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Title: A Design Methodology Based Approach For Robotic Gripper Design

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Los Alamos
NATIONAL LABORATORY
EST. 1943

Abstract

Designing effective end-effector tooling for robotic systems is necessary for all robotics applications. These tools, ranging from specialty items such as grinders and welders to more universal tools such as grippers, represent a critical component in the operations of a robotic system. Performance limitations of a robotic gripper impose performance limitations upon the operations of the system as a whole. By applying classical design methods to the design of a robotic gripper, a robotic gripper that meets the performance requirements and specifications of a system can be developed. This paper demonstrates the use of existing design methods to develop a band gripper design for Los Alamos National Laboratory and presents a robust design process that can yield satisfactory gripper designs. The developed gripper is subsequently tested and evaluated based on the project requirements and specifications to validate the design. The resulting gripper met or exceeded project design requirements and specifications.

A Design Methodology Based Approach to Robotic Gripper Design

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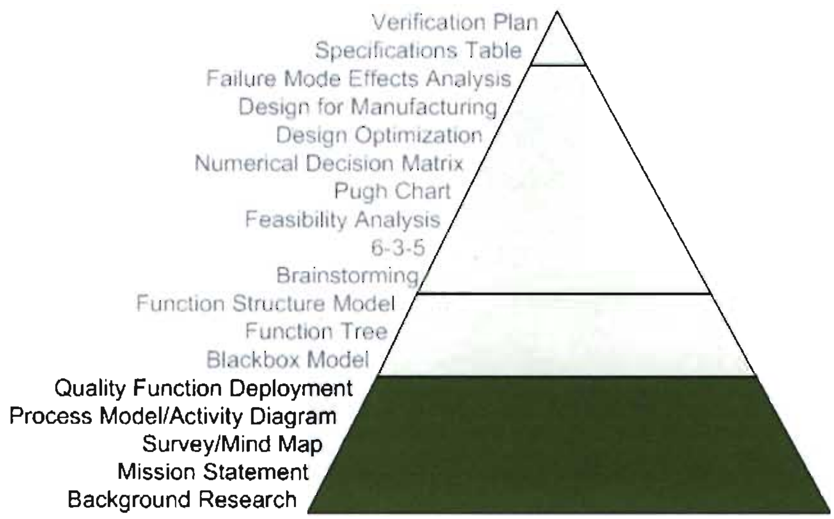
Design Methodology

- Why use a design methodology?
  - Provides a structured design process for problem solving
  - Helps avoid design fixation through independent development of needs and functions, generation of multiple design concepts, and impartial concept evaluation
- What is a classical design methodology?
  - Need Definition
  - Functional Analysis
  - Conceptual Development
  - Design Confirmation

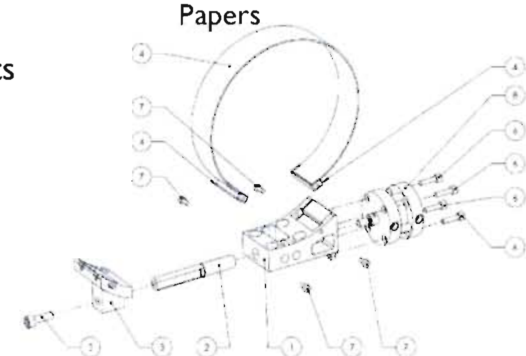
Need Definitions



Needs Definition

Background on the LANL Gripper

- Current Design
  - Asymmetric Closure
  - Knurling Wear
  - Low Factor of Safety
- System Requirements
  - Grasp Cylinders
  - Diameter Range
  - 3+ Contact Points
- System Constraints
  - Glovebox Enclosure
  - Radiation Exposure
- Other Sources
  - Patents
  - Journal Articles/Conference Papers



