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13. ABSTRACT (Maximum 200 words)

AVAcore Technologies in conjunction with Stanford University has developed RTX (Rapid Thermal eXchange) technology for the purpose of enhancing heat transfer with the body core of a mammal. Application of an optimal thermal load and slight negative pressure to certain areas of a mammal containing arteriovenus anastemoses and venous plexus' has been shown to increase heat exchange significantly. Previous versions of RTX required insertion of a hand or foot into a sealed rigid chamber. The current work funded by DARPA through ARO was to design and build RTX devices that incorporate maximum contact to the palmer surface of a hand at rest, provide topical vacuum (no chamber) and a thermal load for ease of use in field applications.

Design criteria were established to accommodate the fifth through ninety fifth percentile hand, be rugged enough to withstand transport in military vehicles during combat operations, and operate regardless of their mounting orientation (vertical or horizontal). Bench testing was performed using a simulated hand to compare heat exchange rates with previous versions of RTX. A 33% increase in heat exchange was observed with the new RTX design. Nine units were built for human testing by others.

14. SUBJECT TERMS
RTX, heat exchange, DARPA, hand cooling, vacuum, thermoregulation, rapid thermal exchange, arteriovenus anastemoses, cooling, heat extraction

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Enclosure 1

US Department of Defense
Defense Advanced Research Projects Agency (DARPA)

Defense Sciences Office (DSO)
Peak Soldier Performance (PSP)

ARO Contract No. W911NF-06-C-0173

Developing and Testing RTX Hand Devices

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Co-Principal Investigators

Final Progress Report

March 26, 2007

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On October 1, 2006 AVAcore Technologies, Inc. (AVAcore) started the project under ARO Contract No. W911NF-06-C-0173. All specified work was completed on 3-1-07. This report summarizes the problem addressed and important results. The appendixes include progress reports that describe work performed and interim results.

1. Problem Addressed

Several Rapid Thermal eXchange (RTX) devices had been developed and tested under DARPA funding. Each of these devices required the hand to be placed in a vacuum chamber sealed at the wrist.

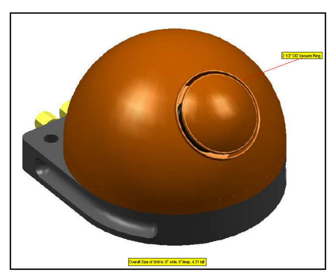
This project addresses a new device to test RTX which applies vacuum only to the palm side of the hand, not to the entire hand surface. Specifically, the device needs to meet the following requirements:

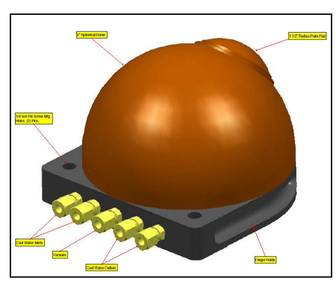
- Provide a distributed **thermal** supply to the palm (including front of fingers and thumb) of the hand; circulate chilled water efficiently and evenly.
- Provide a distributed, topical **vacuum** supply to the palm; provide no vacuum supply to the sides and back of the hand; maximize the area of vacuum application to the hand; minimize device vacuum loss in non-contact areas.
- Meet specified operational requirements:
  - **User**: 95% male to 5% female soldier; long sleeves; left or right hand; in transport; ungloved; wet or dry; possible exposure to topical petroleum or medications.
  - **Environment**: operate in 33°F to 140°F; store in -40°F to 170°F; both in dusty space where personnel and equipment are loaded and unloaded.
  - **Attachment**: attach to horizontal, vertical surfaces; unattached to horizontal surface.
- Provide a surface **shape** that maximizes contact with the palm to accommodate conductive heat transfer and vacuum application; make accessible from user in standing, sitting, and lying positions.

The device should not include thermal or vacuum supplies and controls. The project should not include human-subject testing. (This will be done by others using the device.)

2. Important Results

2.1. Design





The design is a closed thin-walled 6" copper hemisphere with a 2.5" vacuum hole oriented at a 45° to the base at its center. In the hole is another closed thin-walled button about 2.3" in diameter. When a hand is placed on the device depressing the button slightly, a vacuum is activated in the hole and is sustained between a small ridge on the sphere surrounding the hole and the fleshy part of the center of the palm. Vacuum is not applied to other areas of the sphere.

The hemisphere conforms to the natural contour of the hand, maximizes contact area, and is usable by either hand. It has a low form factor to reduce obstruction to soldier ingress/egress in confined transport vehicles.

Vacuum is applied to the center of the palm where blood vessels are most concentrated and close to the palm surface.

This is also where the palm is least calloused. Blood vessels in the fingers are primarily along the sides of the fingers where a topical vacuum cannot reach. There will be little/no vacuum loss before, during, and after use since it is concentrated only in the area where all hands (all sizes and many orientations) will rest.

Cooling water is supplied to the hemisphere and the button independently.

2.2. Testing

The device met all specified functional and usability requirements. Device performance was done on the prototype and AVAcore's B-Unit (with internal supplies removed) with identical external supplies. "Hand" tests were done with a rubber glove perfused with 38°C water without a vacuum.

Value	Unit	Device	B-Unit
Flow rate	ml/sec	13.6	8.5
I/O pressure drop	psi	0.5	4.5
Steady state heat extraction	watts	9.1	8.1
Temp drop top-to-bottom of unit	°C	1.6	1.2

Human testing was not in the scope of the project.

2.3. Production

Nine (9) units were manufactured. All were identical except for the stainless steel screens which covered the "button" in the vacuum hole: three (3) units had a 30 wires/inch mesh; three (3), a 16 wires/inch mesh; three (3), an 8 wires/inch mesh. The University of New Mexico, DARPA, and AVAcore each received one (1) each of the three units and operating instructions.

2.4. Inventions

No inventions resulting from the work are being declared as of this report date.

3. Publications and Technical Reports

The following reports were submitted to DARPA and/or the Defense Contract Management Agency (DCMA):

Workplan (9-28-06)
Product Requirements Specification (10-13-06)
Progress Report – October 2006 (11-3-06)
Progress Report – November 2006 (12-5-06)
Progress Report – December 2006 (1-12-07)
Progress Report – January 2007 (2-14-07)
Abstract for presentation in Miami (2-5-07)
Presentation slides (2-23-07)

None was published or provided to others outside of the project team. No other papers were published.

4. Participating Scientific Personnel

This was a design, engineering, and production project. No new science was pursued or developed. No scientific personnel participated.

5. Bibliography

The following publications were used in the execution of this project:

Clauser, Charles E., Ilse O. Tebbetts, Bruce Bradtmiller, John T. McConville, and Claire C. Gordon. Measurer's Handbook: US Army Anthropometric Survey, 1987-1988. Technical Report NATICK/TR-88/043, AD A202 721.

Gordon, Claire C., Bruce Bradtmiller, Thomas Churchill, Charles E. Clauser, John T. McConville, Ilse O. Tebbetts, and Robert A. Walker.1988 Anthropometric Survey of US Army Personnel: Methods and Summary Statistics. Technical Report NATICK/TR-89/044, AD A225 094.

6. Appendixes

Appendixes are included in the following order:

Product Requirements Specification (10-13-06)
Progress Report – October 2006 (11-3-06)
Progress Report – November 2006 (12-5-06)
Progress Report – December 2006 (1-12-07)
Progress Report – January 2007 (2-14-07)
Abstract for presentation in Miami (2-5-07)
Presentation slides (2-23-07)

Product Requirements Specification

Device Description

The device will provide episodic service and represent a reasonable balance between RTX performance and access/convenience and will conform to the following as possible:

1. Provide a distributed, non-isotropic thermal supply to the palm (including front of fingers and thumb) of the hand.
2. Provide a distributed, topical vacuum supply to the palm; provide no vacuum supply to the sides and back of the hand.
3. Provide feedback to enable vacuum and thermal supply and control.

