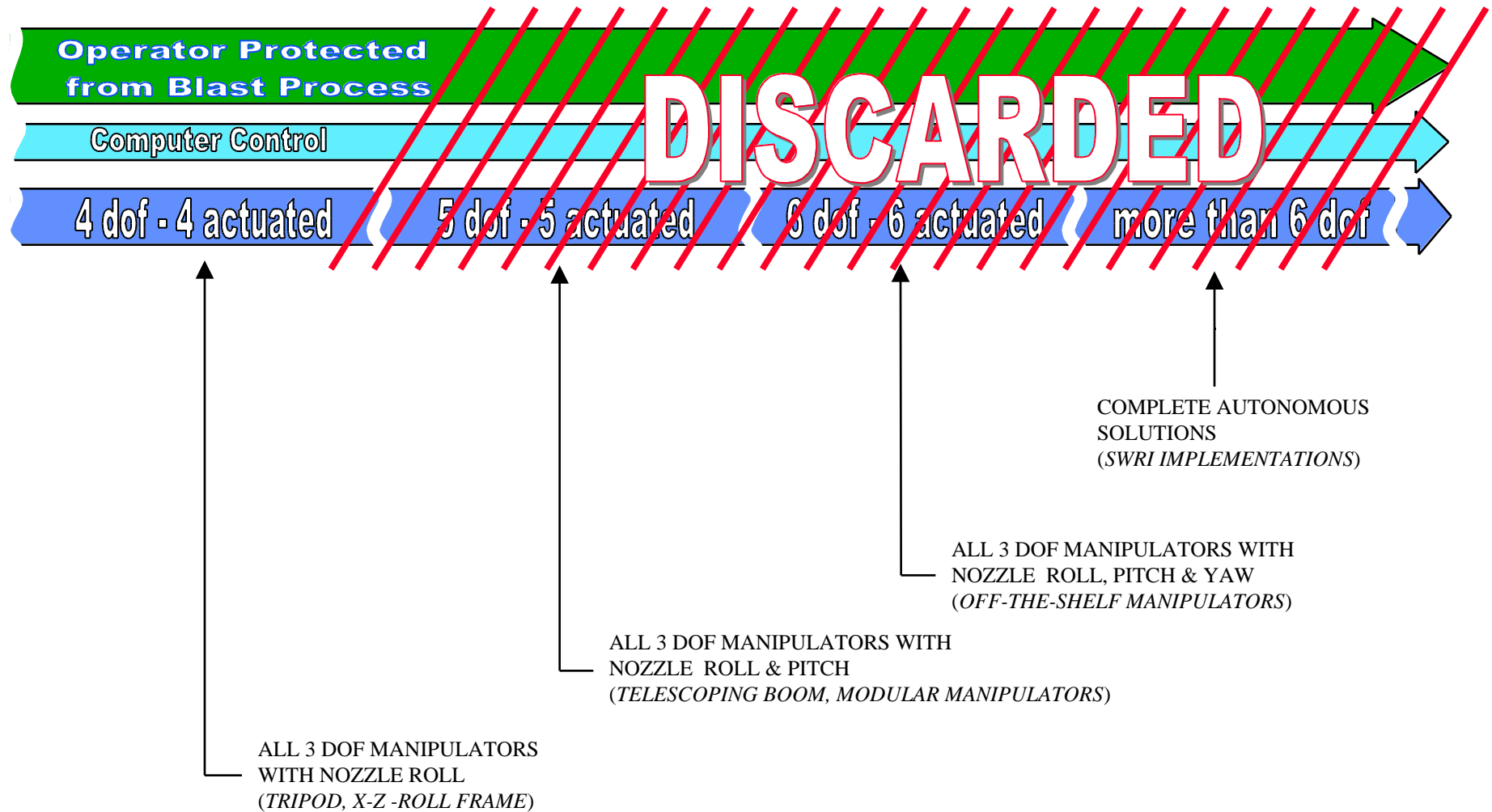
Spectrum of Micro-Manipulator Options

Degrees of Freedom: 0 - 3



Spectrum of Micro-Manipulator Options

Degrees of Freedom: 4 - 6 (and beyond)



Manual Positioners

Micro-Manipulator Concept



PRO

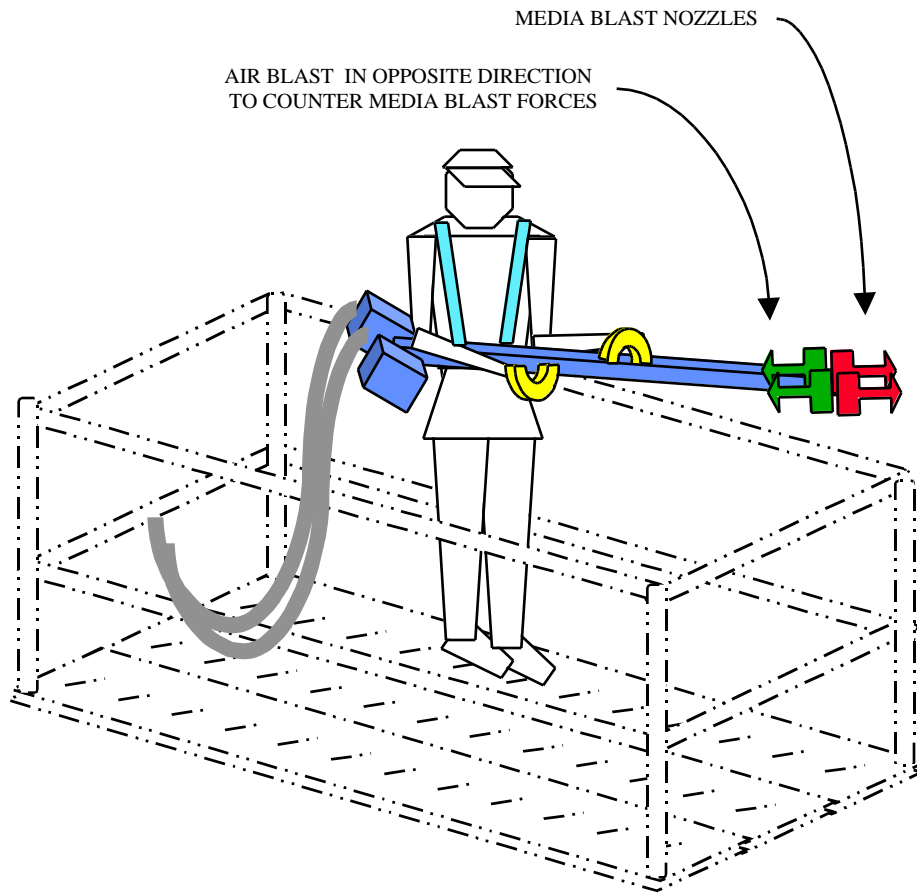
- Simple/Cheap/Reliable
- Provides gravity compensation for heavy tools
- Intuitively positioned by operator (manually)

