*zero*G® Mobility Study

Boeing & Ford Joint Project:

Phases 1&2 Brief

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Background

- Boeing and the Ford Motor companies partnered with Equipois to explore the potential to put a user wearable version of the zeroG tool support system into use for production assembly operations.

- The entertainment industry has been using Steadicam Arms as a game changing camera platform since the 1980's. The offshoot Equipois zeroG arm is established as a tool holding variant for industrial applications with fixed mounts within the production environment.

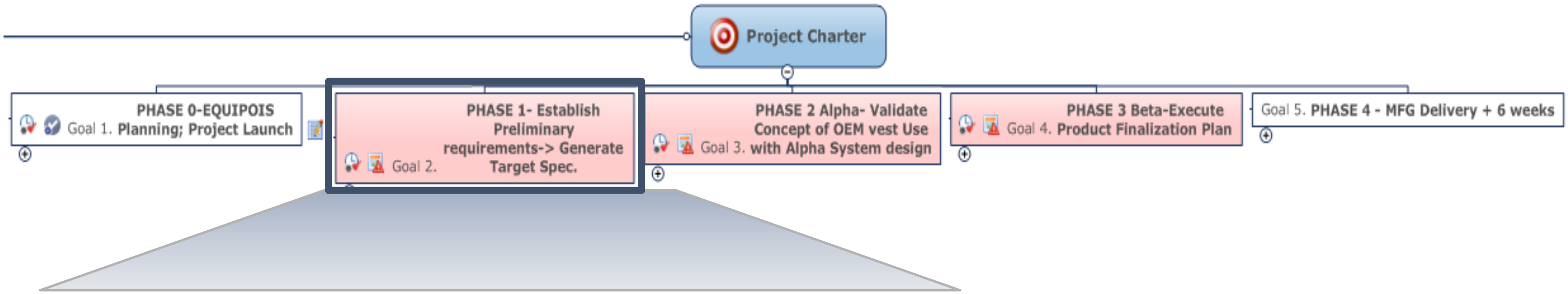
- Steadicam vs. Industrial use:
  The use of body worn arm systems is well established for dedicated owner / operators in film production. The same cannot be said for the industrial manufacturing demographic.

criteria	Steadicam	Industrial
Payload	30-75 lbs	3-25 lbs
Duration (avg.)	5-10 mins.	Continuous
Operator training / skill	extensive	minimal
Work Environment	variable	controlled
Operator hourly wage	$12- $35	$80- $250

Project Description:

- **Opportunity:**
  - Problem: Injury risk caused by holding light tools overhead or at chest level
  - A solution may exist in the form of a low cost, small development project that brings a system to bear for broad industrial use.
- **Provide a wearable means of supporting light tools for chest level and overhead work, ideally by utilizing OEM equipment with appropriate modification. The objectives of the project are:**
  - To establish safe payload and moment loading standards for torso mounted zeroG® exoskeletal support systems and provide insights into future requirements for alternative mounting systems that may enable use for higher load scenarios.
  - To establish usability requirements for a versatile general purpose platform and identify key performance criteria and essential features for future system differentiation.
  - To leverage existing OEM equipment in order to rapidly develop a low cost Beta system for field testing and evaluation that will lead to a unique production zeroG® system for automotive and aerospace assembly and production operations.

Project Design: Phase 1



Phase One:

- Establish Preliminary requirements
- Generate Target Specification

ACTIVITIES:

- Preliminary concept design and prototyping
- Initial OEM Vest Assessment
- Test Fixture design and fabrication
- Identify target applications

Outcomes:

- Payloads between 5-20 lbs
- OEM vest(s) identified and evaluated. Vest performance found to be foundational to usability
- zeroG2 Arm platform + Standard tool holding gimbals
- Shoulder height and above applications; ie: Under body / under wing fastening, assembly and finishing operations
- Test fixture used as control for vest and ergonomic testing validation

Phase 2: OEM Vests

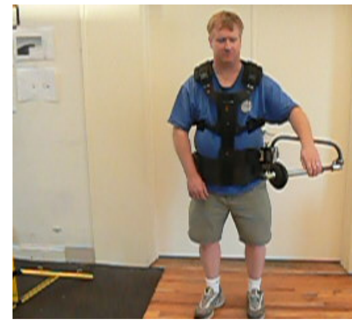
- Initial OEM vest selection *
  - Three chosen for evaluation reflecting a range of price points, features and front & back mounting configurations.