The device will not include thermal supplies and controls or vacuum supplies and controls.

Development Objectives and Qualifications

The device will meet these objectives as possible within the limits of schedule and budget:

1. Meets the **Operational Requirements** outlined in this document.
2. Provides a surface shape that maximizes contact with the palm to accommodate conductive heat transfer and vacuum application.
3. Circulates chilled water efficiently and evenly.
4. Maximizes the area of vacuum application to the hand; minimizes device vacuum loss in non-contact areas.

Because of the **Biological Unknowns** outlined in this document and because **no human testing** will be done in this project, assumptions will be made as to the size, spacing, and location of vacuum holes based on best available information.

Operational Requirements

User

1. The user will be a 95% male to a 5% female US soldier.
2. The user will be in typical desert battle dress including a backpack and long sleeves with associated restricted motion.
3. The user will use his/her left or right hand as available.
4. The user may be in transport on rough terrain.
5. The user's hand will be ungloved and may be wet or dry.
6. The user's hand may have had previous contact with petroleum products and/or standard hand creams or topical medications.

Environment

1. The device will operate over an ambient temperature range of 33°F to 140°F.
2. The device will be stored over an ambient temperature range of -40°F to 170°F.
3. The device will operate and be stored in dusty environments.
4. The device will operate in, be stored in, and withstand the impacts of spaces where personnel and equipment are loaded and unloaded.

Attachment Surfaces

1. The device may be attached to horizontal or vertical surfaces.
2. The device may be used unattached.

Equipment Used for Human Testing (By Others)

1. For human testing, the maximum vacuum pressure will be (TBD1 in psi); the maximum airflow at the connector will be (TBD2 in cfm); the test equipment connector will be (TBD3 in manufacturer and part number).
2. For human testing, the maximum thermal supply head pressure will be (TBD4 in psi); the maximum thermal supply flow rate will be (TBD5 in cfm); the test equipment connectors will be (TBD6 in manufacturer and part number(s)).
3. For human testing, sensor(s) required thermal or vacuum supply control is(are) (TBD7 sensor(s) with required location(s)).

Biological Unknowns

1. The impact on blood flow of applying a vacuum only to the palm and not the entire hand.
2. The areas of the hand that would constrict blood flow if forces consequential to a topical vacuum are applied.
3. The areas of the hand, absent the impact of 2. that would best benefit from vacuum as a means to increase blood flow.
4. The optimum vacuum level(s) to encourage blood flow when applying topical vacuum to small areas.
5. Minimum area of one effective vacuum “hole”; minimum percentage of the area of all vacuum holes to total palm contact area.
6. The impact of cyclic topical vacuum application on blood flow and thermal transfer; the maximum vacuum supply pressure applied to small areas that is unsafe for the user.
7. The maximum thermal transfer rate possible from the palm.
8. Vascular-restrictive effects that result from holding on to a vibrating object.
9. The effect of cooling on subsequent manual dexterity. (25% of the pressure sensitive nerve endings are located in the central whorls of the finger tips. They are adversely affected when skin temp drops below 20ºC.
10. The impact of alternating gripping and relaxation – like during blood donation.

Grip Project / October 2006

This page summarizes the progress realized on AVAcore's "Developing and Testing RTX Hand Devices" project (DARPA No. W911NF-06-C-0173) between 10-2-06 and 11-3-06

Progress

We received contract approval on 9-27-06 and work commenced on 10-2-06 with a project kick-off meeting. A workplan was developed, approved by the team, and sent to John Main, our DARPA program manager, on 10-5-06.

Work has proceeded as planned. Activity included:

Task 1.1 - Develop requirements A product requirements specification was developed and sent as Rev. 0 dated 10-13-06 to John on 10-13-06. Additional information concerning user positions was developed to clarify operational requirements on 10-18-06. These have been considered by the team during development.

Task 1.2 - Approve (DARPA) No revisions to the above spec were requested by DARPA. The team is proceeding based on the current spec. Sue Schneider of UNM was contacted to complete the "Equipment Used for Human Testing" TBDs in the spec (Page 2). Sue will provide what information is available. The team will make assumptions on remaining items.

Task 1.3 - Develop design concepts The team considered various concepts including handles of various shapes supported at one and both ends and the current B-unit shape. It also considered various vacuum hole sizes and distribution patterns and the use of sintered material. The current design concept was selected for the reasons indicated. The team continues to challenge this concept and to consider others.

Task 1.4 - Engineer design 1 Engineering activity has concentrated on the water circulation and thermodynamics of the current design concept in support of prototype fabrication.

Task 2.1 - Procure materials Parts and materials have been purchased for prototype 1.

Task 2.2 - Fabrication of prototype 1 has begun and will be completed on schedule.

Current Design Concept

Design Concept The current concept is a metal sphere (approx. 4 in. diameter - think softball!) with a hole (approx. 2.7 in. diameter) in the top. In the hole is a cooling coil approximating the curvature of the sphere over the hole. When a hand is set on the device, the vacuum is activated in the hole and is sustained between a small ridge on the sphere surrounding the hole and the fleshy part of the center of the palm. Vacuum is not applied to areas of the sphere other than that of the cylinder. The entire surface of the sphere and cylinder are cooled.

Shape The shape conforms to the natural contour of the hand, maximizes contact area, is grip-able in a moving vehicle, is useable under defined users positions by either hand, has a low form factor to reduce obstruction to soldier ingress/egress. The sphere size will accommodate the 95% male palm; the hole size, 5% female palm. Later versions can be reduced in height with a truncated bottom and supplies from the side.

Vacuum Vacuum is applied to the center of the palm where blood vessels are most concentrated and close to the palm surface. And where the palm is least calloused. Blood vessels in the fingers are primarily along the sides of the fingers where a topical vacuum cannot reach. The vacuum is therefore located where it can have the greatest impact. (On Jim Coleman's 50% male hand, total contactable surface area including fingers is 26 sq.in.; hole size is 8.5 sq.in. or 33% of the palm area.) There will be little/no vacuum loss before, during, and after use since it is concentrated only in the area where all hands (all sizes and orientations) will rest.

Thermal Cooling is fully conductive in the vacuumized area of the palm on the coil and the balance of the palm on the cooled metal sphere. Supplies to the coil and the sphere will be plumbed independently but be connected to the same controlled source. (With more sophisticated supplies and controls, the temperature of the coil could be made cooler/warmer than that of the rest of the sphere. This may increase heat removal from the center of the palm and reduce the chance of vaso-constriction.)

Contract Administration

Amendment Request Mark Smith submitted a revised Statement of Work on 11-2-06. Various project team changes were indicated. No changes to the work, deliverables, schedule or total contract budget were requested.

Property Control Procedure Jim Coleman submitted a draft of AVAcore's "Property Control Procedure" to Don Wallace, DCMA Detroit Property Administrator, on 10-2-06. It was approved and resubmitted in final form the same day.

Budget

Total expenditures for the first month have not been collected. A summary of budget vs. actual will be included in next month's report.

Schedule

On schedule per the workplan.

Questions concerning this progress report may be directed to Jim Coleman, PI and project manager.

Report date 11-3-06

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Grip Project / November 2006

This page summarizes the progress realized on AVAcore's "Developing and Testing RTX Hand Devices" project (DARPA No. W911NF-06-C-0173) **between 11-6-06 and 12-1-06**

Progress

Since October, work has proceeded according to the workplan. Activity included:

Task 2.2 - Build prototype 1 Prototype 1 was built consistent with the "Current Design Concept" in the October progress report. (See PIC1 PIC2 PIC3) Prototype 1a was built to examine a different vacuum hole orientation. (See PIC1 PIC2 PIC3) The prototypes were developed in the FEI shop with input from Hoff & Associates.

Task 2.3 - Test prototype 1 Test hardware and software was developed. (See PIC1 PIC2) Prototypes 1 and 1a were tested for form and function. Conclusions from these tests are included in the current design concept below.

