

Projeto Assistido por Computador no Apoio à Conceção de Ferramentas de Extrusão

J. M. Nóbrega e O.S. Carneiro

mnobrega@dep.uminho.pt / olgasc@dep.uminho.pt



Universidade do Minho
Escola de Engenharia



PIEP - Pólo de Inovação em Engenharia de Polímeros



IPC – Instituto de Polímeros e Compósitos
I3N – Instituto de Nanoestruturas, Nanomodelação e Nanofabricação

XXVII Seminário de Plásticos

27 a 29 de Outubro de 2011 - Aveiro

Associação Portuguesa da
Indústria de Plásticos



- Motivação
- Introdução
- Cabeças de Extrusão
- Calibradores
- Desenvolvimentos em Curso

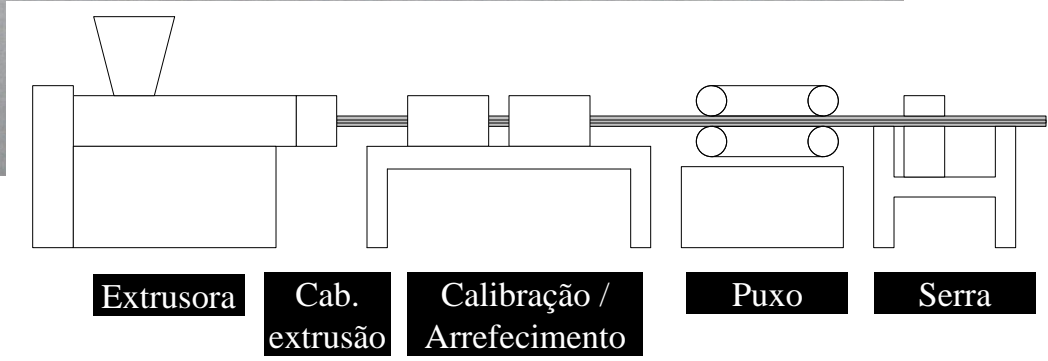
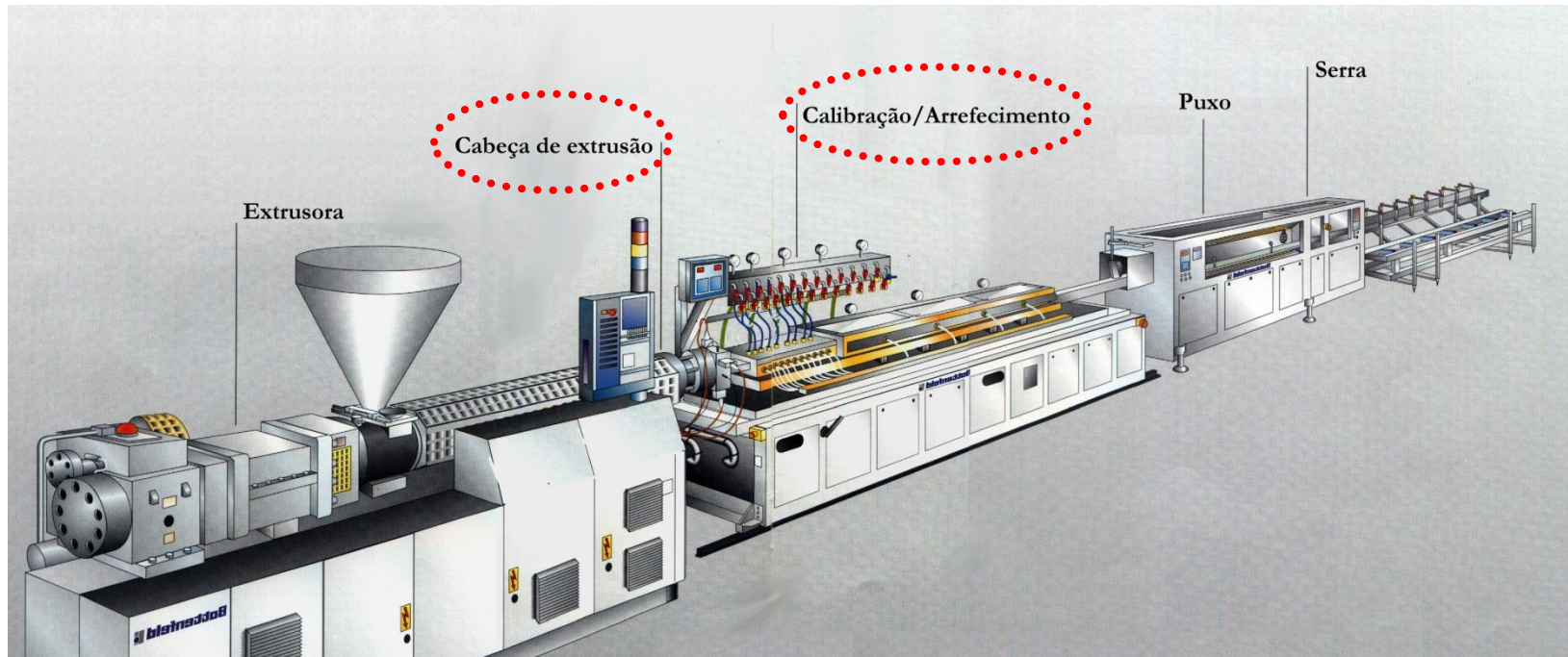
Projeto de Moldes

The logo for Moldflow, featuring the word "moldflow" in a green, lowercase, sans-serif font with a registered trademark symbol.The logo for Moldex3D, with "Moldex3D" in a red, stylized font and "Professional CAE Software for Injection Molding" in a smaller black font below it.The logo for C-MOLD, with "C-MOLD" in a blue, stylized font and a globe icon integrated into the letter "O".

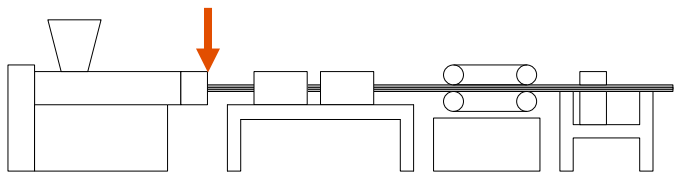
Extrusão de perfis

The logo for polydynamics, featuring the word "polydynamics" in a green, lowercase, sans-serif font with a globe icon integrated into the letter "y".The logo for compuplast, featuring the word "compuplast" in a blue, lowercase, sans-serif font with a globe icon integrated into the letter "p".The logo for Polyflow ANSYS, with "Polyflow" in a black, sans-serif font above "ANSYS" in a yellow, sans-serif font on a black background.