CON

- Mechanisms only compensate for gravity
- Ganged nozzles require reaction force compensation by mechanism
- Can not compensate for nozzle reaction forces
- Forces must be directed through joint at base to avoid causing moment (motion)
- Mechanisms have considerable inertia which may generate fatigue or collision

Manual Positioners

Shoulder Harnessed Wand



PRO

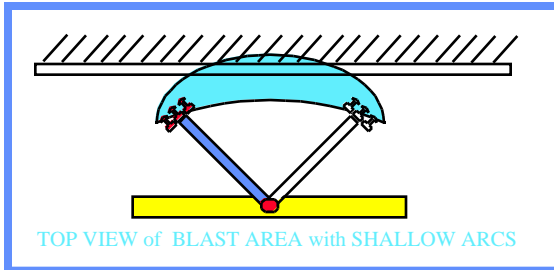
- Intuitive to use, based on weed whacker model
- Can go anywhere current wands go

CON

- Air blast to counter media nozzle reaction forces is completely experimental
- Operator fatigue
- Not practical for more than two ganged nozzles

Manual Positioners

Single Segment Wand



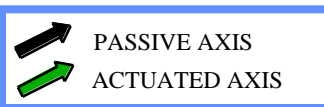
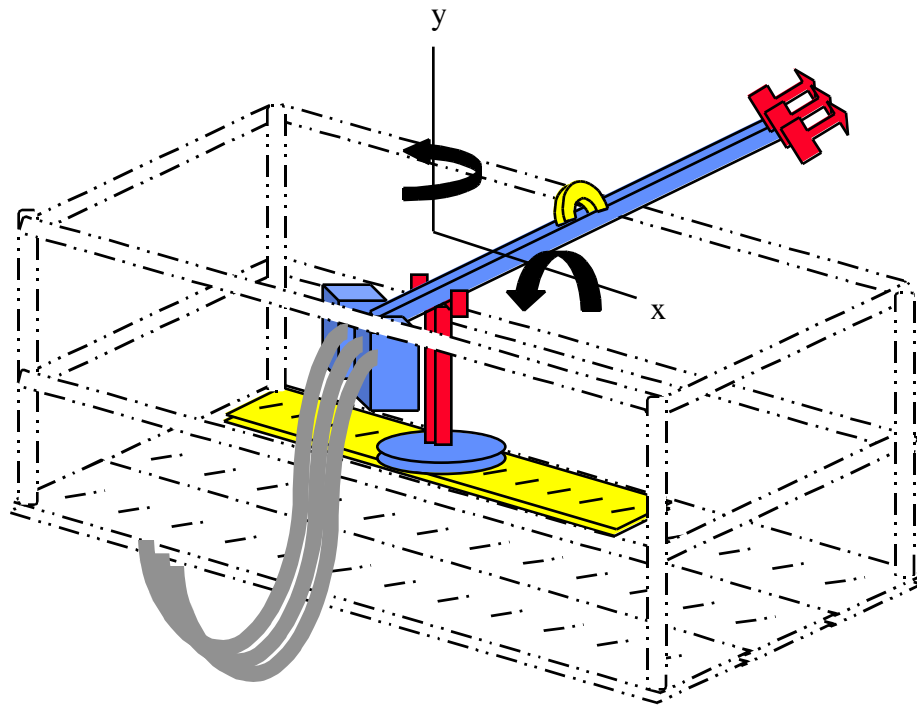
Degrees of Freedom: 2 Actuated Axes: 0

PRO

- Single (straight or bent) arm pivots at universal joint in rear
- Passively counterweighted for gravity
- All reaction forces directed through joint
- Workvolume can be improved with addition of indexable linear slide

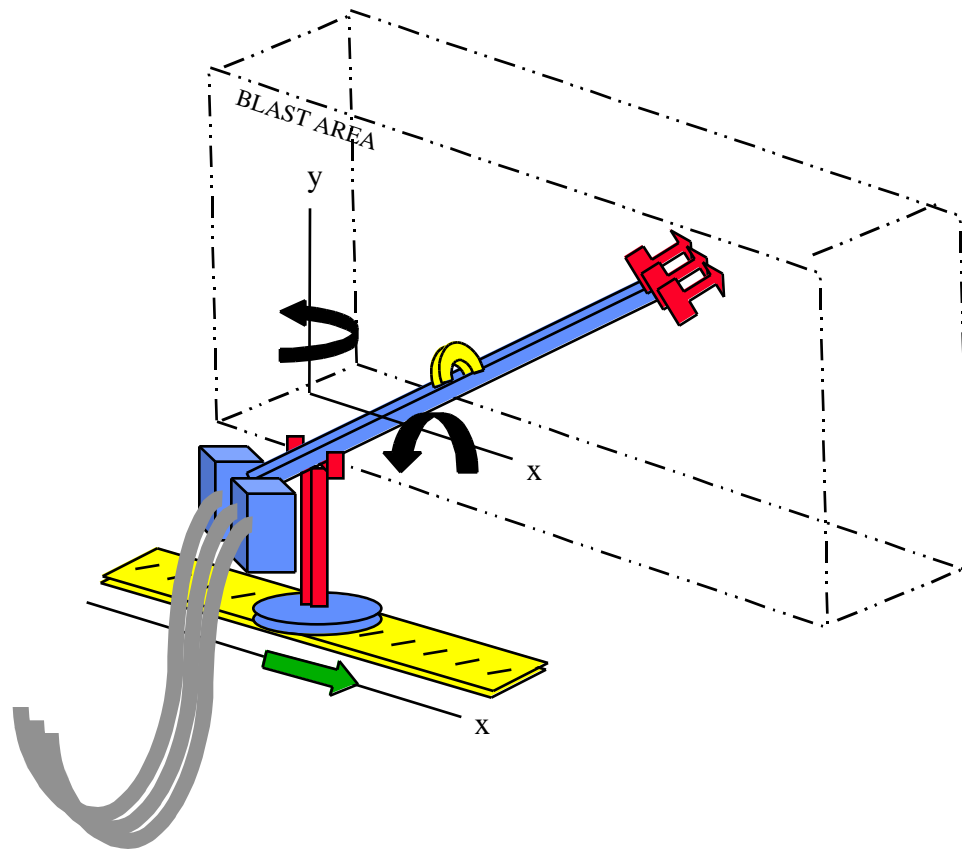
CON

- X, Y motions form arcs
- Arc motions constrain nozzle angles
- Stand-off distance impossible to maintain
- Counterweights increase inertia, add to fatigue
- Relatively small workvolume