Task 3.1 - Engineer design 2 The thermal and vacuum supply information from CSA Engineering was incorporated into the Product Requirements Specification. Design 2 was started based on the findings of Task 2.3 and the resulting current design concept. The team continues to challenge this concept and to consider others.

Task 4.1 - Procure materials for prototype 2 The device has been designed to use all stock parts and materials. No custom tooling is required. What has not been purchased can be gotten within two days.

Current Design Concept

Changes Changes to the design concept since the October progress report include the following:

a. Increased the **sphere diameter** from 4" to 6" to enable easier vacuum seals, more natural hand draping, greater surface contact, and less inclination for harder grips causing reduced blood flow.

b. Reduced **vacuum hole diameter** from 2.75" to 2.5" to accommodate smaller hands.

c. Moved the **vacuum hole centerline** from perpendicular to the base to a 45° angle to reduce wrist bend for most users and overall device height to 4.3".

d. Replaced the copper cooling coil **palm interface** inside the vacuum hole with a copper cooling plate with a surface diameter of 3" covered with a copper screen or ridged surface to allow vacuum access. This improves contact area, manufacturability, and durability.

e. Added a **base** through which supplies (two in-waters, two out-waters, one out-air) extend in parallel out the back.

Images These images of the design are current as of the report date: FRONT BACK BOTTOM They are preliminary and subject to change.

Contract Administration

Amendment Request Mark Smith submitted a revised Statement of Work on 11-15-06 proposing Mark and Jim Coleman as co-PIs. No changes to the work, deliverables, schedule, or total contract budget were requested.

Budget

As of 11-24-06, the follow data apply:

Total budget spent	**33%**	Based on actual Oct and estimated Nov invoices (two months, $36,758) and the contract amount of $112,500
Total work completed	**37%**	Based on earned value of budgeted MHs on completed tasks

Schedule

On schedule per the workplan.

Questions concerning this progress report may be directed to Jim Coleman, co-PI and project manager.

Report date 12-5-06

Grip Project / December 2006

This page summarizes the progress realized on AVAcore's "Developing and Testing RTX Hand Devices" project (DARPA No. W911NF-06-C-0173) **between 12-4-06 and 1-12-07**

Progress

During December, work proceeded according to the workplan. Activity included:

Task 3.1 - Engineer design 2 Design and engineering were completed according to the design concept included in the November progress report. Engineering support continued during prototype 2 construction. Additional thermal analyses were done on the water flow through the sphere to maximize the uniformity of sphere surface temperature. This delayed the completion of the prototype.

Tasks 4.2 thru 4.6 - Build and test prototype 2 Prototype construction was completed on 1-8-07. Testing continues.

Final Design

Only minor changes to the concept design have been made since the November progress report. Prototype 2 as shown below will be the basis for production under Task 5 with some cosmetic changes:

a. The **base** will be black; the sphere and palm plate, a matte silver coating on the copper and brass metal surfaces.
b. Three different (weave spacing) **metal screens** will cover the palm plates of each of the three units going to each of the sites. The screens enable vacuum access to the center of the palm. The three options will provide various contact-surface-to-vacuum-surface ratios for human testing. The palm plates are removable and interchangeable between units.
c. The **finger ridges** in the base (for lifting) will be smaller.

Images

Prototype 2 images: **FRONT SIDE/BACK BOTTOM**
Prototype 2 design sections: **FRONT/BACK PALM-PLATE CYLINDER**

Contract Administration

No actions this month.

Budget

As of 12-29-06, the follow data apply:

Total budget spent	**60%**	Based on actual Oct-Dec invoices ($67,378) and the contract amount of $112,500
Total work completed	**71%**	Based on earned value of budgeted MHs on completed tasks

Schedule

Building and testing of prototype 2 were delayed pending the issue noted under Progress above. We anticipate completion of the all work by 2-2-07, one week later than planned.

Questions concerning this progress report may be directed to Jim Coleman, co-PI and project manager.

Report date 1-12-06

Grip Project / January 2007

This page summarizes the progress realized on AVAcore's "Developing and Testing RTX Hand Devices" project (DARPA No. W911NF-06-C-0173) **between 1-12-07 and 2-14-07**

Progress

During January, work proceeded according to the workplan. Activity included:

Task 5.1 - Procure materials All materials were purchased for the production units.

Task 5.2 - Produce units After initial unit assembly there were water leaks during pressure testing. Several dis/reassemblies were required to find a reliable solution. Reengineering of some seals and seams was required. The final solution has been determined. Units are in final assembly and will be going to a local company to coat the copper spheres. It is expected that three (3) units will be shipped to DARPA by February 20. Another unit will be taken to the Miami meeting on February 22-23.

Task 5.3 - Prepare report The final report is completed in draft form. It will be completed pending the results of the Miami meeting.

Final Design

The final design is consistent with that described in the December progress report.

Contract Administration

Don Wallace of DCMA Detroit did a Property Control System Analysis of project material and equipment on 1-17-07. His report dated 1-19-07 indicated that he found no exceptions.

An abstract of AVAcore's presentation at the DARPA meeting in Miami was spent on 2-5-07.

Budget

As of 1-26-07 (most recent invoice period ending), the follow data apply:

Total budget spent	**76%**	Based on actual Oct-Jan invoices ($85,600 est.) and the contract amount of $112,500
Total work completed	**85%**	Based on the earned value of budgeted MHs on completed tasks

Schedule

Because of delays in prototype build/testing (1 week) and in unit production (2 weeks), we anticipate shipment of the units by 2-20-07, three (3) weeks later than planned. Final report will be submitted by 3-2-07

Questions concerning this progress report may be directed to Jim Coleman, co-PI and project manager.

Report date 2-14-07

Developing and Testing RTX Hand Devices

<u>AVAcore Technologies, Inc</u>
James Coleman (co-PI, project manager), jhColeman LLC
Mark Smith (co-PI, RTX consultant), AVAcore Technologies, Inc.
Thomas Armstrong, Ph.D. (ergonomics, physiology consultant), University of Michigan
Tim Beard (design/engineering manager), Hoff & Associates
James Freese (prototype/test manager), Freese Enterprises, Inc.

Objective

Develop a device to test the efficacy of Rapid Thermal eXchange (RTX) while meeting the following requirements:

1. Provide a distributed **thermal** supply to the palm (including front of fingers and thumb) of the hand; circulate chilled water efficiently and evenly.
2. Provide a distributed, topical **vacuum** supply to the palm; provide no vacuum supply to the sides and back of the hand; maximize the area of vacuum application to the hand; minimize device vacuum loss in non-contact areas.
3. Meet specified operational requirements:
   User: 95% male to 5% female soldier; long sleeves; left or right hand; in transport; ungloved; wet or dry; possible exposure to topical petroleum or medications.
   Environment: operate in 33°F to 140°F; store in -40°F to 170°F; both in dusty space where personnel and equipment are loaded and unloaded.
   Attachment: attach to horizontal, vertical surfaces; unattached to horizontal surface.
4. Provide a surface **shape** that maximizes contact with the palm to accommodate conductive heat transfer and vacuum application; make accessible from user in standing, sitting, and lying positions.

The device will not include thermal or vacuum supplies and controls.

The project will not include human-subject testing.