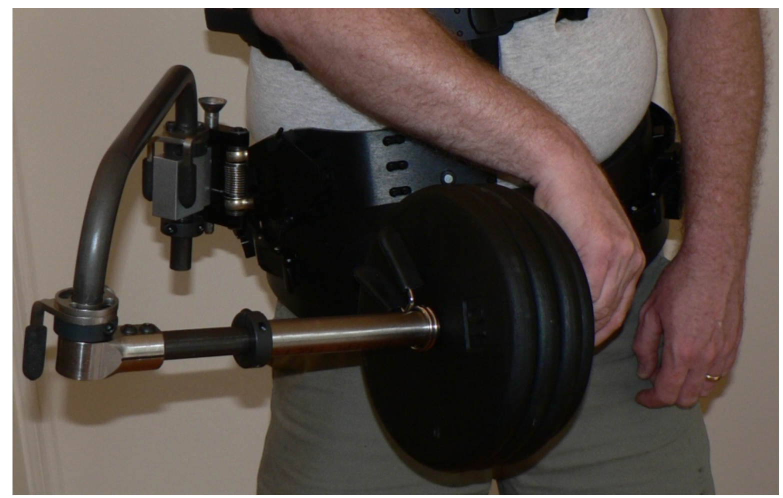
mfg	model	Mount type	Retail Price	Notes
Sachtler	Artemis	Back	$1200	Back Mount has useful vertical Height adjustment. Potentially less lateral stability. May be less comfortable for Women
Steadicam	Zephyr	Front	$2995*	Both Steadicam items secure more snugly to torso, so improved lateral fit. Has more points of adjustment, May be hotter. Better fit for most women.
Steadicam	LX	Front	$3995*	A bit more padding , improved comfort. Should be better for longer durations.

***ExoVest**: A fourth candidate, still under development emerged midway through the project. This vest appeared at this stage to perform better then all others currently available.

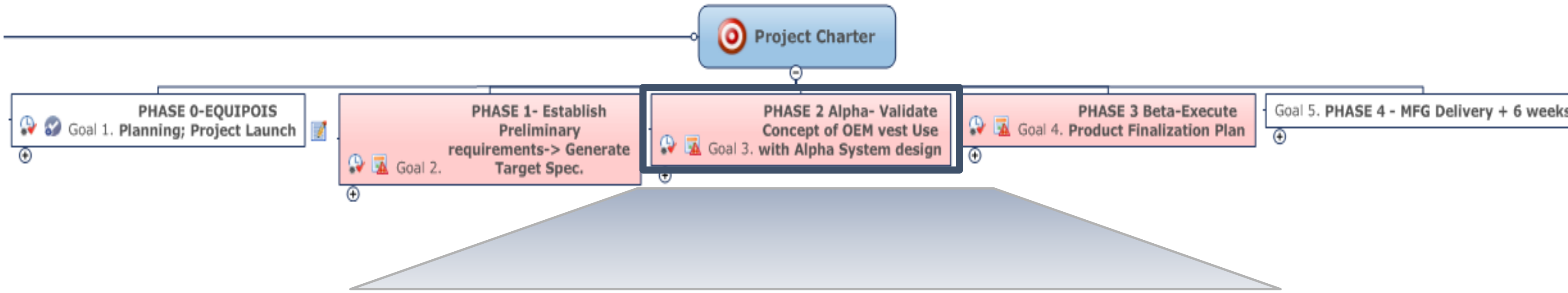
Phase 1: Test Fixture

- Test Fixture Rationale:
  - The test fixture consisted of a light weight rigid articulating attachment designed to produce the cantilevered moment loads that an operator may be subjected to while in use without potentially confounding effects from a fully dynamic live tool simulation.
  - Purpose: Establish gross maximum static loading and duty cycle thresholds to aid in the design of the ergonomic assessment and insure the safety of the human trial participants for IRB approval.





Project Design: Phase 2



- **Phase Two:**
  - Concept Validation
  - Ergonomic testing

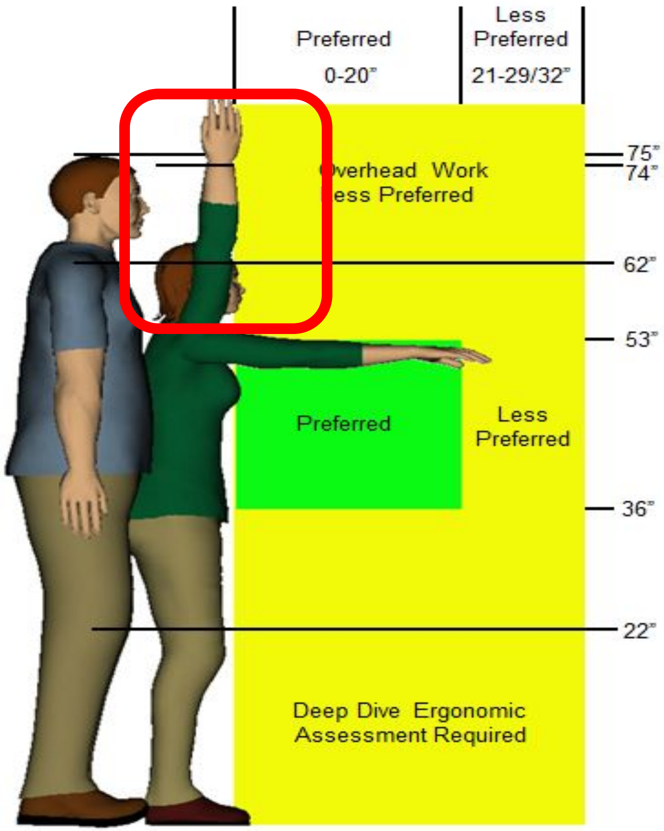
  ACTIVITIES:
  - System prototype: zeroG2 arm, Gimbal and Tools, w/sub selection of vests
  - Ergonomic assessment study design
  - 3rd party ergonomic study
  - Refinement of use case descriptions