Introdução - Extrusão de Perfis



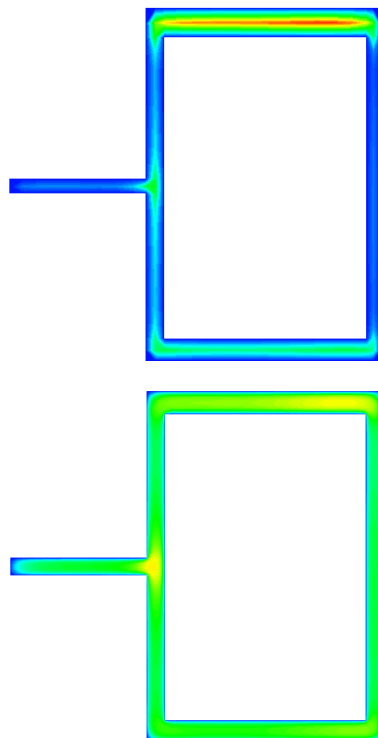
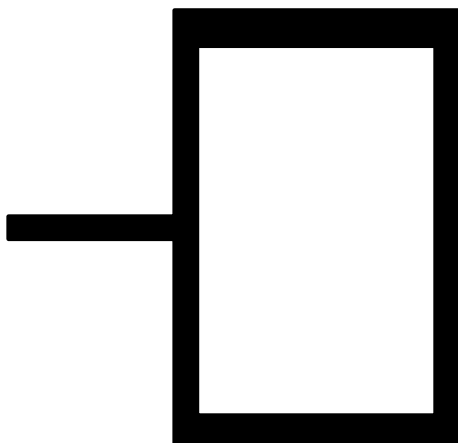
Cabeças de Extrusão – Equilíbrio de Fluxo



Secção transversal

Distribuição de Velocidades

Ensaio Experimental

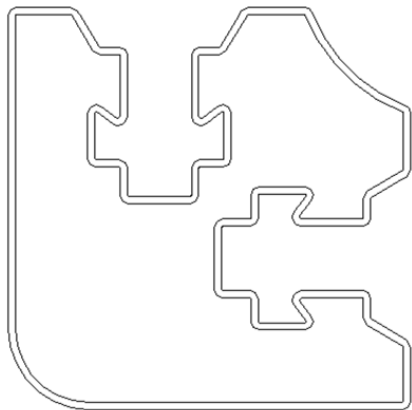


Fluxo nOK



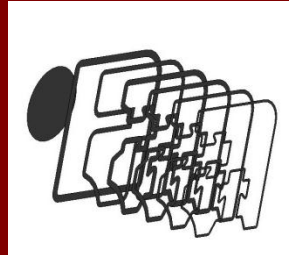
Fluxo OK

Perfil

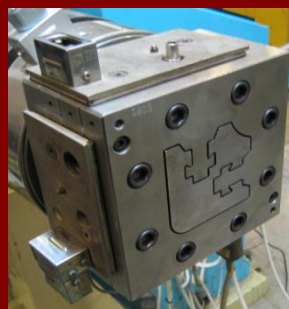


Concepção

Projeto



Maquinagem



Teste



Fontes de Erro

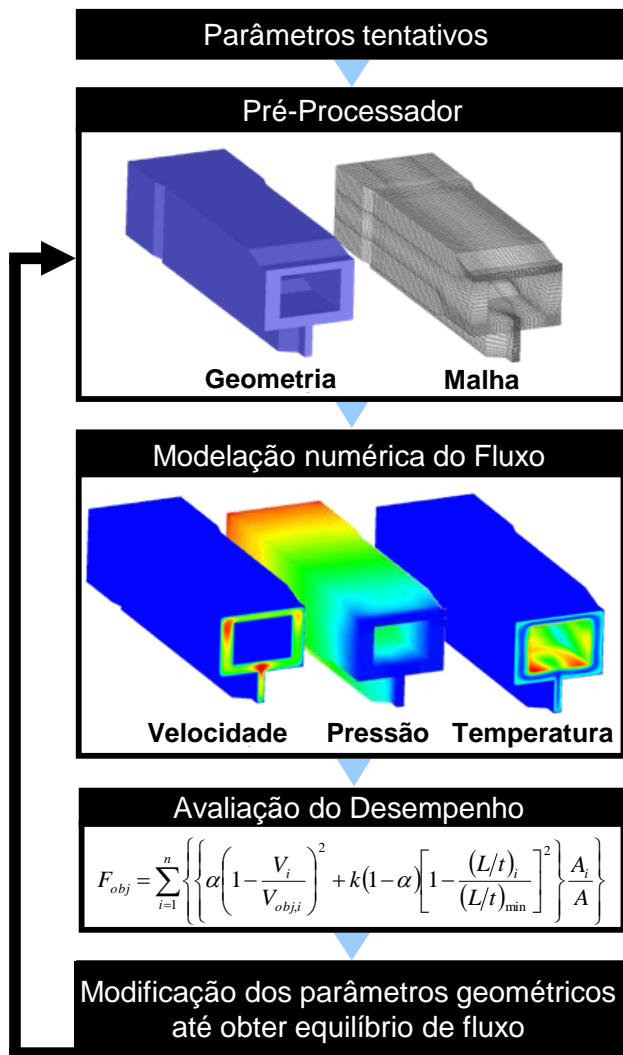
Precisão do modelo

Precisão de maquinagem

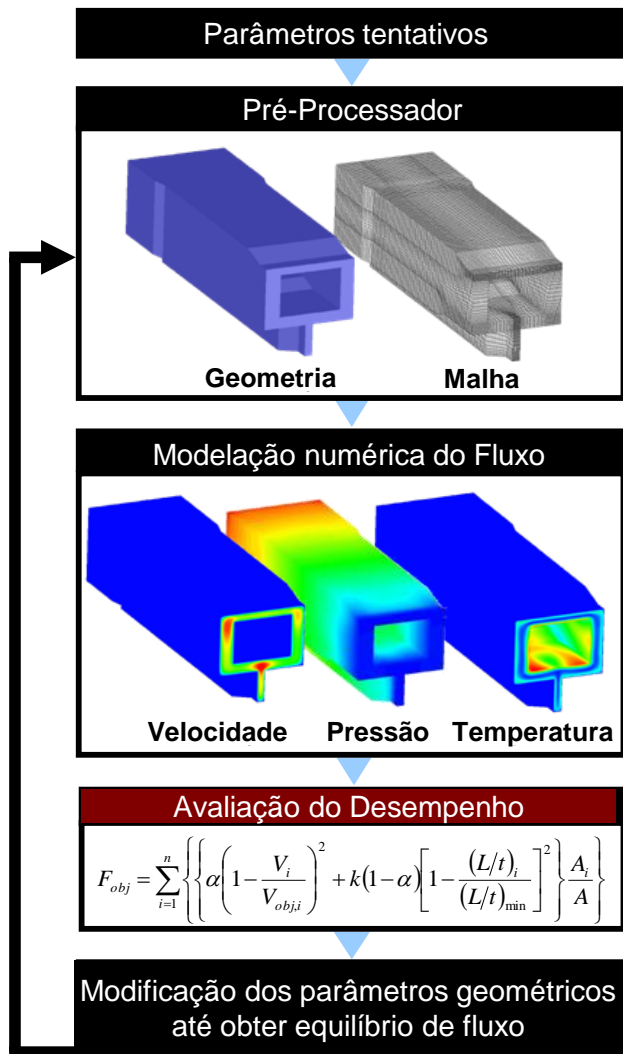
Variações dos parâmetros do processo e no comportamento da matéria-prima