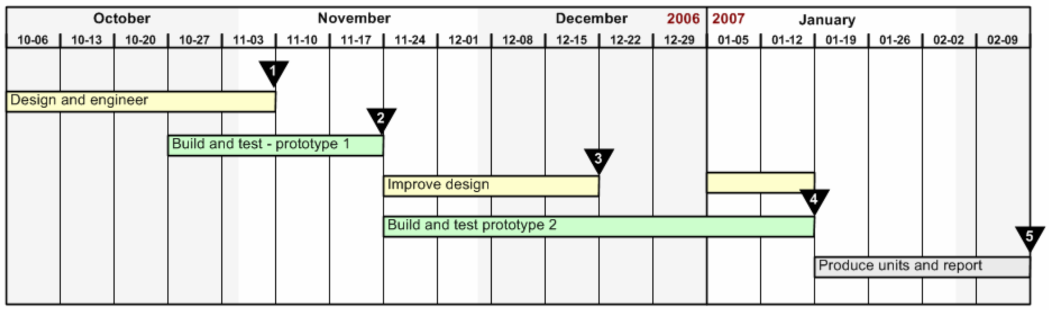
Biological Unknowns

The following were/are unknown:

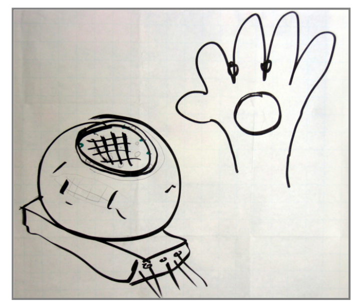
1. The impact of applying a **vacuum only to the palm** and not the entire hand; **palm areas** that would best benefit from vacuum.
2. The **optimum vacuum** level to encourage blood flow when applying topical vacuum to small areas; the maximum **safe vacuum** level applied to the same area.
3. Minimum area of one effective **vacuum "hole"**; minimum percentage of the area of all vacuum holes to total palm contact area;
4. The maximum **thermal transfer** rate possible from the palm.
5. Vascular-restrictive effects that result from holding on to a **vibrating** object.

Milestones

Project was completed according the following work plan. Activities and results under each milestone are shown below.



Milestone 1 – Design and engineer



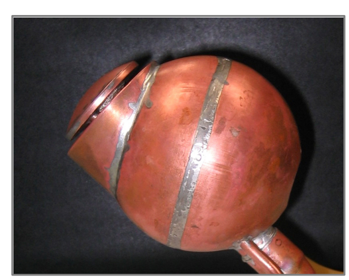
Functional requirements were developed and submitted to DARPA. Design concepts were developed with wood, PVC, Styrofoam, white board, and paper. CAE models were used to simulate various grip configurations. Direction for general form and functional was given for prototype 1 development.

Major direction included *1.* a 4" sphere best maximized contact with a relaxed hand and offered easy ambidextrous access and *2.* vacuum would be confined to center of the palm to enable vacuum containment, concentration, and activation.

Milestone 2 – Build and test prototype 1

Two prototypes were built with 4" copper spheres, a 2.75" independently-cooled palm plates that, when depressed, activated the vacuum. The first unit (right-top) did not allow the palm to drape easily over the area around the vacuum hole.

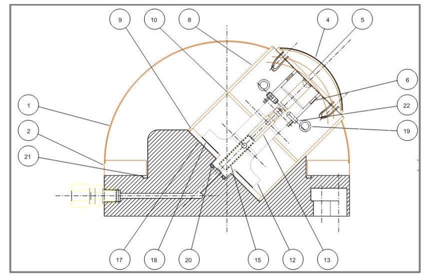
A second unit (right-bottom) with the same materials enabled improved contact when the hand was aligned properly.



Metal screens placed over the palm plate provided improved vacuum access to the entire applied area.

After testing with various hand sizes, the following major conclusions were derived: *1.* increase the sphere to 6", *2.* reduce the vacuum hole size to 2.5", *3.* make the palm plate from 2.5" sphere, *4.* place the vacuum hole on a 45° angle to the base, *5.* plumb the chilled water supplies to the sphere and the palm plates independently to enable flexible testing of the unit, and *6.* prove different screen gauges over palm plates for testing to determine the best size.

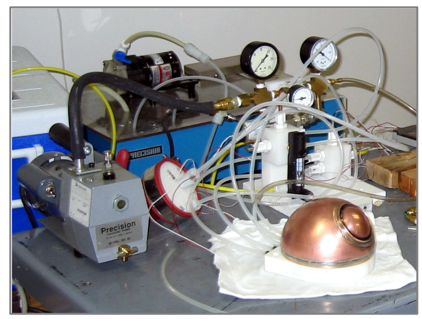
Milestone 3 – Improve design



Detailed design drawings were done based on prototype 1 conclusions with regular manufacturability reviews. Analytical analyses were done on the water flow and thermal transfer in the sphere. After the initial design was released additional analyses and revisions were made to the water flow and part materials prior to construction of the production units.

Chilled water is injected into the sphere at the top and drained in the bottom to assure best cooling in the hand area. The palm plate is spring loaded. The spring would be selected heuristically during prototype 2 construction.

Milestone 4 – Build and test prototype 2



Prototype 2 was constructed according released drawings and was tested. There were of two types of tests.

Air and water leaks were identified and fixed through small design and manufacturing process changes. Vacuum “grip” was confirmed with a 5% female and 90% male.

Unit performance was done on the prototype and AVAcore’s B-Unit (with internal supplies removed) with identical external supplies. “Hand” tests were done with a rubber glove perfused with 38°C water without vacuum.

Value	Unit	Device	B-Unit
Flow rate	ml/sec	13.6	8.5
I/O pressure drop	psi	0.5	4.5
Steady state heat extraction	watts	9.1	8.1
Temp drop top-to-bottom of unit	°C	1.6	1.2

Milestone 5 – Build units

Nine (9) units were built and distributed as specified.

Units provide the following features:
- Meet specified requirements.
- Provide low form factor; are attachable
- Accommodate independent chilled water supplies
- Enable use of three (3) palm plate screens
- Have durable, non-stain, low-reflective surface
- Enable ambidextrous use at many approach angles

Units provide a basis for testing of this alternative RTX application and assessment of possible end-user applications.

AVAcore Technologies, Inc.

Developing and Testing RTX Hand Devices

DARPA / PSP / Phase 2 / Year 2 Review

Miami / February 23, 2007

Jim Coleman

333 Parkland Plaza, Suite 700, Ann Arbor, MI 48103, 734-332-3777

Current Device

RTX technology
Vacuum chamber
Wrist seal
Two-handed operation

Regulated thermal supply
Regulated vacuum supply

Commercial, military use

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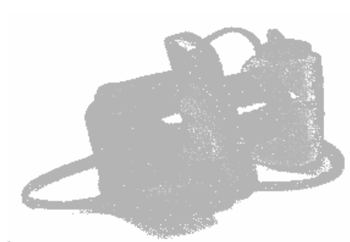
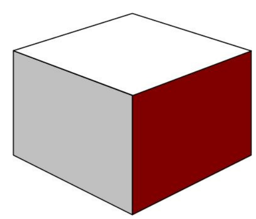
Current Device	New Device
RTX technology	Same
Vacuum chamber	Topical vacuum
Wrist seal	No wrist seal
Two-handed operation	One-handed operation
Regulated thermal supply	Same (by others)
Regulated vacuum supply	Same (by others)
Commercial, military use	Research, development





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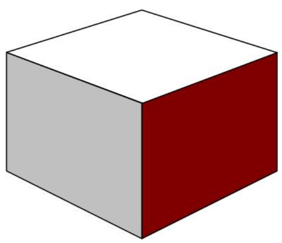
Requirements



- **RTX**
  - Deliver regulated thermal, vacuum
  - (Supplies by others)
- **Operational**
  - User hand: male/female, ambidextrous, wet, dirt/oil/med
  - Environment: 33°-140°, dusty, rough
- **Shape**
  - Maximize RTX benefit
  - Quick use, ergonomic; sit, stand, lie
- **Unknowns**
  - Impact of topical vacuum
  - Contact area vs. vacuum area