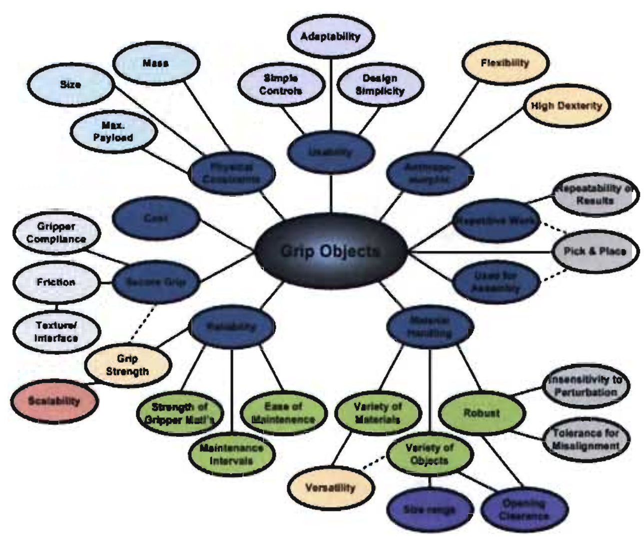
Needs Definition

Mission Statement

- Goal
  - To produce an effective gripper design improving on the performance of the previous gripper design while meeting system constraints and project requirements.
- Relevant Deadlines
  - Design Review
  - Functional Prototype
  - Final Report & Testing
- Concerns
  - Material Selection, Operating Conditions
- Inspiration
  - Symmetric Closures, Alternate Grasping Techniques