Manual Positioners

Single Segment Wand (with horizontal linear slide)



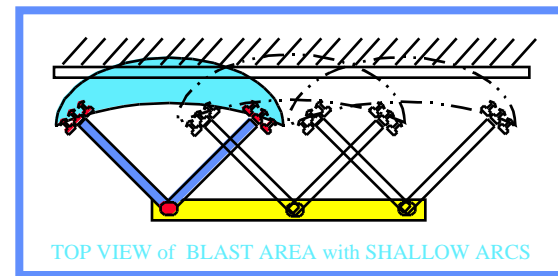
Degrees of Freedom: 3 Actuated Axes: 0 or 1

PRO

- Linear slide increases workvolume over Single Segment Wand
- Slide can be indexable or actuated

CON

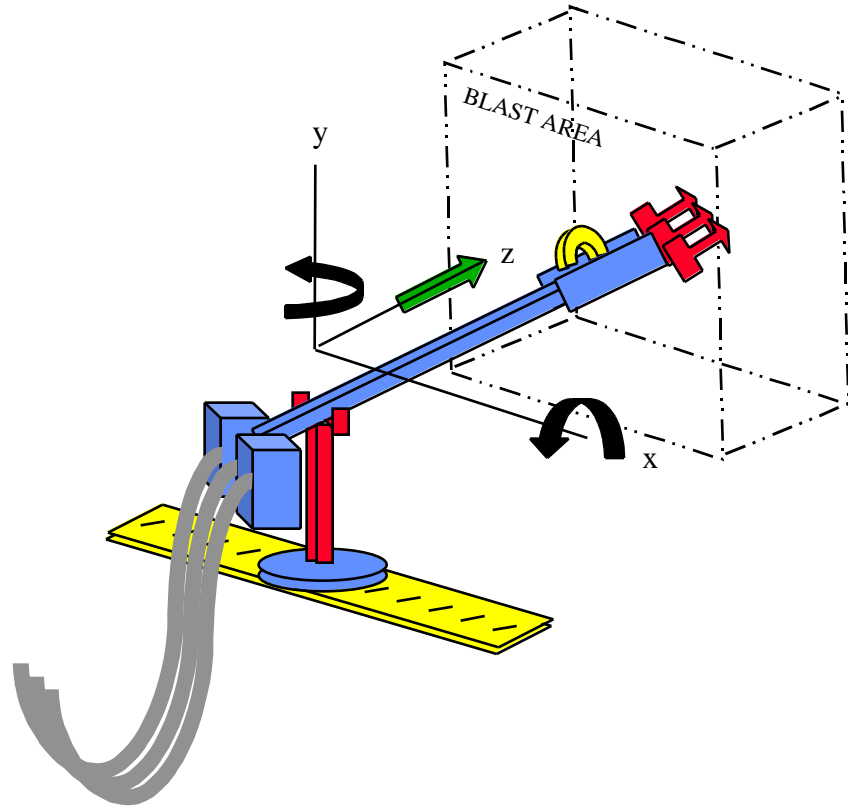
- Linear slide cannot be passive due to variable direction of nozzle reaction forces



➡ PASSIVE AXIS
➡ ACTUATED AXIS

Manual Positioners

Single Segment Wand (with telescoping reach)



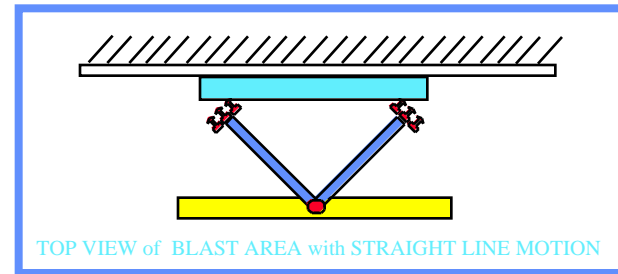
Degrees of Freedom: 3 Actuated Axes: 1

PRO

- Telescoping reach allows straight line motion of blast nozzles
- Work volume can be further improved by adding a linear slide

CON

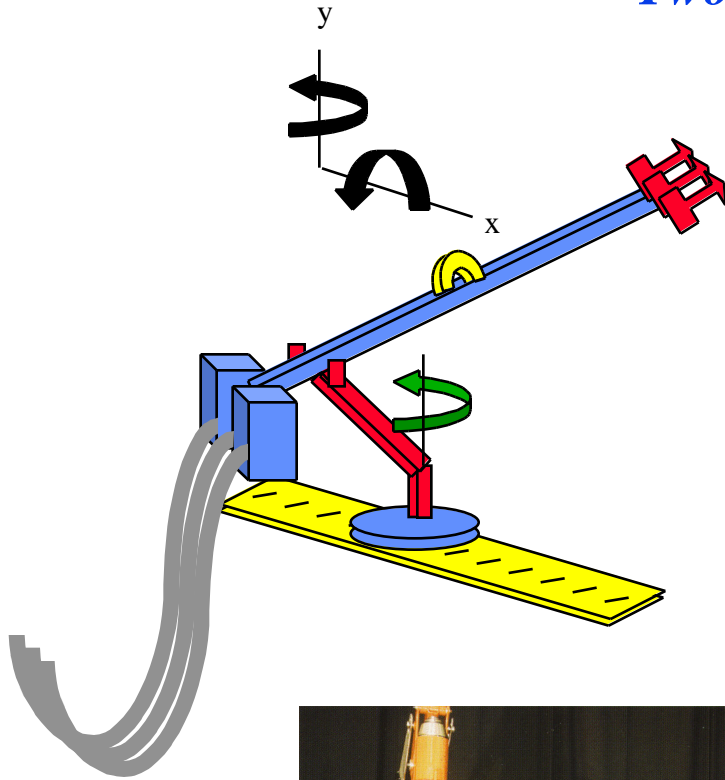
- Telescoping reach cannot be passive due to nozzle reaction forces