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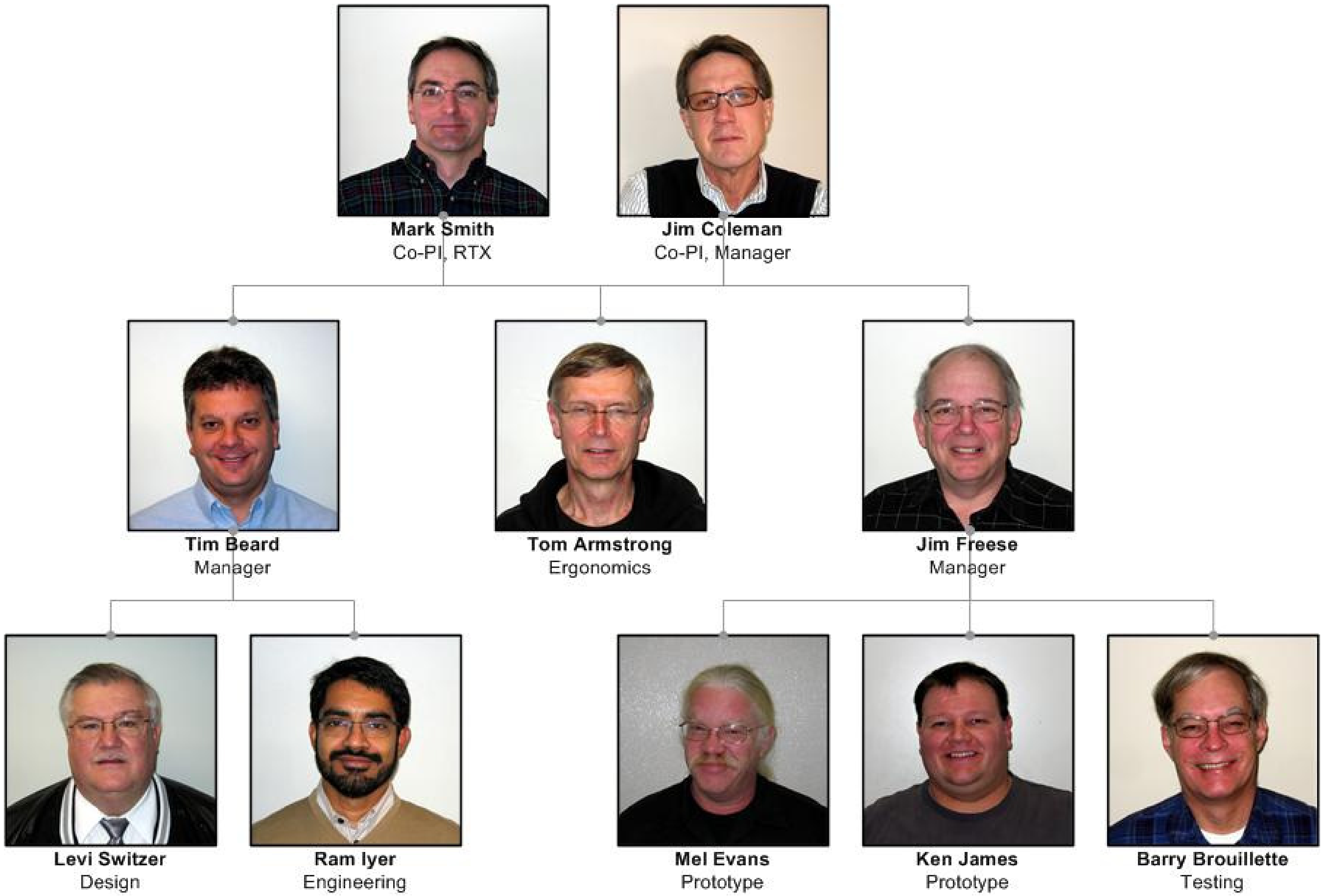
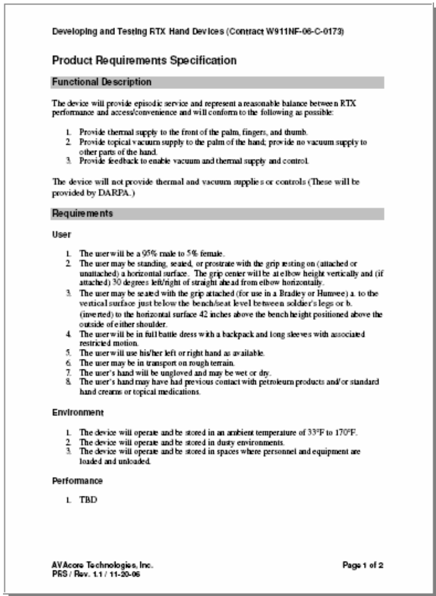
Team



Mark Smith
Co-PI, RTX
Jim Coleman
Co-PI, Manager
Tim Beard
Manager
Tom Armstrong
Ergonomics
Jim Freese
Manager
Levi Switzer
Design
Ram Iyer
Engineering
Mel Evans
Prototype
Ken James
Prototype
Barry Brouillette
Testing

Milestone 1 Design and engineer

Requirements



Developing and Testing RTX Hand Devices (Contract W911NF-06-C-0173)

Product Requirements Specification

Functional Description

The device will provide episodic service and represent a reasonable balance between RTX performance and access/convenience and will conform to the following as possible:

1. Provide thermal supply to the front of the palm, fingers, and thumb.
2. Provide topical vacuum supply to the palm of the hand; provide no vacuum supply to other parts of the hand.
3. Provide feedback to enable vacuum and thermal supply and control.

The device will not provide thermal and vacuum supplies or controls (These will be provided by DARPA.)

Requirements

User

1. The user will be a 95% male to 5% female.
2. The user may be standing, seated, or prostrate with the grip resting on (attached or unattached) a horizontal surface. The grip center will be at elbow height vertically and (if attached) 30 degrees left/right of straight ahead from elbow horizontally.
3. The user may be seated with the grip attached (for use in a Bradley or Humvee) a. to the vertical surface just below the bench/seat level between soldier's legs or b. (inverted) to the horizontal surface 42 inches above the bench height positioned above the outside of either shoulder.
4. The user will be in full battle dress with a backpack and long sleeves with associated restricted motion.
5. The user will use his/her left or right hand as available.
6. The user may be in transport on rough terrain.
7. The user's hand will be ungloved and may be wet or dry.
8. The user's hand may have had previous contact with petroleum products and/or standard hand creams or topical medications.

Environment

1. The device will operate and be stored in an ambient temperature of 33°F to 170°F.
2. The device will operate and be stored in dusty environments.
3. The device will operate and be stored in spaces where personnel and equipment are loaded and unloaded.

Performance

1. TBD

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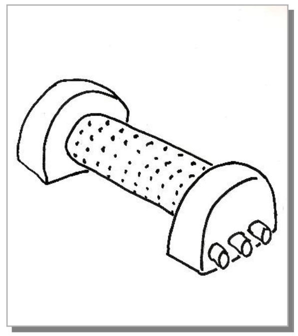
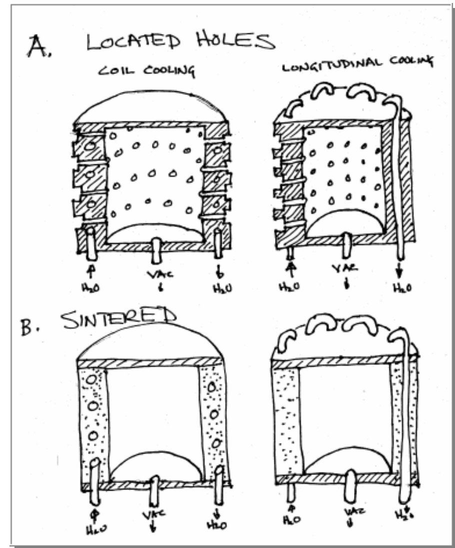
Grip Shape



Grip Works



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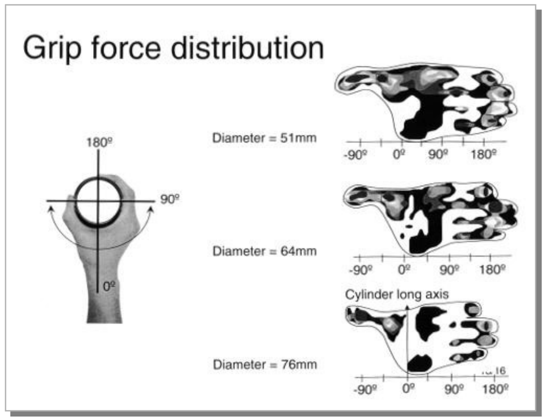
Milestone 1 Design and engineer