Cabeças de Extrusão – Projeto Automático



Cabeças de Extrusão – Projeto Automático



Função Objetivo

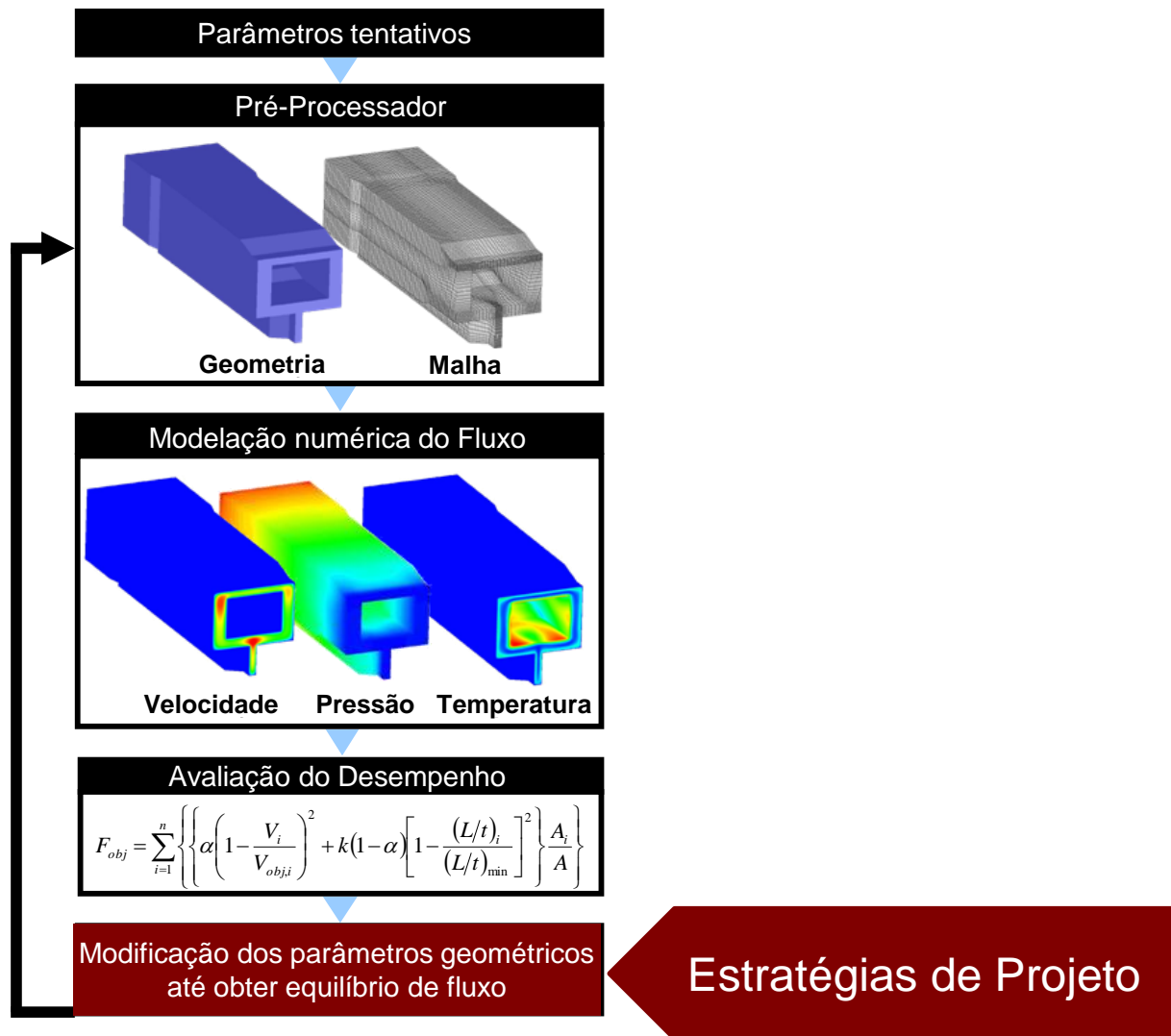
$$F_{obj} = \sum_{i=1}^n \left\{ \underbrace{\alpha \left(1 - \frac{V_i}{V_{obj,i}} \right)^2}_{\text{Distribuição de Fluxo}} + k(1-\alpha) \left[1 - \frac{(L/t)_i}{(L/t)_{min}} \right]^2 \right\} \underbrace{\left\{ \frac{A_i}{A} \right\}}_{\text{Área relativa}}$$