➔ PASSIVE AXIS
➔ ACTUATED AXIS

Manual Positioners

Two Segment Wand



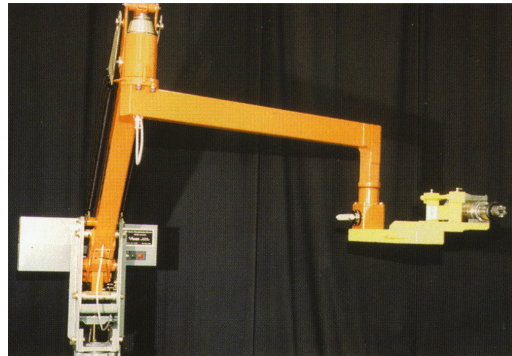
Degrees of Freedom: 3 Actuated Axes: 1



PRO

- Two (straight or bent) arms allows greater and more intuitive workvolume
- Straight line motion possible
- Stand-off distance maintainable
- Still passively counterweighted for gravity
- Workvolume can be further improved with addition of indexable linear slide

CON

- Arc motions effect nozzle angles
- Counterweights increase inertia, add to fatigue
- Workvolume is limited



 PASSIVE AXIS
 ACTUATED AXIS

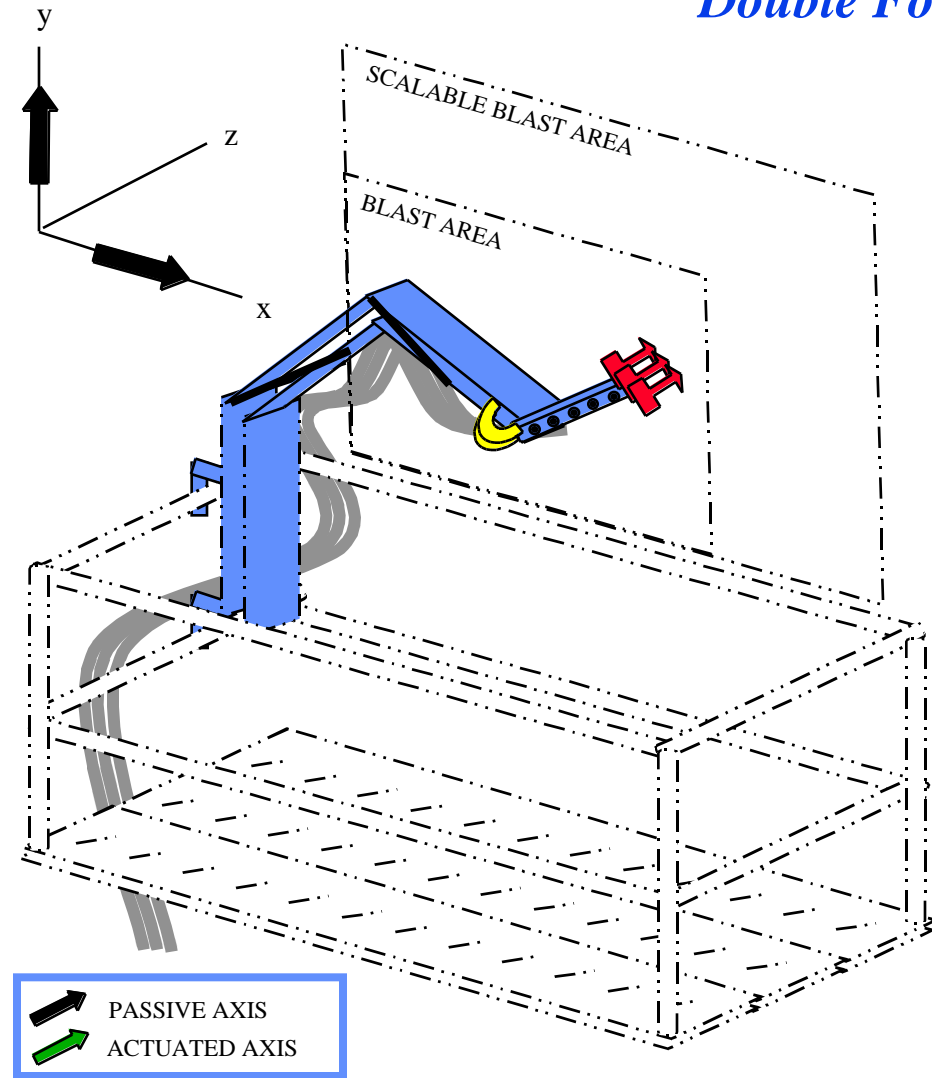
Manual Positioners

Double Four Bar Arm

Degrees of Freedom: 2 Actuated Axes: 0

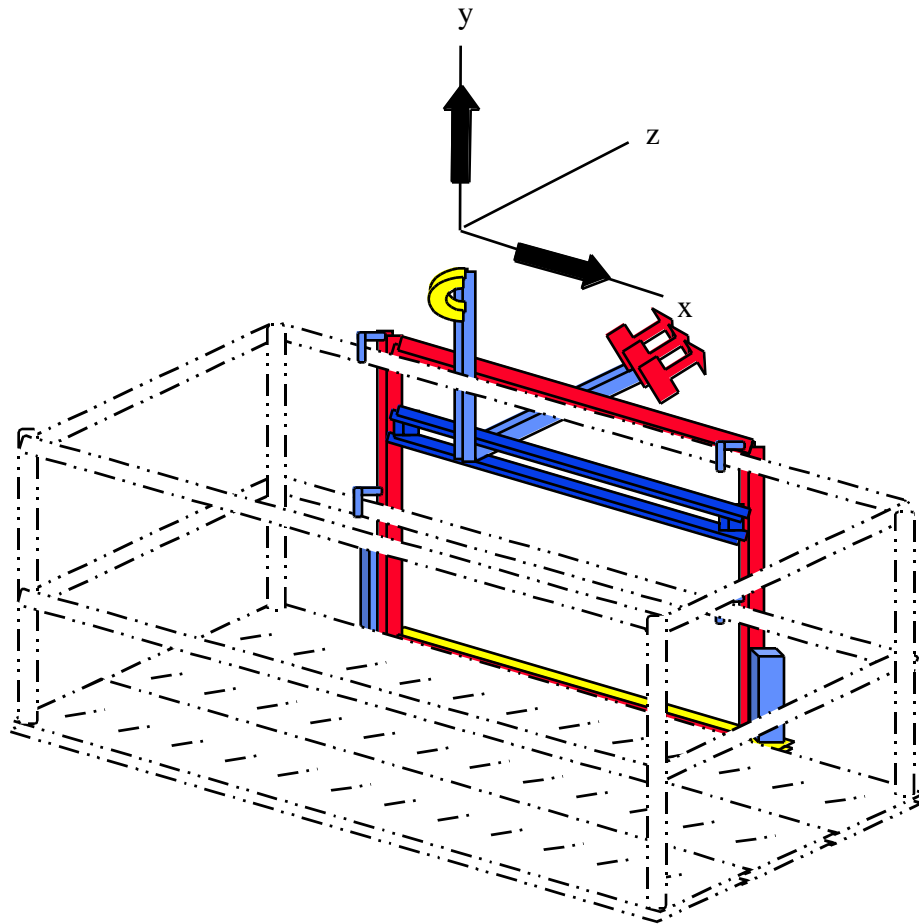
PRO

- Intuitive straight line motions in x-y plane
- Stand-off distance maintainable and indexable
- Passively compensated for gravity
- Attaches to RoboCrane or Aerial Lift basket
- Scalable configuration and reversible mounting
- Upgradable to actuated system with master/slave or joystick input
- Based on commercial equipment