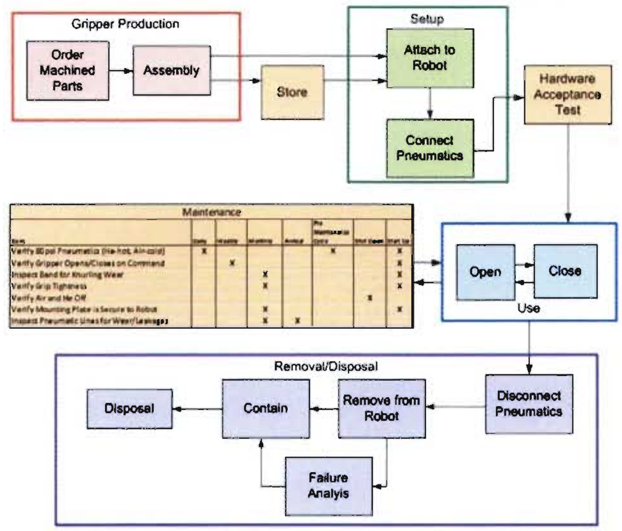
Needs Definition

Needs Survey and Mind Map



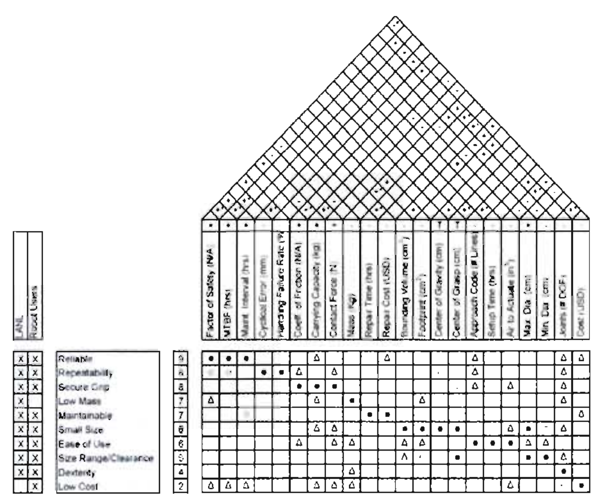
Needs Definition

Process Model/Activity Diagram

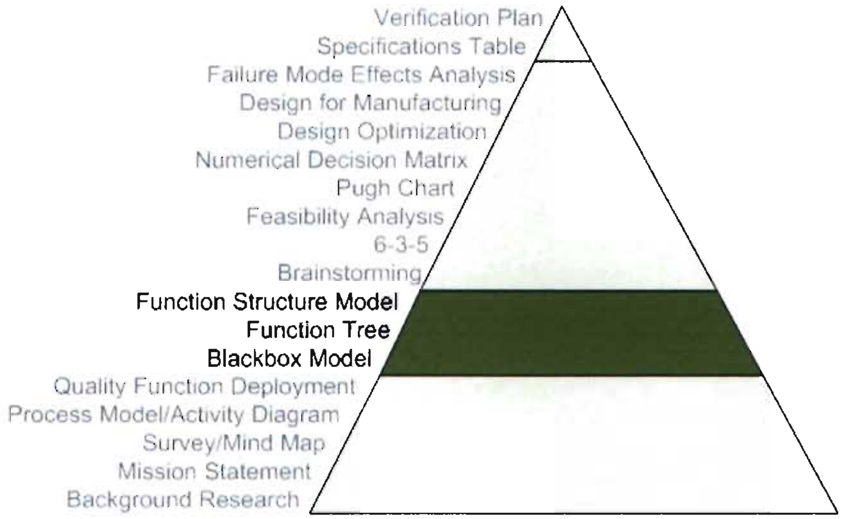


Needs Definition

Quality Function Deployment

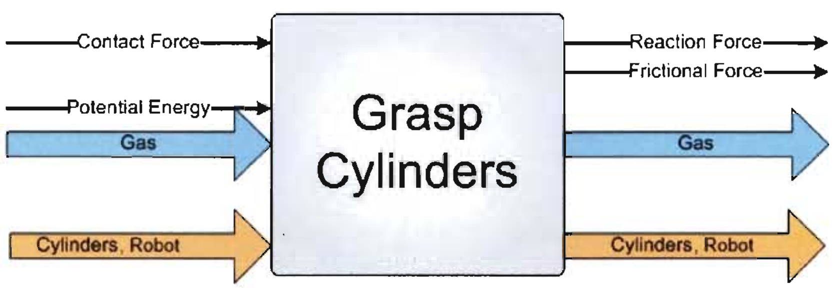


Functional Analysis



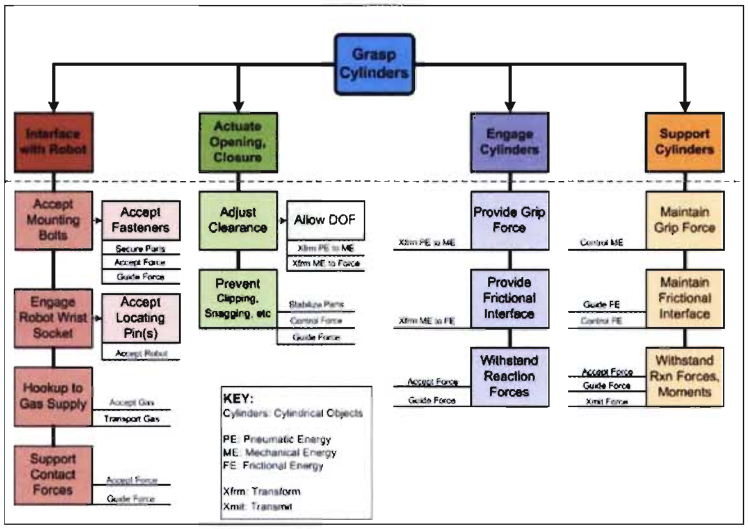
Functional Analysis

Blackbox Model



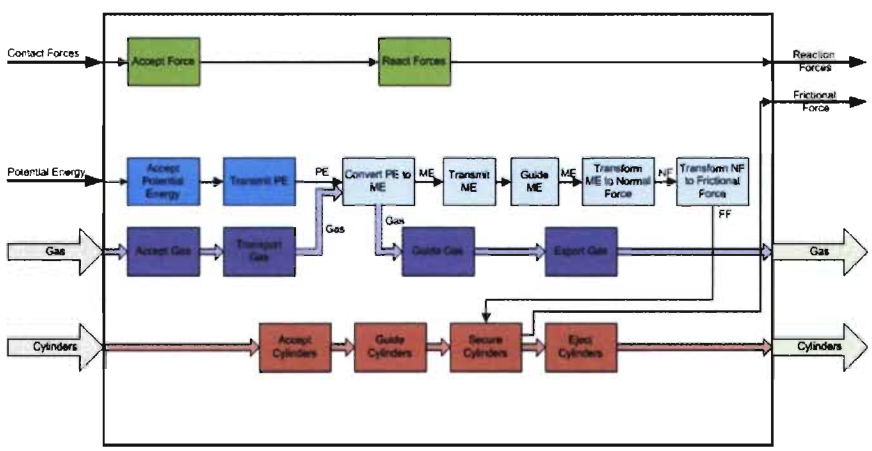
Functional Analysis

Function Tree

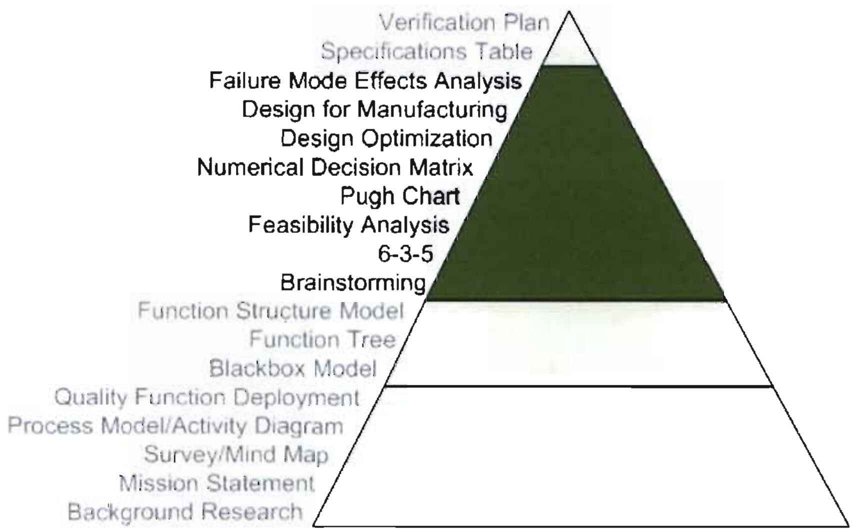


Functional Analysis

Function Structure



Conceptual Development

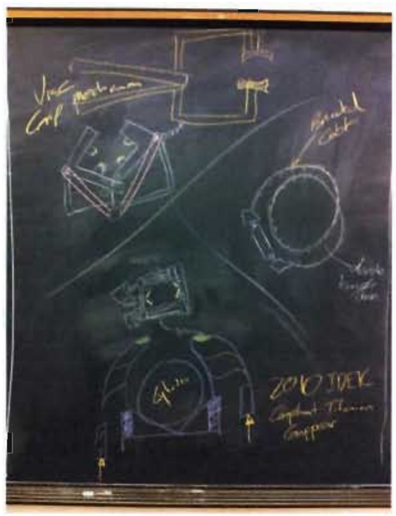


Brainstorming

- Project Experts (Group Members)
  - Provides the most feasible concepts
  - Often have more knowledge about the project
  - May suffer from design fixation
- Outsiders (Draftees)
  - Need background on project before effective at ideation
  - More likely to suggest alternate solutions
- Moderator
  - Guides the discussion
    - Stops excessive time wasting
    - Instigates potential design solutions and discussions
  - Needs thorough background on project to answer questions

Conceptual Development

6-3-5



Conceptual Development

Feasibility Analysis

- Physical Realities
  - Does the concept rely on existing technologies?
  - Will the concept require resources beyond system capabilities?
- Robot Interface
  - Is it possible to design so that it can connect with the robot?
- Manufacturability
  - Is it possible to manufacture?
- System Requirements
  - Can it be designed to meet the functions and needs of the system?