Distribuição de Fluxo

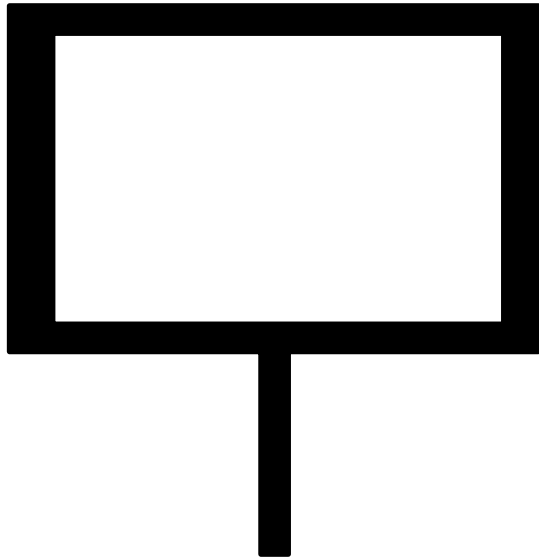
Valor L/t Admissível

Área relativa

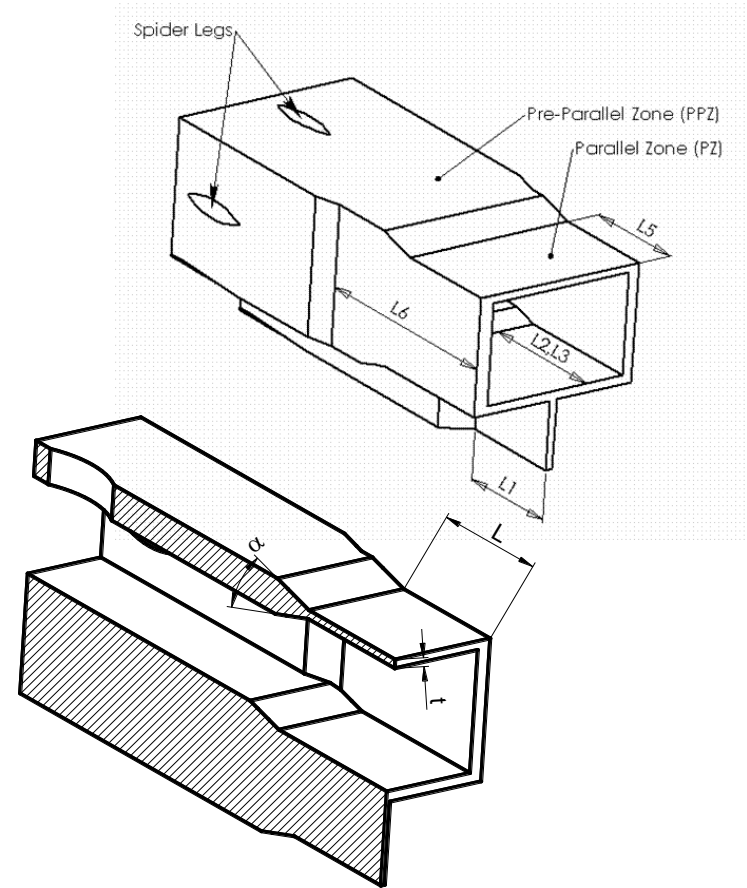
Cabeças de Extrusão – Projeto Automático