Manual Positioners

Passive X-Y Frame



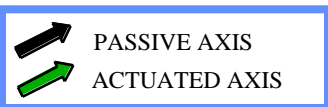
Degrees of Freedom: 2 Actuated Axes: 0

PRO

- Intuitive straight line motions in x-y plane
- Stand-off distance maintainable and indexable
- Passively counterweighted for gravity
- Attached to RoboCrane or Aerial Lift basket
- X-Y frame is below operator line of site
- Upgradable to actuated system with master/slave or joystick input
- Based on existing equipment

CON

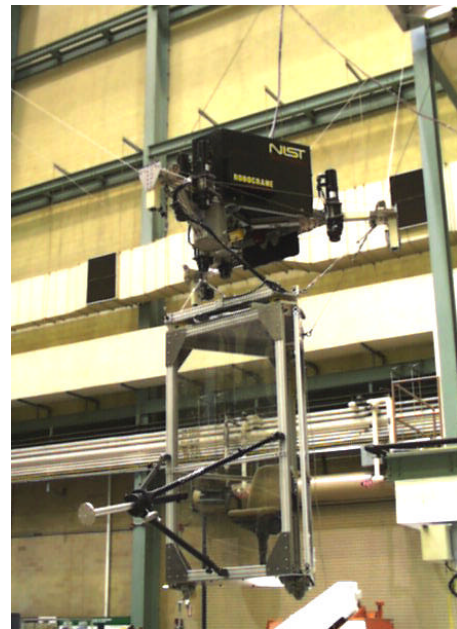
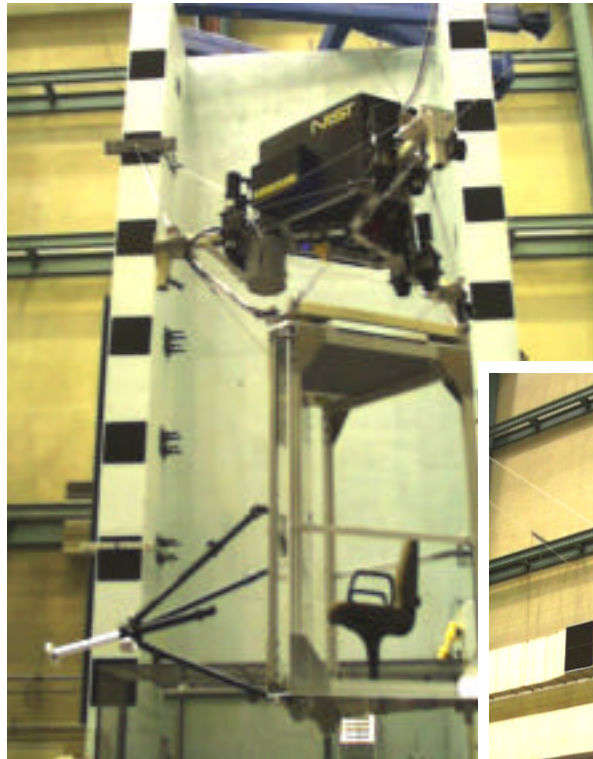
- Larger structure than arm based approaches



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Static, Reconfigurable Tripod (No Control)

Micro-Manipulator Concept



PRO

- Extremely Simple/Cheap/Modular/Reliable
- Easily scalable in size to long reaches
- High payload/weight ratio
- Extremely rigid configuration
- Allows simple tool stand-off in front of personnel cab
- Easily reconfigurable to allow assorted tool positions and orientations

CON

- No independent motion, all process motion must derive from macro-manipulator (no patches)

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Joystick Controlled Tripod (Direct Control)

Micro-Manipulator Concept



Degrees of Freedom: 2 Actuated Axes: 2

PRO

- Simple/Cheap/Modular/Reliable
- Easily scalable in size with same actuators
- High payload/weight ratio
- Extremely rigid configuration
- Configurable for both aerial and floor versions
- Intuitive joystick control
- No sensors or computer
- Electric, pneumatic, or hydraulic actuation
- Nozzle orientation control optional
- **Power Failure Mode: No motion**

CON

- Smaller workvolume than fully controlled tripod
- No straight line motion (shallow arcs)
- No collision avoidance or standoff control
- No operator assist modes available
- Not commercial (\$50K prototype, \$25K production)

Recommendation:

Best low cost, low tech, high reliability solution.

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Joystick Controlled Tripod (Sensory Interactive)

Micro-Manipulator Concept



Recommendation:

*Best low cost,
modest tech,
high performance
solution.*

Degrees of Freedom: 3 Actuated Axes: 3

PRO

- Modular/Relatively Cheap/Reliable
- Easily scalable in size with same actuators
- High payload/weight ratio
- Extremely rigid configuration
- Configurable for both aerial and floor versions
- Intuitive joystick control
- Straight line motion inherent
- Stand-off control and surface following available
- Collision avoidance and anti-dwell safeguards
- Other operator assist modes available (velocity, nozzle direction, indexing, rastering...)