Grip Size

More Grip Size



Conclusions

Shape

- Grip too hard
- Need more contact area

Vacuum

- Uncovered holes
- Dirt in holes

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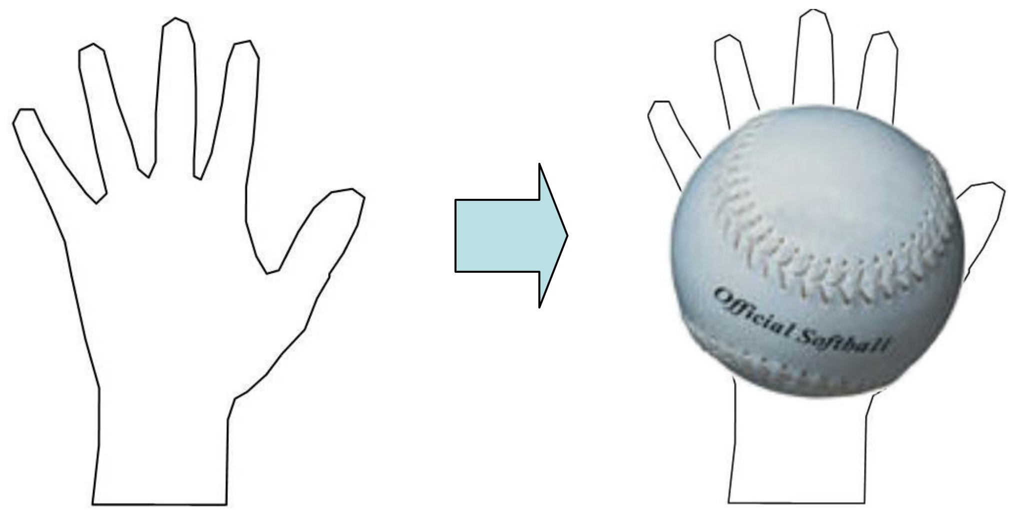
Hand Shape

Device Shape



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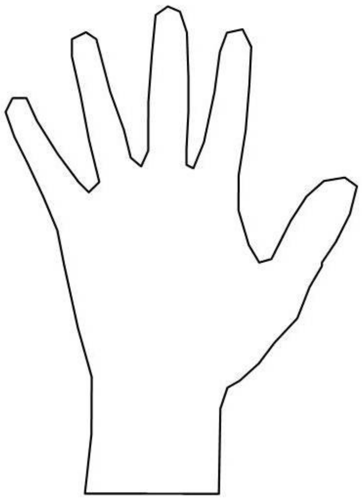
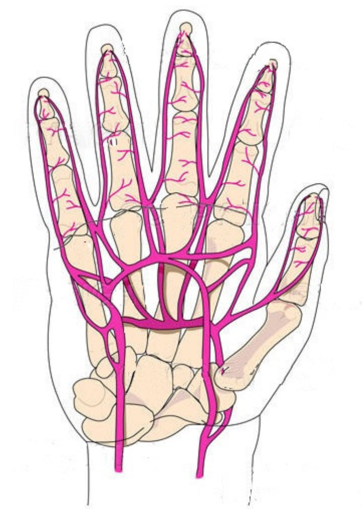
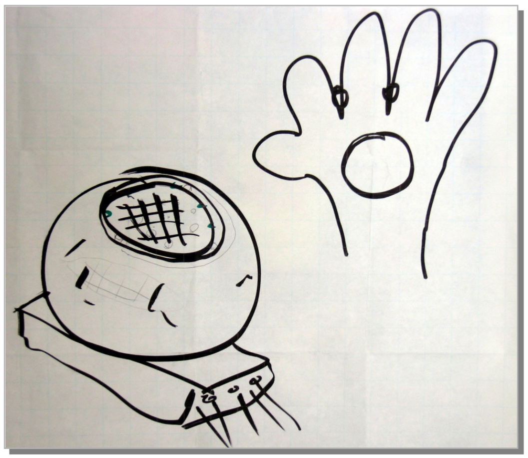
Hand Area



Hand Map



Vacuum Idea



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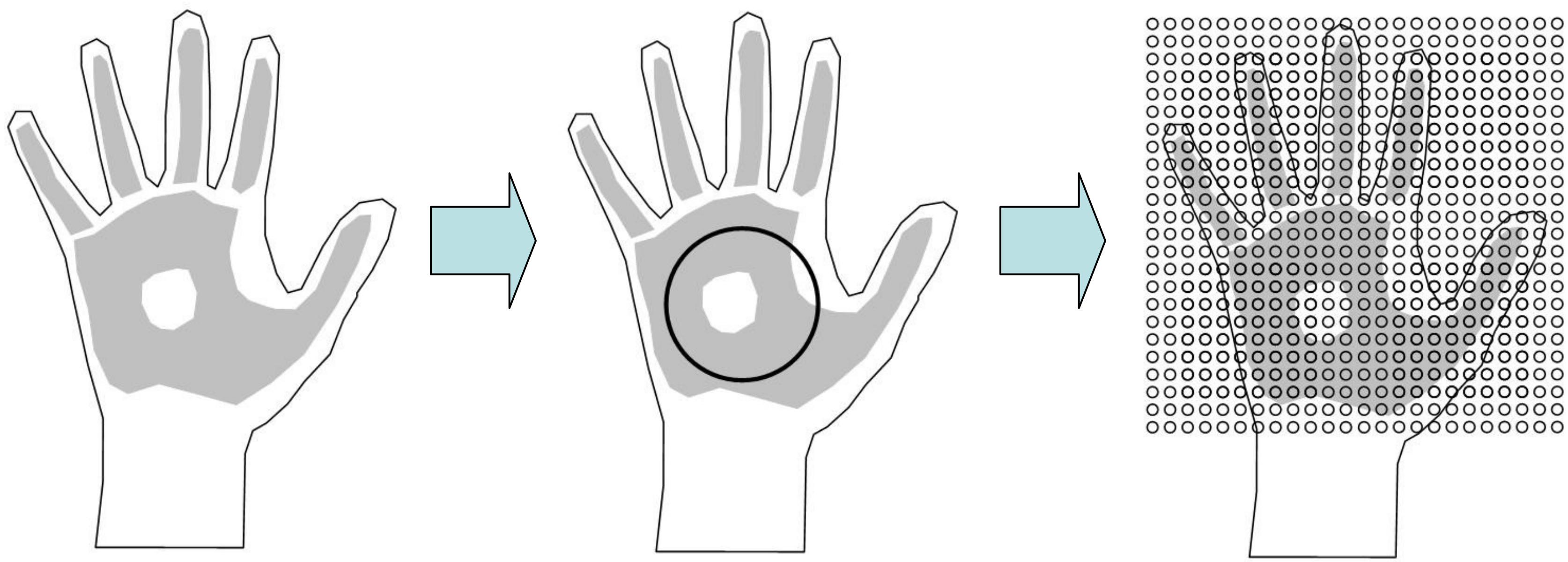
Milestone 1 Design and engineer

Contact Area | Vacuum Area | Vacuum Area



Contact: 16 sq.in.