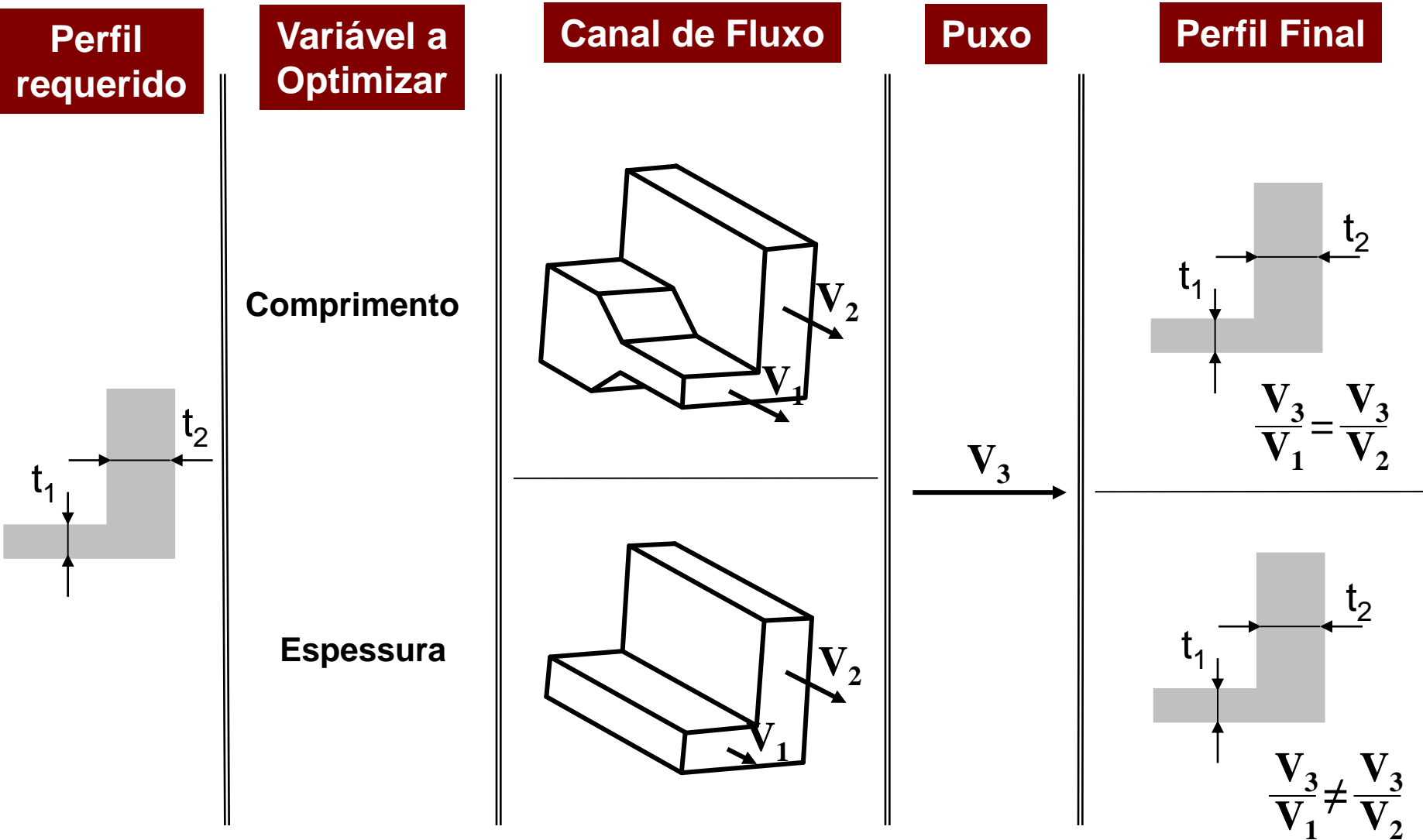
Perfil



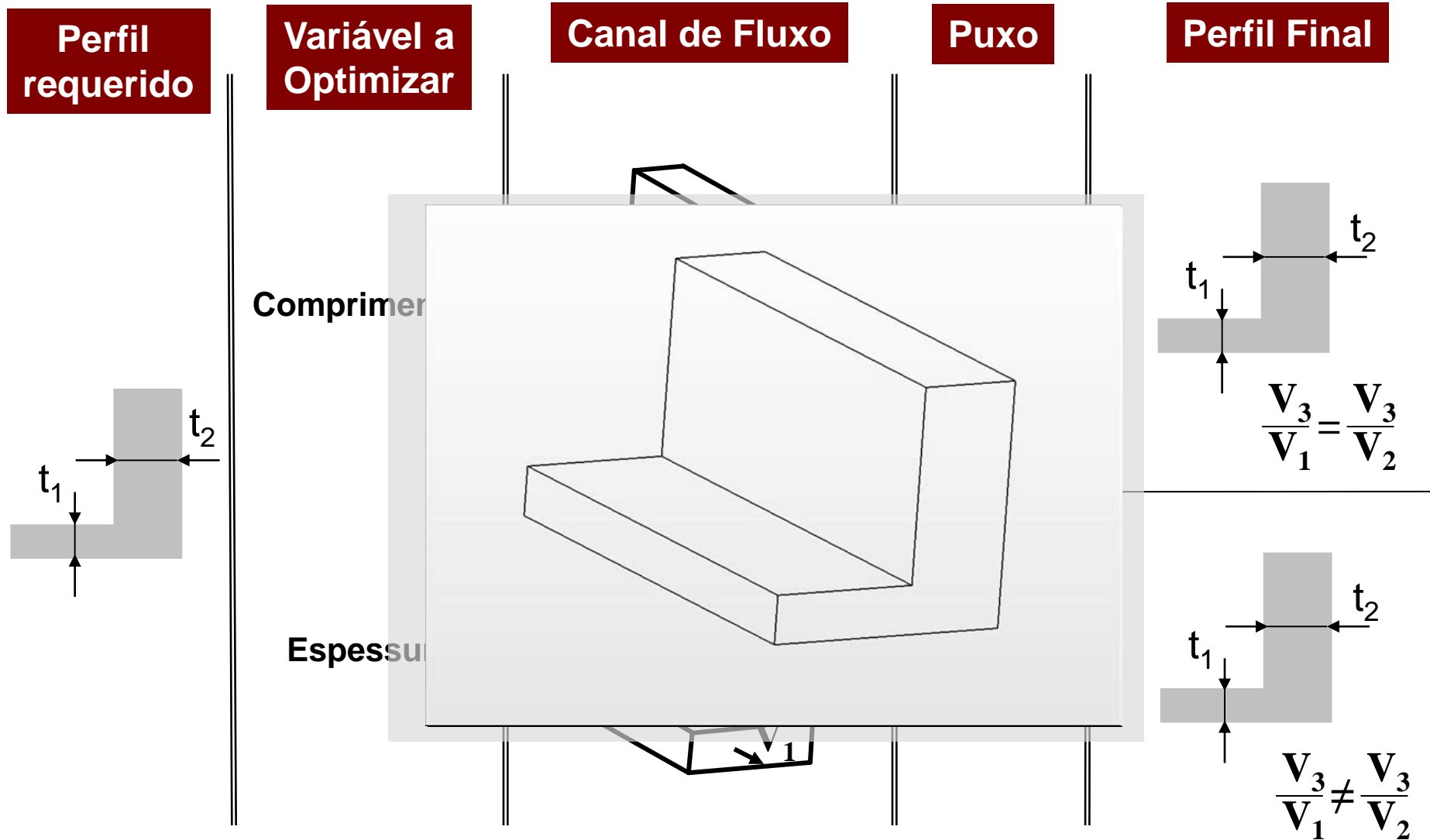
Geometria do Canal de Fluxo



Cabeças de Extrusão – Estratégias de Projeto

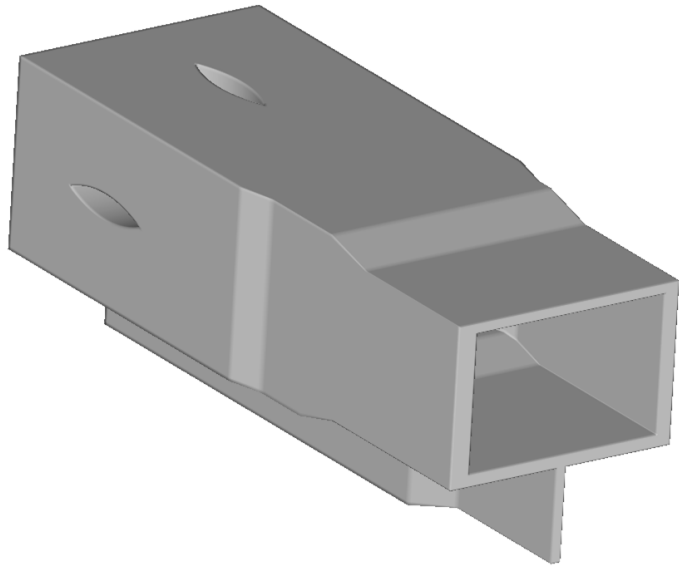


Cabeças de Extrusão – Estratégias de Projeto

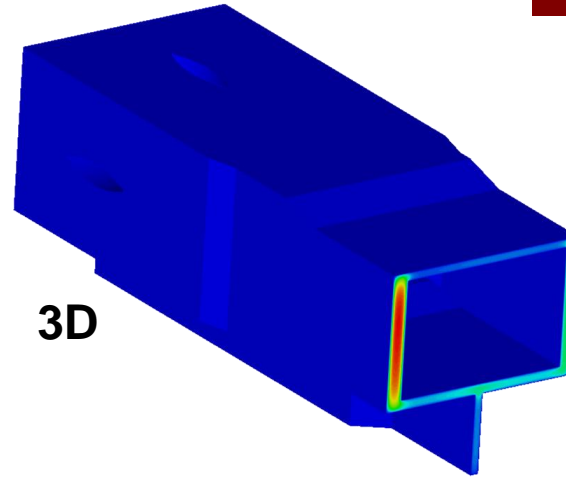


Cabeças de Extrusão – Requisitos da Modelação

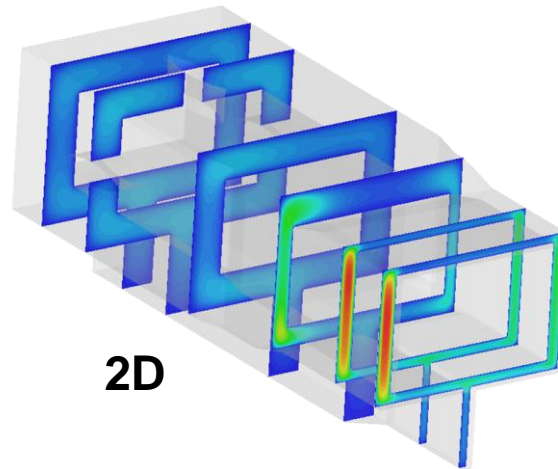
Canal de Fluxo



Modelação Numérica



3D



2D

Estratégia de Projeto

L

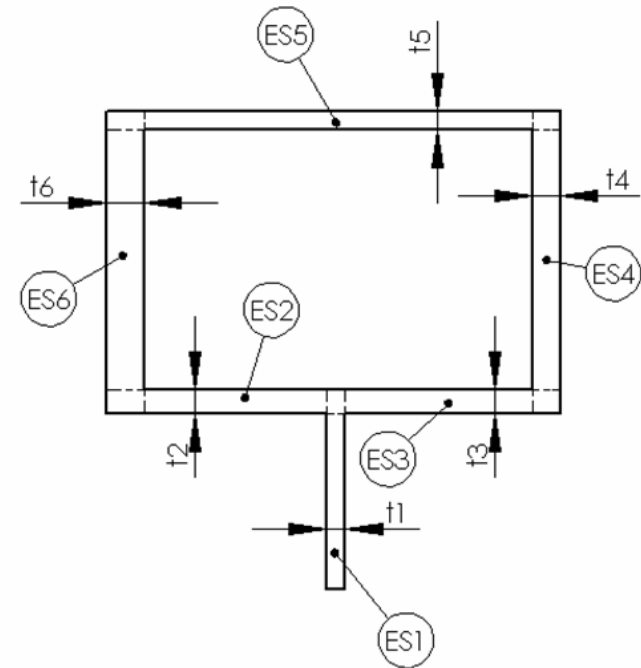
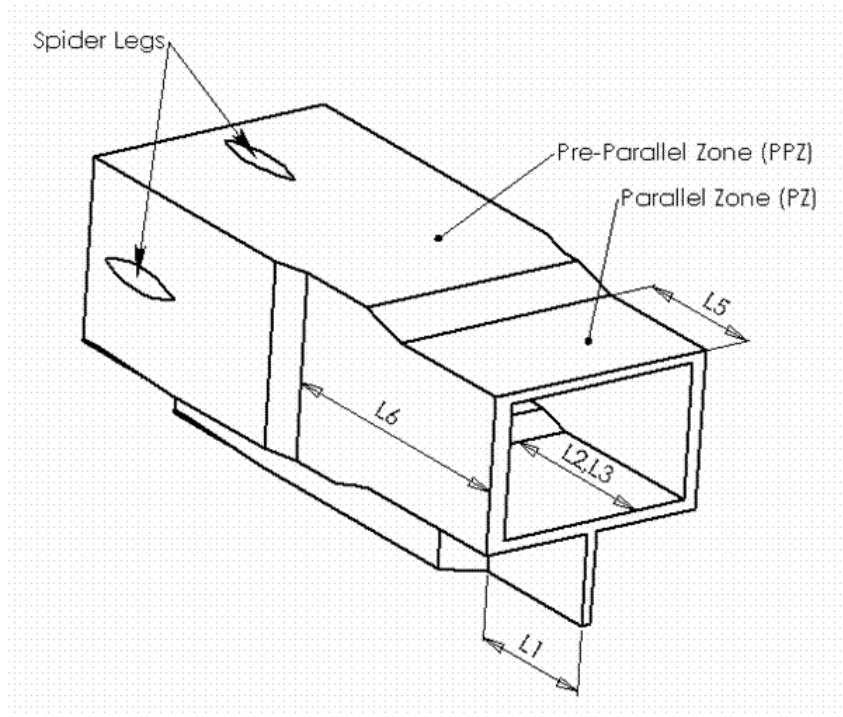
T



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INSTITUTE FOR
INTEGRATED
MANUFACTURING AND
INDUSTRIAL INNOVATION

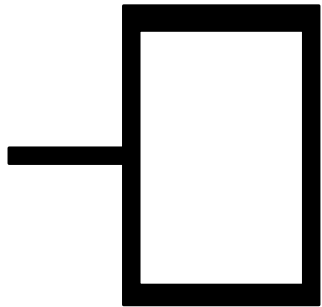