Conceptual Development

Pugh Chart Analysis

Criteria	Design													
	LANL	#3	#4	#5	#7	#9	#11	#13	#15	#16	#17	#18	#20	#24
Mass	S	-	-	-	+	-	+	-	-	-	+	+	-	S
Size	S	S	-	-	+	-	-	-	S	-	S	S	S	-
Repeatability	S	S	+	+	-	S	+	S	S	-	-	+	S	S
Maximum Contact Force	S	+	+	+	S	+	+	-	+	S	S	S	+	+
Control Simplicity	S	+	+	+	-	+	+	+	+	S	S	+	+	S
Diameter Range	S	+	+	+	+	+	S	+	S	+	+	+	+	S
Damage Resistance	S	S	S	-	+	-	-	-	-	-	-	S	-	-
Design Simplicity	S	-	-	-	S	-	-	-	-	-	-	S	-	-
Total	0	1	1	0	2	-1	1	-3	-1	-4	-1	4	0	-2
+	0	3	4	4	4	3	4	2	2	1	2	4	3	1
-	0	2	3	4	4	4	3	5	3	5	3	0	3	3

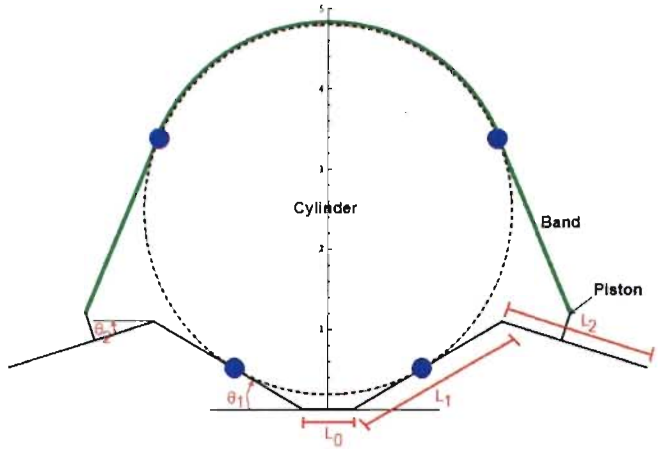
Conceptual Development

Numerical Decision Matrix

Criteria	Weight	Design						
		LANL	3	4	5	18	20	24
Repeatability	0.17	75 / 12.75	66 / 11.22	94 / 15.98	82 / 13.94	93 / 15.81	80 / 13.6	60 / 10.2
Mass	0.15	90 / 13.5	77 / 11.55	35 / 5.25	62 / 9.3	86 / 12.9	80 / 12	45 / 6.75
Control Simplicity	0.15	20 / 3	50 / 7.5	90 / 13.5	50 / 7.5	70 / 10.5	55 / 8.25	55 / 8.25
Max. Contact Force	0.14	40 / 5.6	53 / 7.42	98 / 13.72	70 / 9.8	65 / 9.1	75 / 10.5	80 / 11.2
Size	0.13	70 / 9.1	65 / 8.45	60 / 7.8	50 / 6.5	70 / 9.1	65 / 8.45	50 / 6.5
Damage Resistance	0.10	50 / 5	45 / 4.5	80 / 8	40 / 4	60 / 6	45 / 4.5	20 / 2
Design Simplicity	0.08	90 / 7.2	70 / 5.6	29 / 2.32	85 / 6.8	80 / 6.4	80 / 6.4	20 / 1.6
	0.08	15 / 1.2	40 / 3.2	86 / 6.88	80 / 6.4	83 / 6.64	55 / 4.4	30 / 2.4
Summation	1.00	57.35	59.44	73.45	64.24	76.45	68.1	48.9
Difference from LANL		0.00	2.09	16.1	6.89	19.1	10.75	-8.45