- Nozzle orientation control available
- **Power Failure Mode: No motion**

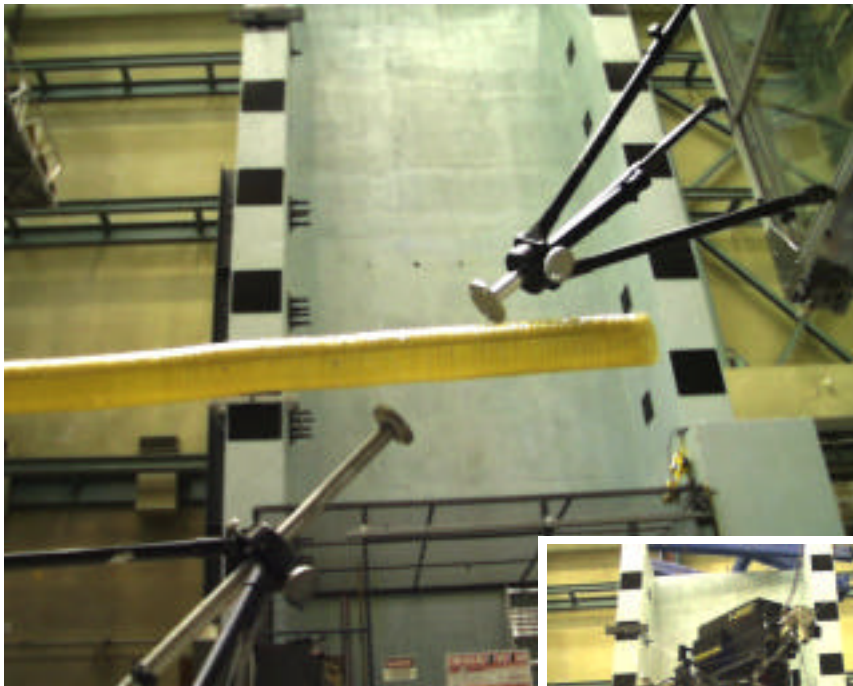
CON

- Computer and sensors required
- Not commercial (\$90K prototype, \$45K production)

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Personnel Cab/Tripod Modularity

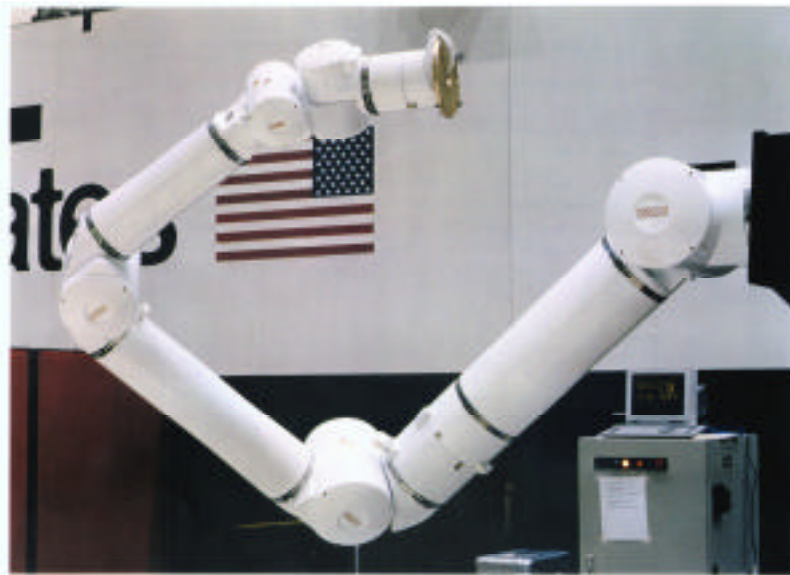
Same Components, Multiple Uses



- Entire system deployed from:
 - *Above:* RoboCrane
 - *Ground:* Commercial, maneuverable ground vehicle (with or without lift capability)
 - *Ground:* Manually positioned cart (casters and stabilizers)
- Tripod mount to personnel cab configurations:
 - Lower front of cab for under fuselage
 - Upper front of cab for mid fuselage
 - Bottom of cab for top fuselage
 - Top of cab for under wing
- Operator enhancements:
 - Intuitive joystick control
 - Improved process control
 - Better ergonomics limit fatigue/injuries
- Enclosed personnel cab improves:
 - Breathing (forced fresh air, filters)
 - Visibility (no hood)
 - Comfort (limited protective clothing)
 - Safety (belted into seat)

Commercial Manipulator: Torque Control

Micro-Manipulator Concept



ROBOTICS
RESEARCH

SAT-1 Servicing Aid Tool

PRO

- Existing, low risk, commercial technology
- Gravity compensation mode makes arm compliant to touch anywhere on the arm
- High dexterity
- Intuitive joystick control
- Straight line motion inherent
- Nozzle orientation control inherent
- Stand-off control and surface following available
- **Power Failure Mode: No motion**

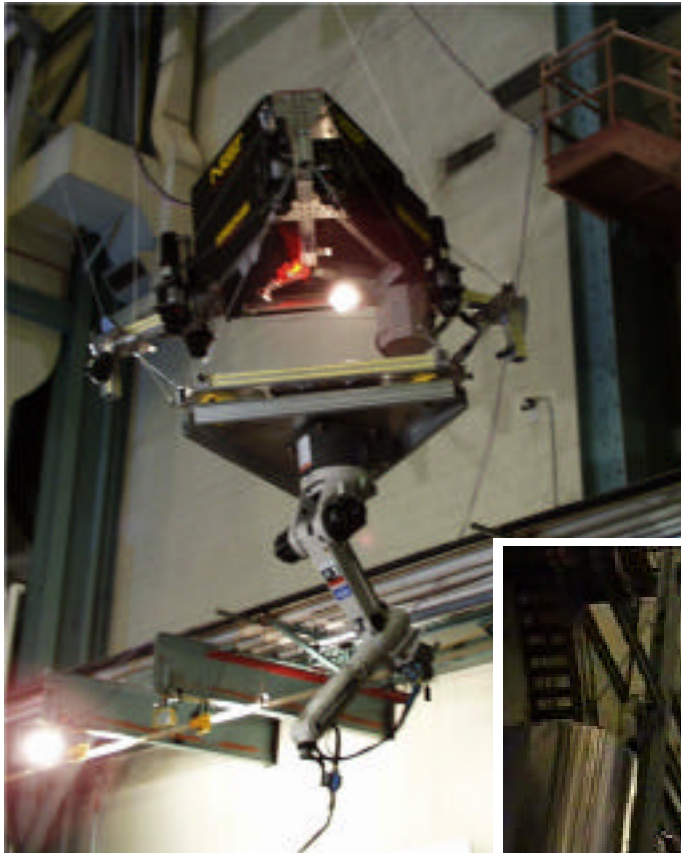
CON

- Expensive: \$200K
- Computer and sensors required
- Low payload/weight ratio
- Not scalable or reconfigurable

See RRC Video

Commercial Manipulator: Conventional Control

Micro-Manipulator Concept



PRO

- Existing, low risk, commercial technology
- Intuitive joystick control
- Straight line motion inherent
- Nozzle orientation control inherent
- Stand-off control and surface following available
- **Power Failure Mode: No motion**