Vac Area: 6 sq.in.
(37% of contact)
w/2.75 in. dia. hole

Vac Area: 6 sq.in.
equivalent

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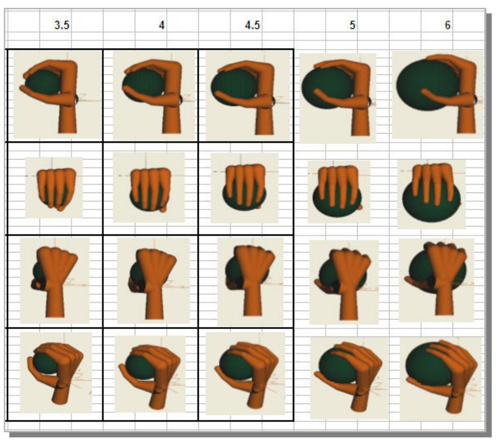
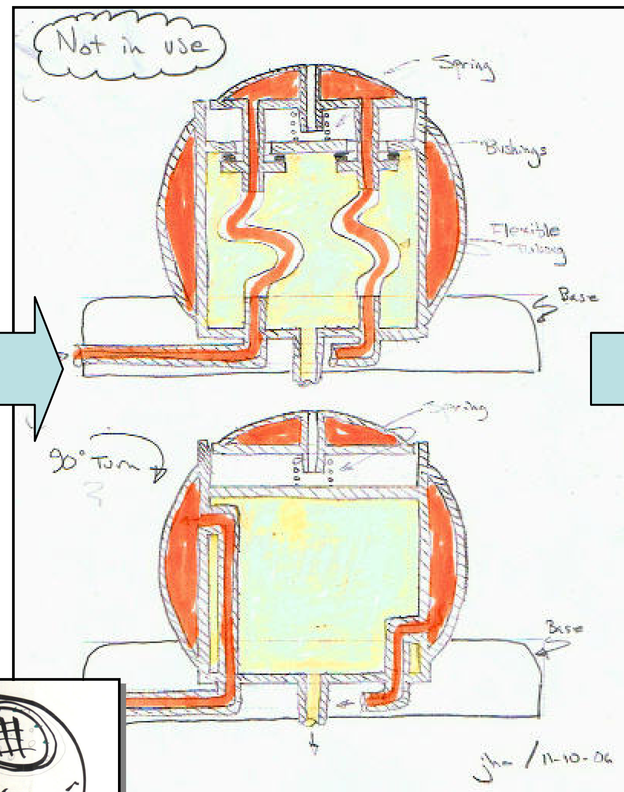
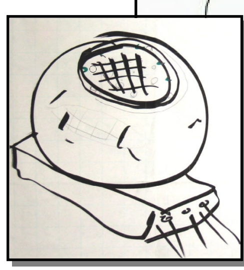
Milestone 1 Design and engineer

Device Size



Device Works





Conclusions

- 4" copper sphere
- 2.75" vacuum hole
- Palm plate activated vacuum
- Independent water supplies
- Vacuum accumulator

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Milestone 2 Build and test prototype 1

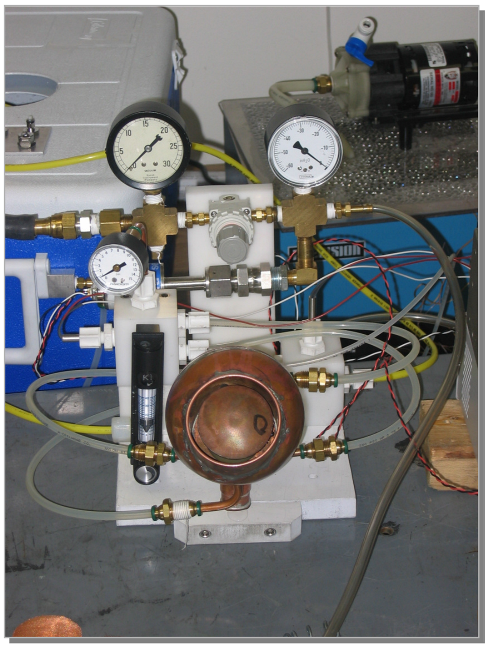
Prototype 1a

Test

Prototype 1b

Milestone 2 Build and test prototype 1

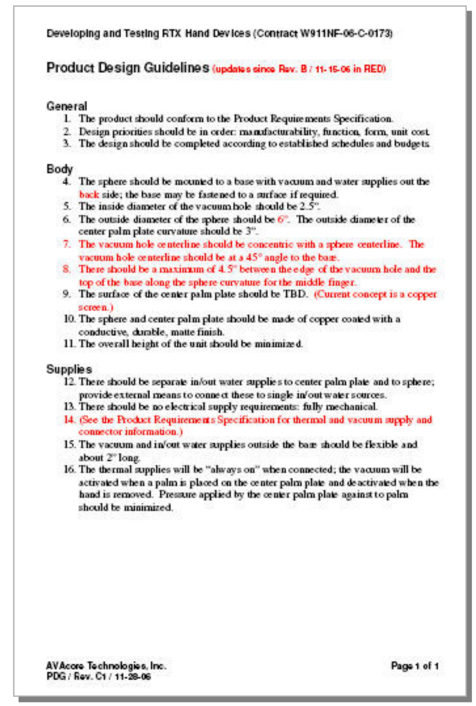
Test



Conclusions

- 6" copper sphere
- 2.5" vac hole
- 2.5" palm plate surface diameter
- Palm plate screens for vacuum access

Design Spec



Developing and Testing RTX Hand Devices (Contract W911NF-06-C-0173)

Product Design Guidelines (updates since Rev. B / 11-15-06 in RED)

General
1. The product should conform to the Product Requirements Specification.
2. Design priorities should be in order: manufacturability, function, form, unit cost.
3. The design should be completed according to established schedules and budgets.

Body
4. The sphere should be mounted to a base with vacuum and water supplies out the back side; the base may be fastened to a surface if required.
5. The inside diameter of the vacuum hole should be 2.5".
6. The outside diameter of the sphere should be 6". The outside diameter of the center palm plate curvature should be 3".
7. The vacuum hole centerline should be concentric with a sphere centerline. The vacuum hole centerline should be at a 45° angle to the base.
8. There should be a maximum of 4.5" between the edge of the vacuum hole and the top of the base along the sphere curvature for the middle finger.
9. The surface of the center palm plate should be TBD. (Current concept is a copper screen.)
10. The sphere and center palm plate should be made of copper coated with a conductive, durable, matte finish.
11. The overall height of the unit should be minimized.

Supplies
12. There should be separate in/out water supplies to center palm plate and to sphere; provide external means to connect these to single in/out water sources.
13. There should be no electrical supply requirements: fully mechanical.
14. (See the Product Requirements Specification for thermal and vacuum supply and connector information.)
15. The vacuum and in/out water supplies outside the base should be flexible and about 2" long.
16. The thermal supplies will be "always on" when connected; the vacuum will be activated when a palm is placed on the center palm plate and deactivated when the hand is removed. Pressure applied by the center palm plate against to palm should be minimized.

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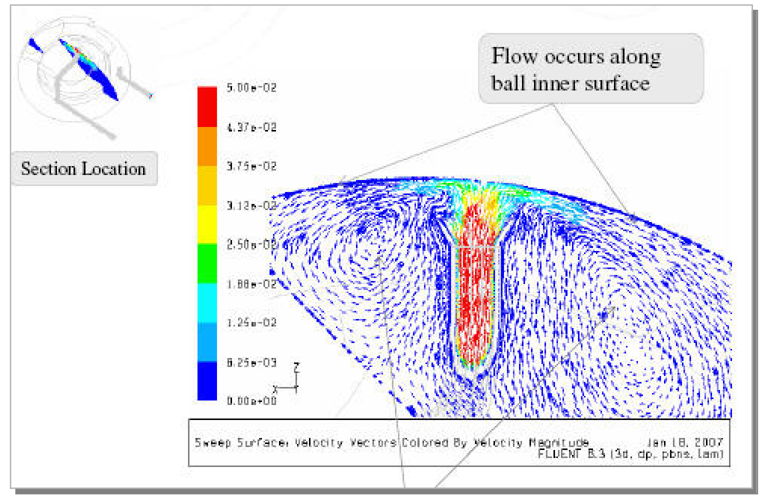
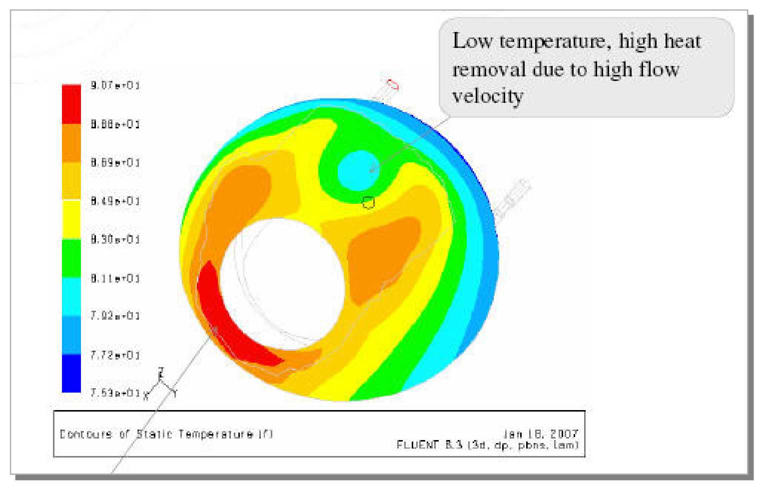
Milestone 3 Improve design