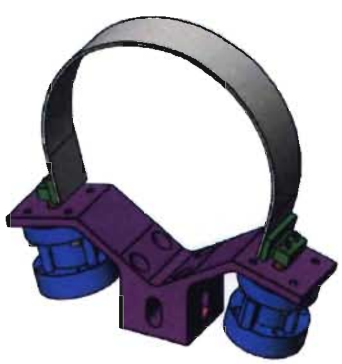
Conceptual Development

Design Optimization



Conceptual Development

Design for Manufacturing



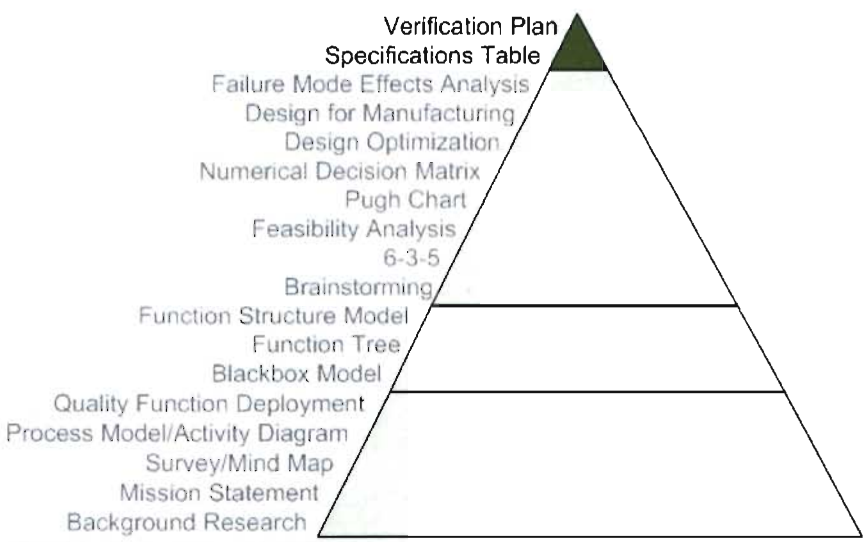
- Filleted Interior Edges
- Standardized Features
- Standardized Fasteners
- Minimized Repositioning

Conceptual Development

Failure Mode Effects Analysis

#	Part	Failure Mode	Potential Effects of Failure	S	Potential Causes	O	Current Design Controls	D	Recommende d Action	RPN
1	Band	Wear of Friction Surface	Reduced ability to grip cans	4	Wear over time, Misaligned Grasp, Insufficient Grasp Force	9	Grasp Clearance, Symmetric Closure	4	Inspection Schedule	144
2	Band	fracture near welds	Drops Current Payload, Spalling, Completely Non-Functional	8	Overloading Pistons, Manufacturing Flaw	4	Steel Material and Band Thickness, Design FOS	9	GTAW (TIG) Welds	288
3	Band	Deformation	Non-Functional, Reduced Clearance	6	Collisions, Too much payload	3	Maximum Specified Load	2	User Manual/Opera tor Training	36
4	Band Attachment Screws	Exceeding Yield Strength	Band Detaches, Deformed Closure, Dropped Payload, Increased Stress on Piston Rods	6	Overloading Pistons, Manufacturing Flaw, Assembly Error	1	Assembly Procedures, BOM, Maximum Specified Load	10	Specify SAE Grade 8 Bolts	60
5	Piston Rods	Bending	No Actuation	5	Bending Stresses from Load, Collision	3	Material Choice, Tangent Band Forces	4	Dual Rod Piston	60
6	Pneumatic Seals	Wear or Extrusion	Leaking, Loss of Grip Force, Non-Actuation	5	Contamination, Aging, Fatigue	1	None	3	User Manual/Opera tor Training	15
7	Gripper Base	Cracking/ Fracture	Total Loss of Function, Dropped Payload	7	Collision, Fatigue, and Overloading	2	Design FOS, Thickness, Fillets	3	Optimize Fillet Size and Base Thickness	42