CON

- Relatively expensive: \$90K
- Computer and sensors required
- Low payload/weight ratio
- Not scalable or reconfigurable

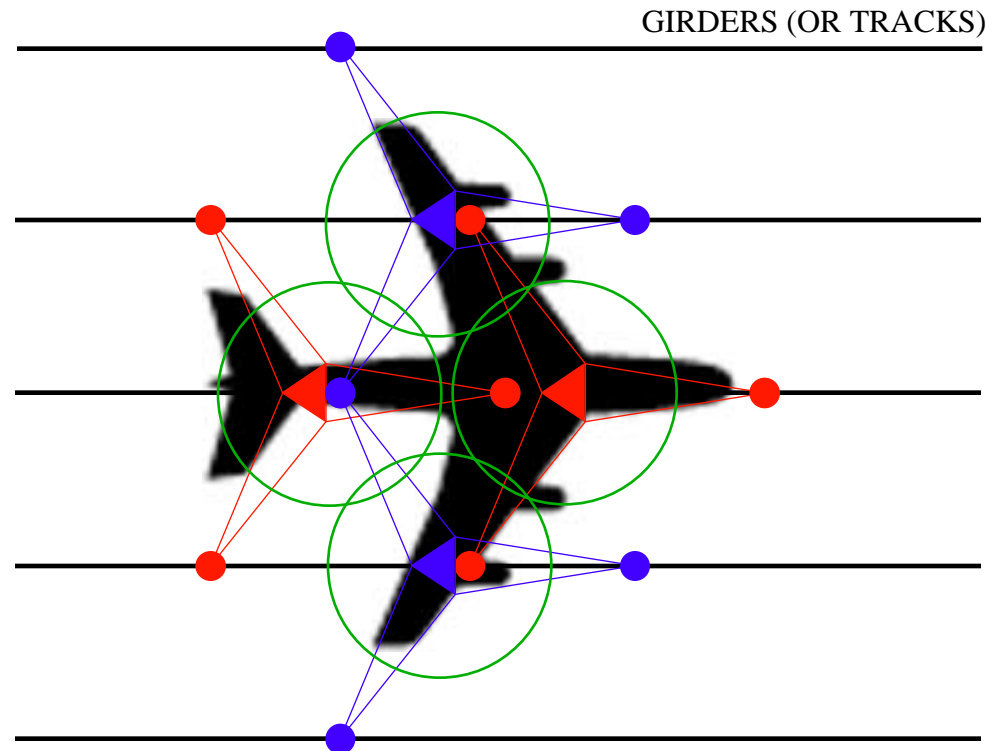
Additional RoboCrane Slides



Facility Mounted RoboCrane

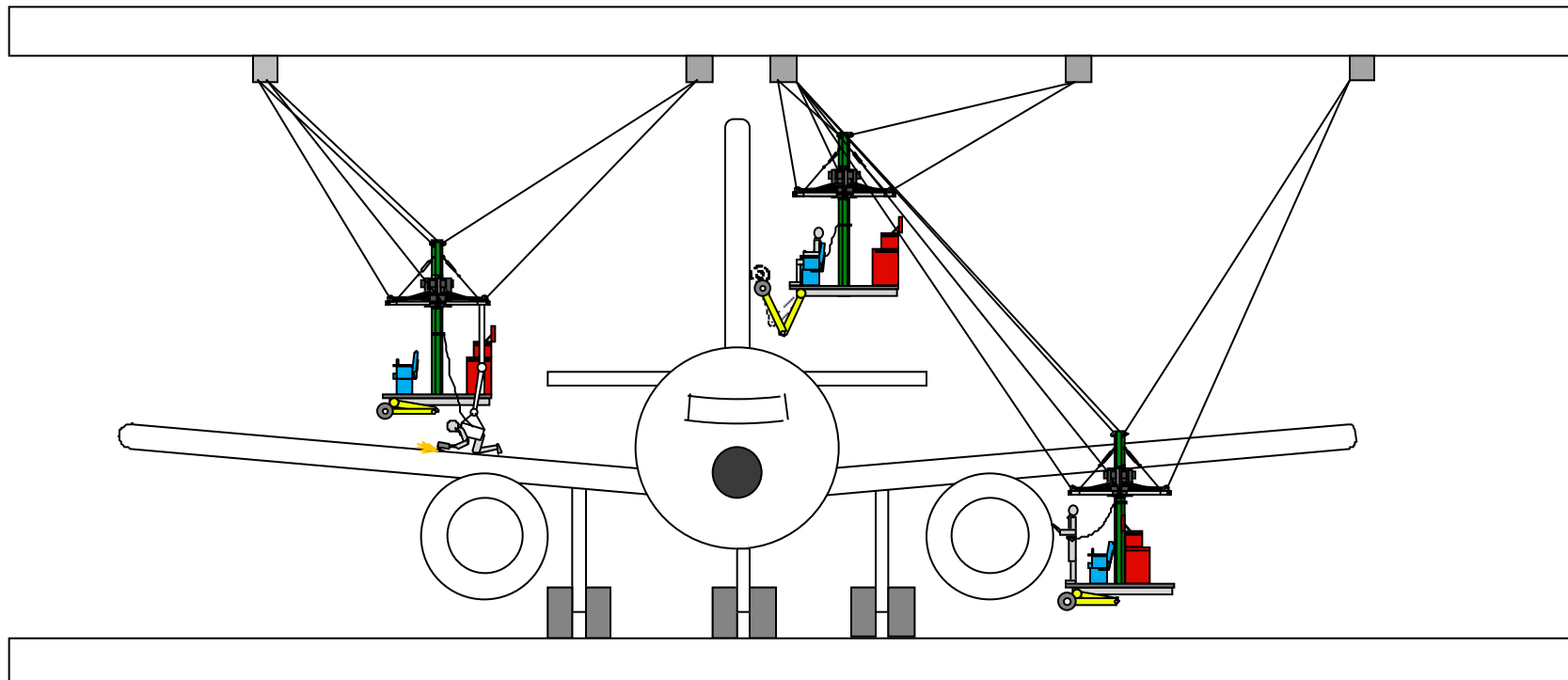
Proposed Hangar Configuration

- Mounting to ceiling
 - Simple girder clamps work well
 - Several interleaved platforms
 - Static mounting points are configured for aircraft position
 - Systematic mounting points may cover multiple aircraft placements
 - Tracks allow sliding and nesting of work volumes - max flexibility
- Scalable paradigm
 - Pattern can be repeated in all directions for larger facilities
 - Relative positions can vary from sparse to dense