Size, Angle

Flow





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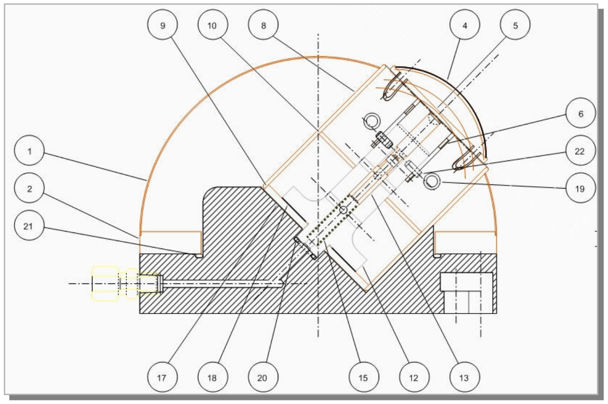
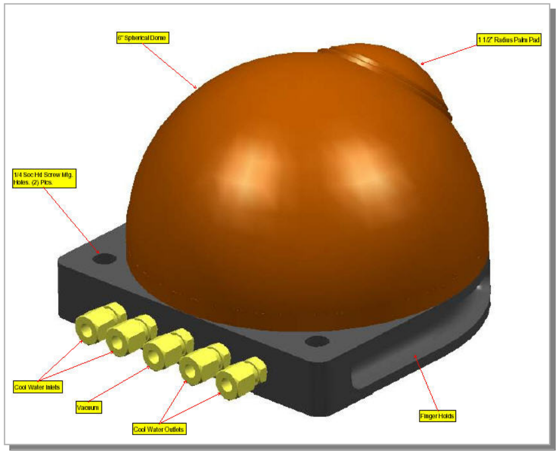
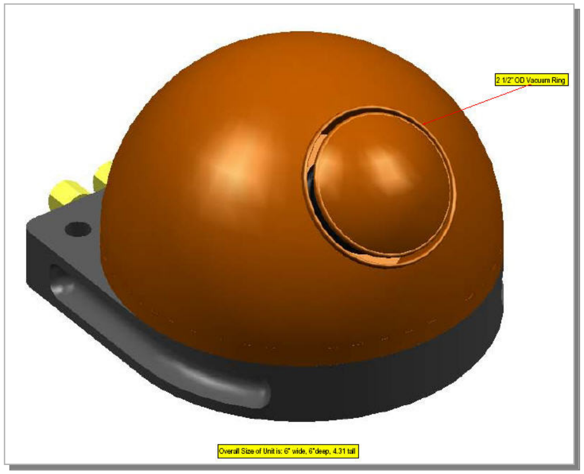
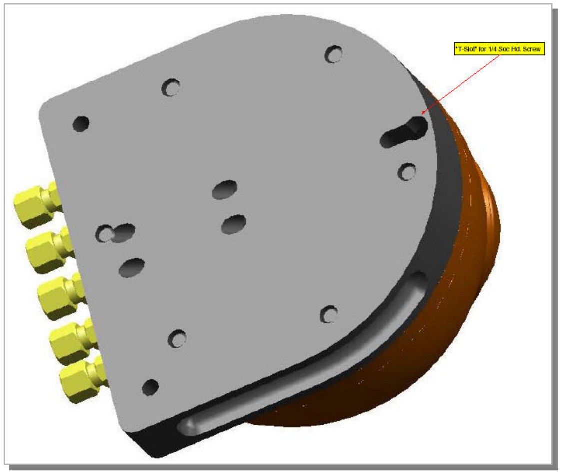
Milestone 3 Improve design

Design









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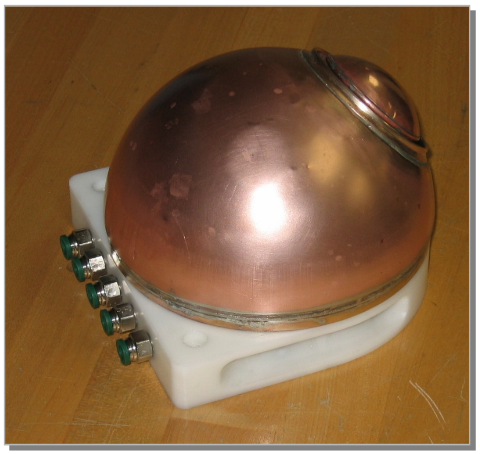
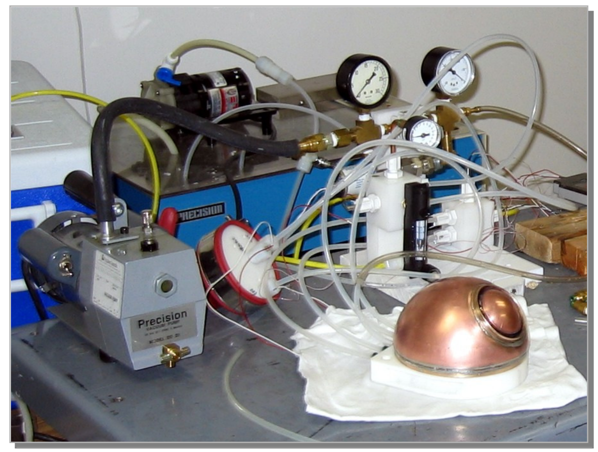
Milestone 4 Build and test prototype 2

Prototype



Test

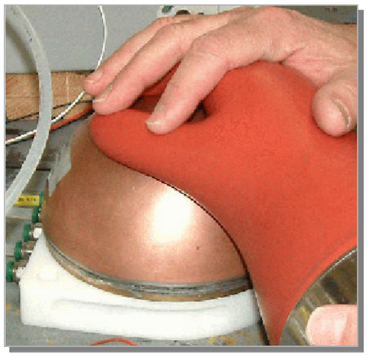


Tweaks

- Select palm plate spring
- Reconfigure water supply in sphere
- Replace vacuum valve material
- Improve solder joint reinforcements

Milestone 4 Build and test prototype 2

Test



- Same thermal supply @ 20.5°C
- Heat extraction with perfused rubber glove @ 38°C
- No vacuum

Results

Value	Units		
Flow rate	ml/sec	13.6	8.5
I/O pressure drop	psi	0.5	4.5
Steady state heat extraction	watts	9.1	8.1
Temp drop top-to-bottom of unit	°C	1.6	1.2

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Milestone 5 Build units

- Meets requirements
- Low form factor
- Independent thermal supplies
- Three palm plate screens, interchangeable
- Durable, non-stain, low reflective surface
- Ambidextrous use at many approach angles

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Next Phase Actions

- Test performance (by others)
- Solicit form, function feedback
- Identify specific applications
- Combine with custom supplies, controls
- Production-ize design

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Questions?