Cabeças de Extrusão – Optimização



Dimensões iniciais do Canal de Fluxo

ES	1	2	3	4	5	6
t_i [mm]	2.0	2.5	2.5	3.0	2.0	4.0
L_i [mm]	30.0	37.5	37.5	45.0	30.0	60.0
L_i/t_i	15.0	15.0	15.0	15.0	15.0	15.0



Equação Constitutiva

$$\eta(\dot{\gamma}, T) = F(\dot{\gamma} \times H(T)) H(T)$$

$$F(\dot{\gamma}) = \eta_{\infty} + \frac{\eta_0 - \eta_{\infty}}{(1 + (\lambda \dot{\gamma})^2)^{\frac{1-n}{2}}}$$

$$H(T) = \exp\left[\alpha \left(\frac{1}{T} - \frac{1}{T_{\alpha}}\right)\right]$$

Condições de Fronteira

Fluxo	20 kg/h
Temperatura à entrada	230 °C
Temperatura das parede	230 °C
Paredes internas	adiabático

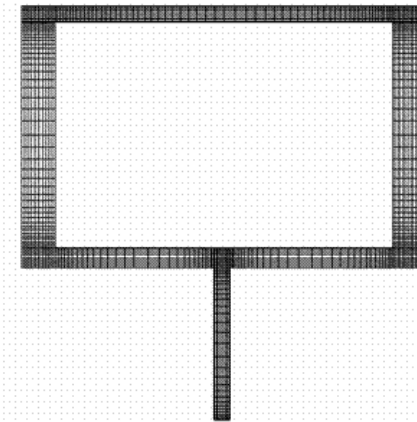
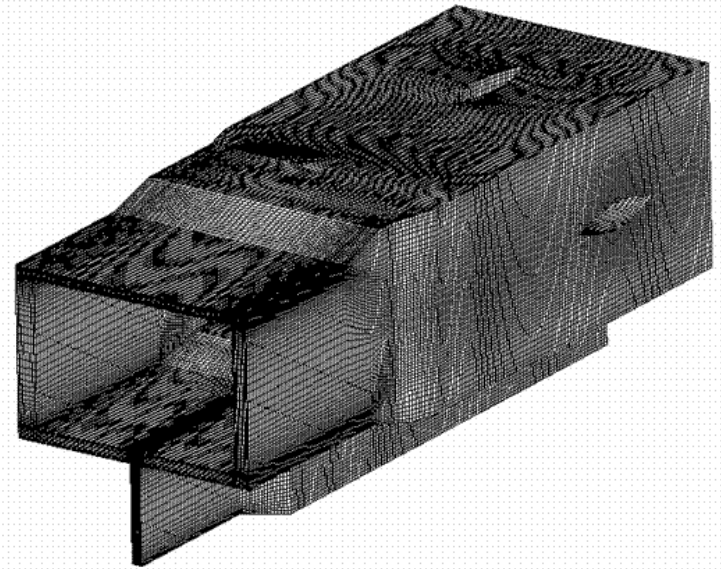
Designação das Geometrias