- **Outcomes:**
  - Functional prototype evaluated
  - Vest selection completed (ExoVest)
  - System configuration established
  - Payload and application range defined
  - 3rd party ergonomic assessment and human trials completed

Phase 2:

- Target Work Zone

Below for reference is document supplied from Ergonomics dept.



Notes – Vertical Parameters

22" – Standing knee height* of M_Clearance_v71s
36" – Standing knuckle height* of M_Clearance_v71s
53" – Standing shoulder height* of F_Strength_v71s
62" – Standing shoulder height of M_Clearance_v71s
74" – Acceptable vertical grip* of F_Strength_v71s
75" – Vertical clearance for a M_Clearance_v71s

Note: A portable platform must be provided if work zone falls between 71.5" and 76".

Notes: Horizontal Parameters

20" – Standing forward reach of F_Strength_v71s measured from edge of workstation.
29" – Standing forward 2-handed reach of F_Strength_v71s measured from edge of workstation with the Operator bending with a 45 degree trunk angle. *Requirement 1: Top edge of workstation over which she is leaning must not exceed 30" in height.*
32" – Standing forward 1-handed reach of F_Strength_v71s measured from edge of workstation with the Operator bending with a 45 degree trunk angle. *Requirement 1: Top edge of workstation over which she is leaning must not exceed 30" in height.*

Note: 1-hand reaches forward to 35" are acceptable if trunk can be supported (ie using opposite hand) and Requirement 1 is achieved.

* **Details:** Includes a 1" allowance for shoe height. All measurements are taken Siemens Jack v7.1.
(msmets, 2012-06)

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Phase 2: Alpha Design

- System Components:
  - Vest: ExoVest is preferred to a conventional Steadicam vest, but may be 30-40% more costly at this time*
  - Arm: Standard zeroG^2 arm
  - Gimbal: S2 Ring Set with MAG
  - Evaluation tools:
    - Ford: Atlas Copco Rt. Angle Nut Runner
    - Boeing: Quackenbush Rt. Angle Drill

(above) Front Mount - Std . Vest
(below) Back Mount - ExoVest

*Equipois anticipates a licensing agreement with the developers of the ExoVest that will include an version that is optimized for Industrial use and is expected to cost about the same as current conventional vests.

Boeing tool & Gimbal

Ford tool & Gimbal

Phase 2: Ergonomic Assessment

- Two Part Study Ergonomic Study conducted:

  Virginia Tech Department of Industrial and Systems Engineering, Industrial Ergonomics and Biomechanics Lab;

  Maury A. Nussbaum, Ph.D., CPE

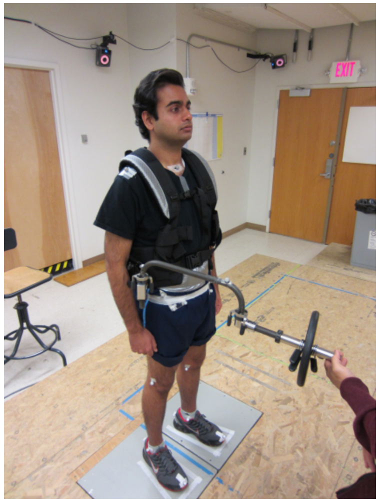
- Part 1: Low-back Moment Tolerance (utilizing Test Fixture)

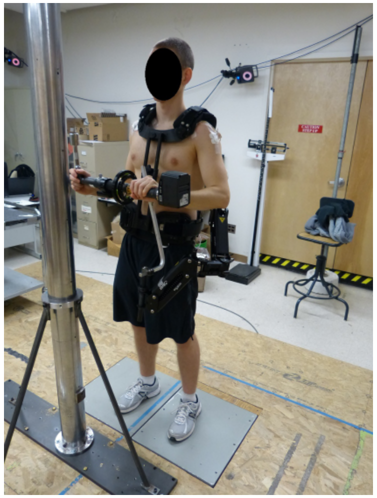
  Since upper-extremity loads are transferred largely to the low back as external moments, it was of interest initially (Part I) to determine whether such low back loads would be tolerable, and over what range. Secondary goals of the first study were to:

  - 1) determine if this tolerance differs between Assistive Device (AD) designs (i.e., rigid front vs. rigid back);
  - 2) assess the effects of wearing the AD on postural control;
  - 3) to obtain preliminary usability results regarding the AD.