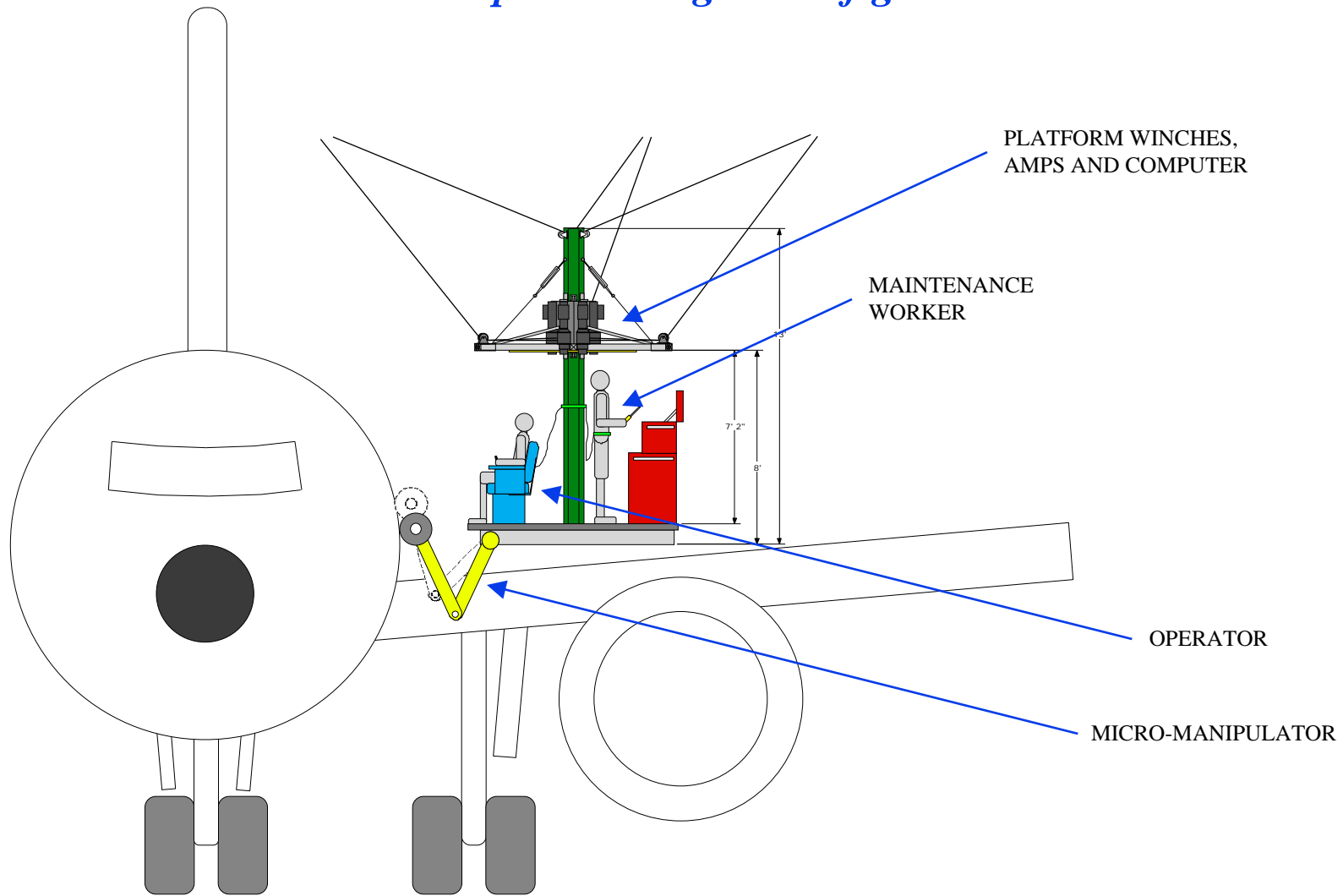
Facility Mounted RoboCrane

Proposed Hangar Configuration



Facility Mounted RoboCrane

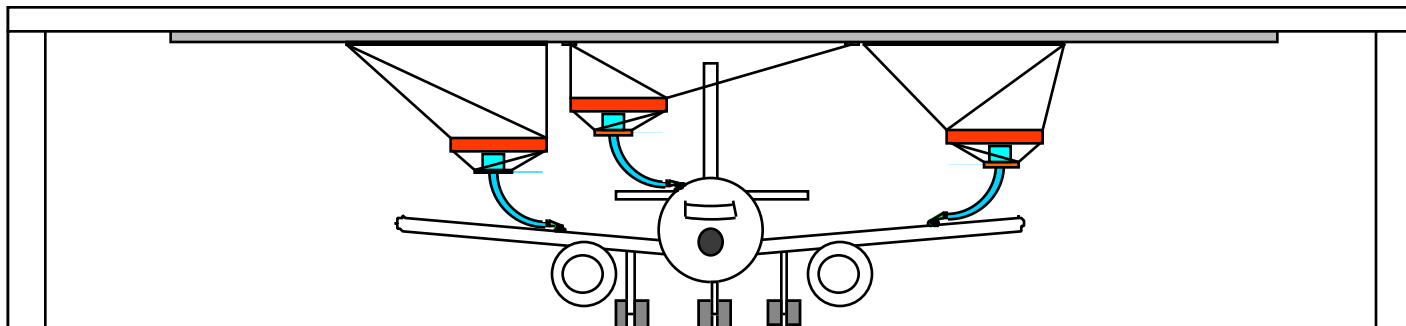
Proposed Hangar Configuration



Facility Mounted RoboCrane

Proposed Hangar Configuration

- RoboCrane deploys
 - Personnel (*for tasks such as masking, inspection, hand tools*)
 - Manipulators (*for washing and depainting*)
 - Cargo (*such as engines and cargo doors for large scale assembly*)
- Collision avoidance capabilities
 - Proximity sensor integration into controller prevents collisions
 - Tension controlled cables provide early warning of contact (shutdown)
 - Suspended platform naturally gives way if collision occurs



Phase I Demo Slides



Intended Demo Scenario

Targeted Surfaces of Aircraft

- **RoboCrane** (with and without micro manipulators) intended to access large upper surfaces of airframe
- **Aerial Lift** (with and without micro-manipulators) intended to access large lower surfaces including under wings
- **Tripod** and **Wand** manipulators will be investigated to access underside of fuselage
- Manual methods will be used to perform detail work and around obstacles