DieNI – Tentativa inicial

DieL – Optimização do Comprimento

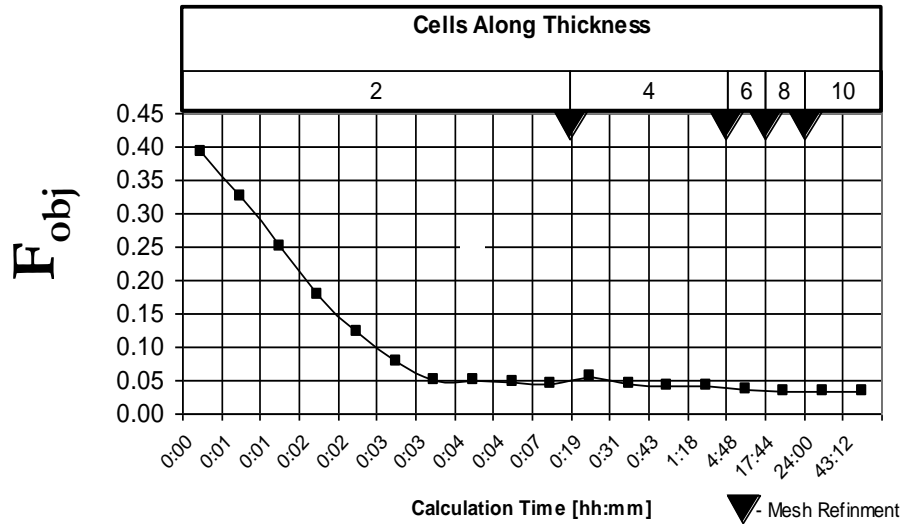
DieT – Optimização da Espessura

Malha computacional

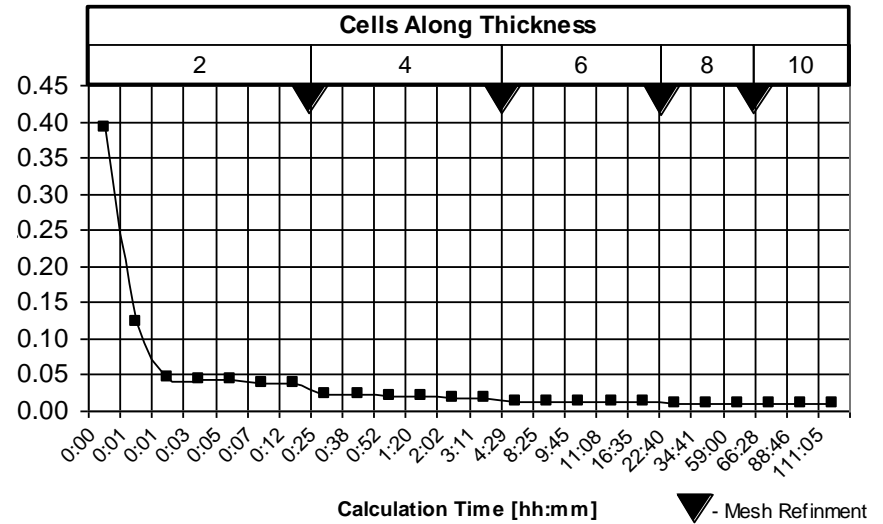


Cabeças de Extrusão – Optimização

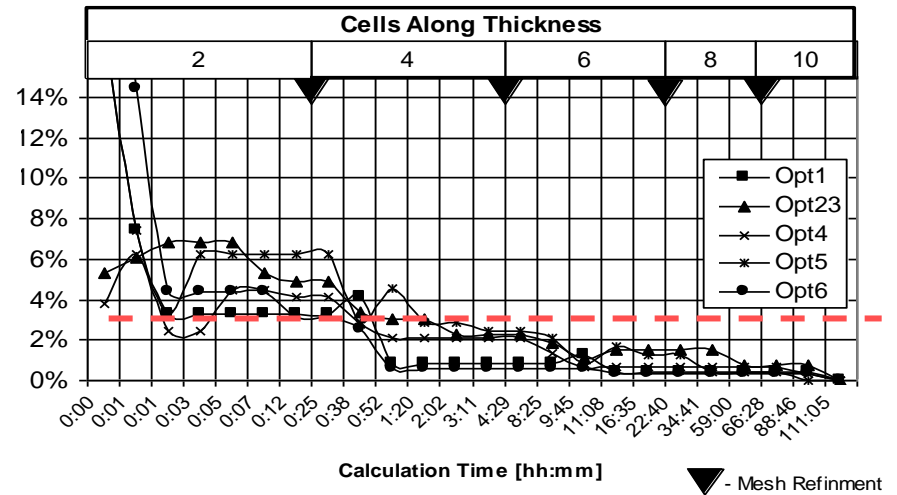
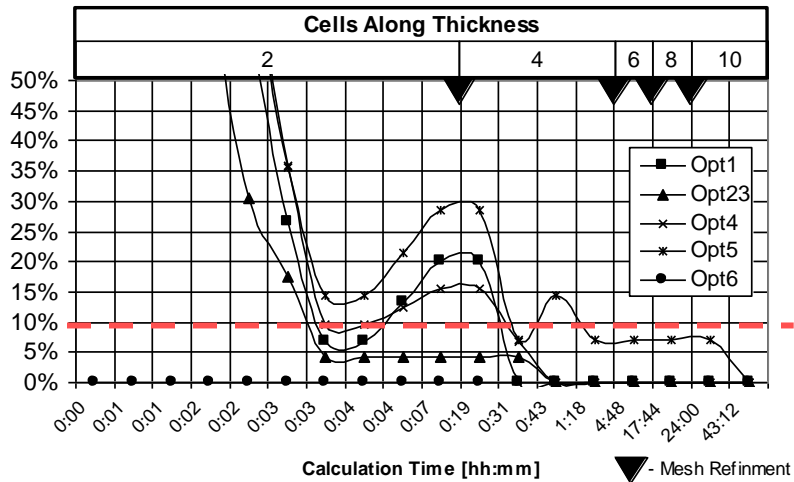
DieL