- Part 2: Effects of Using the Exo Vest

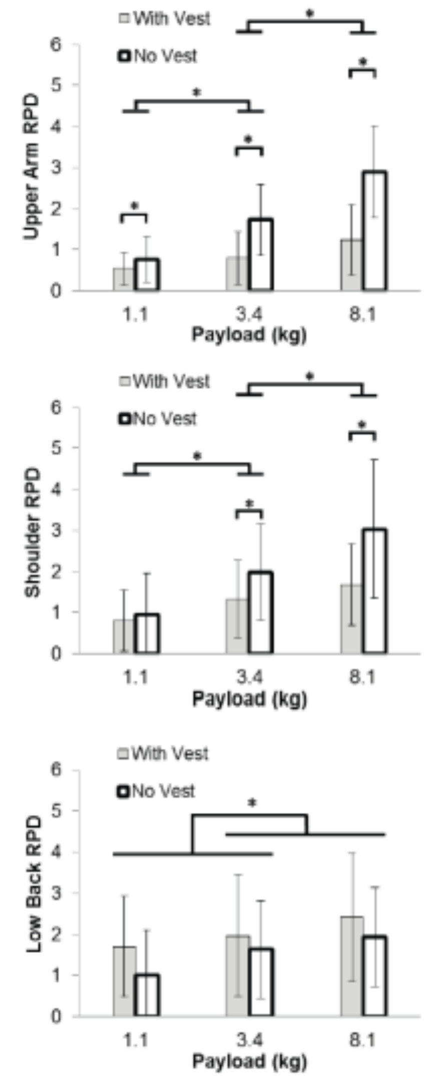
  Participants performed a simulation of intermittent, repetitive overhead work, in each of six different experimental conditions. These conditions were based on discussions with the sponsors, and intended as representative of expected future use of the AD.





Ergonomic Assessment Outcomes

- Low-back moments induced when using the assistive device (vest), appeared to be at “tolerable” levels.
- A back-mount vest design may be somewhat more effective than a front-mount design.
- Shoulder loads decrease while low-back loads increase. However, the latter increase seemed to be smaller than the former increase.
- Acceptable levels of low back loads, when using the vest, may be exceeded with prolonged use.
- Use of the vest may provide the most benefit when using relatively heavy tools during overhead tasks.
- A redesign of the vest may help overcome some limitations related to movement of the vest relative to the torso.



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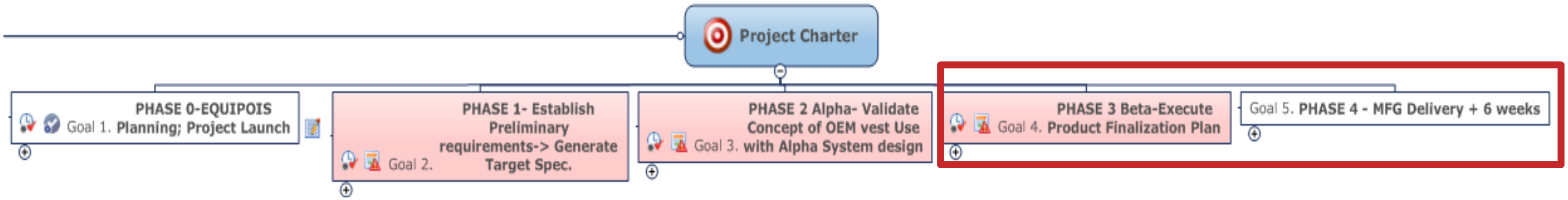
Path Forward:



- There is sufficient validation to support continued development of an OEM equipment based Assistive Device to support shoulder to overhead height applications.
- The research indicates that there is a range of payloads and moment loads for which the proposed system is not only effective, but is expected to provide a reduction of overall effort and incidence of injury due to .
- Ford has funded Phase 3: Beta design and build for in situ trials in early 2013 once production ExoVests are available.
- Successful completion of Phase 3 is intended to provide a rapid path to production a scalable volumes.

Roadmap

- In conjunction with our ongoing technology survey of full body exoskeleton systems, this partnership project and research further indicates a viable roadmap for higher payloads and extended reach applications that include a range of alternative exoskeleton techniques and implementations to provide human worn assistive devices for use in:
  - Logistics
  - Depot operations
  - Material handling
  - Component placement
  - Tool and Fixture applications