Design Confirmation



Design Confirmation

Specifications Table

Date	Demand/Wish	Function vs Constraint	Engineering Requirement	Responsibility	Test
10/6/2010	D	F	Factor of Safetly	David	Sim1, Sim2
10/6/2010	W	F	Mean Time Between Failures	David	Phys1
10/6/2010	W	F	Maintenance Interval	David	Calc7
10/6/2010	D	F	Cyclical Error	David	Phys1
10/6/2010	D	C-Operation	Handling Failure Rate	David	Phys1
10/6/2010	D	F	Coefficient of Friction	Paul	Calc4
10/6/2010	D	C-Load Imposed By	Carrying Capacity	Paul	Sim1, Sim2, Phys2
10/6/2010	D	F	Contact Force	Paul	Calc6
10/6/2010	W	C-Load Imposed By	Mass	John	Mod3
10/6/2010	W	F	Repair Time	Paul	Calc2
10/6/2010	W	F	Repair Cost	Paul	Calc2
10/6/2010	W	F	Bounding Volume	John	Mod4
10/6/2010	W	F	Footprint	John	Mod5
10/6/2010	W	C-Geometric	Center of Gravity	John	Mod1
10/6/2010	W	C-Geometric	Center of Grasp	John	Mod2
10/6/2010	W	F	Approach Code	David	Phys3
10/6/2010	W	F	Setup Time	Beth	Phys4
10/6/2010	W	C-Operation	Air to Actuate	David	Calc1
10/6/2010	D	C-Geometric	Maximum Diameter	Beth	Sim4, Phys6
10/6/2010	D	C-Geometric	Minimum Diameter	Beth	Sim3, Phys5
10/6/2010	W	F	# of Joints (DOF)	Beth	Calc3
10/6/2010	W	F	Cost	Beth	Calc5

Design Confirmation

Verification Plan

Methods	Requirement	Test Type	Given	Find
Mod1	Center of Gravity	Model	• Gripper assembly CAD model, origin at robot interface	• Center of Gravity
Mod2	Center of Grasp	Model	• Gripper assembly CAD model, origin at robot interface	• Center of Grasp
Mod3	Mass	Model	• Gripper assembly CAD model	• Mass
Mod4	Bounding Volume	Model	• Gripper assembly CAD model	• Bounding Volume
Mod5	Footprint	Model	• Gripper assembly CAD model	• Largest area
Sim1	Factor of Safety	Simulation	• Gripper assembly CAD model • Gravity oriented to simulate horizontal grip • 6kg load distributed along face of band in the direction of gravity • Fix interface to simulate robot connection	• Von Mises stress • Shear stress • Primary stress • Factor of safety for all above values • Strain
	Carrying Capacity	Simulation		
Sim2	Factor of Safety	Simulation	• Gripper assembly CAD model • Gravity oriented to simulate horizontal grip • 6kg load distributed along face of band in the direction of gravity • Fix interface to simulate robot connection	• Von Mises stress • Shear stress • Primary stress • Factor of safety for all above values • Strain
	Carrying Capacity	Simulation		
Sim3	Minimum Diameter	Simulation	• Gripper assembly CAD model • Fix interface to simulate robot connection • Fixed deflection to minimum closure	• Minimum diameter
Sim4	Maximum Diameter	Simulation	• Gripper assembly CAD model • Fix interface to simulate robot connection • Fixed deflection to maximum opening	• Maximum diameter
Calc1	Air to Actuate	Calculation	• Piston actuation area • Working piston throw	• Volume air used
Calc2	Repair Time	Calculation	• Potential failures • Material and parts costs	• Failure modes • Repair complexity • Estimated cost
	Repair Cost	Calculation		
Calc3	# of Joints (DOF)	Calculation	• Gripper Design	• Number of joints