DieT

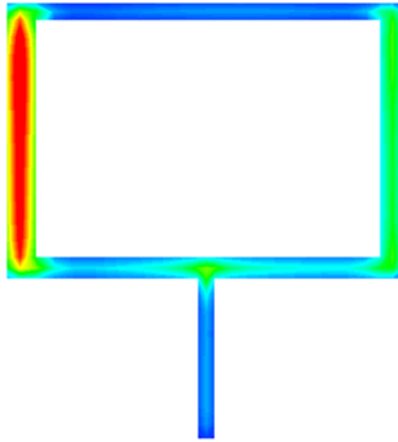


Diferença para a Final

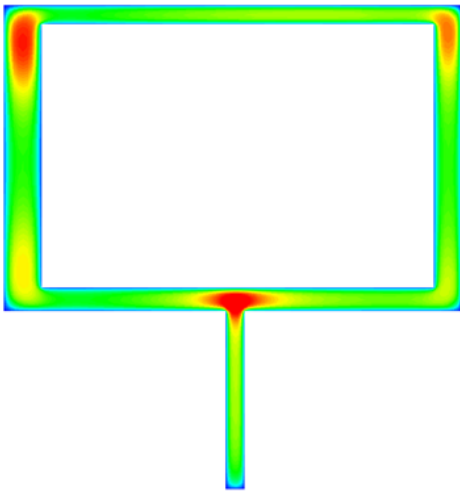


Cabeças de Extrusão – Optimização

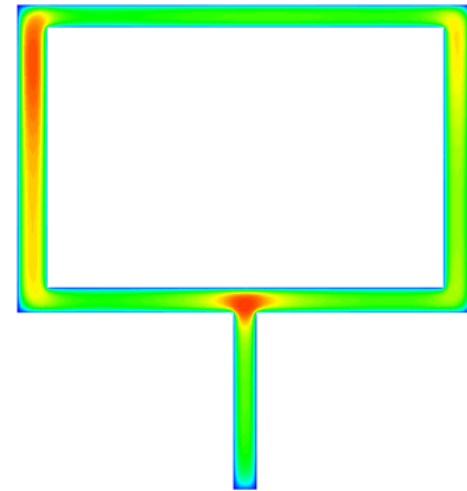
DieIni



DieL



DieT



Velocidade [m/s]

0.000

0.004

0.008

0.012

0.016

0.020

0.024

0.027

0.031



DieIni

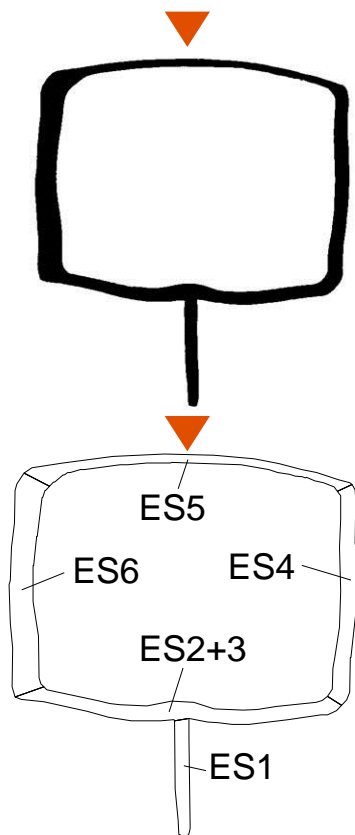


DieL



DieT





Áreas relativas das Secções Elementares

Run ID		ES1	ES2+3	ES4	ES5	ES6
INI	M	3.2	18.3	19.2	7.1	52.2
	C	2.9	16.2	19.2	6.7	55.0
	D	-9.4 %	-11.5 %	0.0 %	-5.6 %	5.4 %
	I	9.0 %	9.5 %	4.2 %	14.2 %	3.9 %
L	M	8.3	26.0	18.7	18.2	28.7
	C	8.2	25.4	19.1	18.9	28.4
	D	-1.2 %	-2.3 %	2.1%	3.8%	-1.0%
	I	6.7%	4.9%	5.6%	8.8%	3.9%
T	M	7.4	26.2	20.2	20.2	26.0
	C	7.4	25.8	19.7	20.3	26.8
	D	0.0 %	-1.5 %	-2.5 %	0.5 %	3.1 %
	I	6.3 %	4.4 %	4.9 %	8.2 %	5.6 %

Medida (M), Calculada (C), Diferença(D), Incerteza (I)

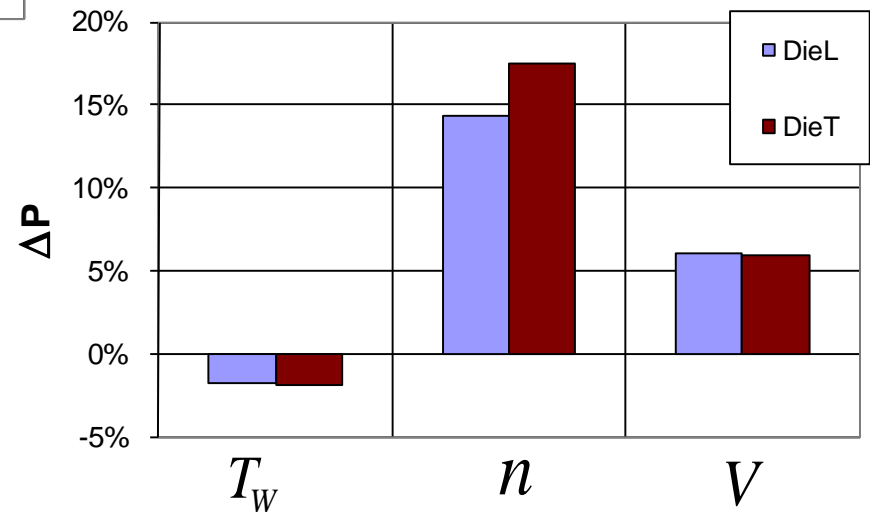
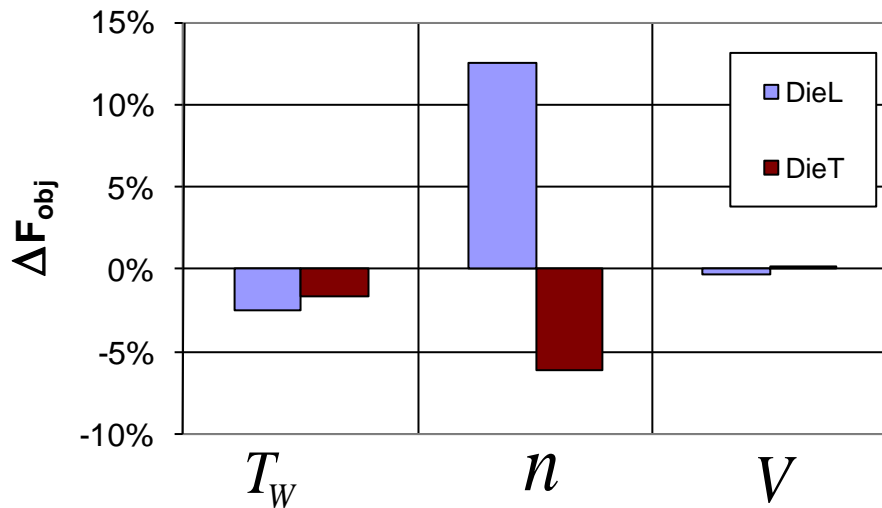
Sensibilidade aos Parâmetros do Processo e propriedades da matéria-prima

Os fatores considerados foram divididos em dois grupos:

- i) Condições de processamento: V , T_w
- ii) Propriedades da matéria-prima: n

Os testes (simulações) foram efetuados com base numa análise de Taguchi, considerando três níveis para cada fator

Sensibilidade aos Parâmetros do Processo e propriedades da matéria-prima



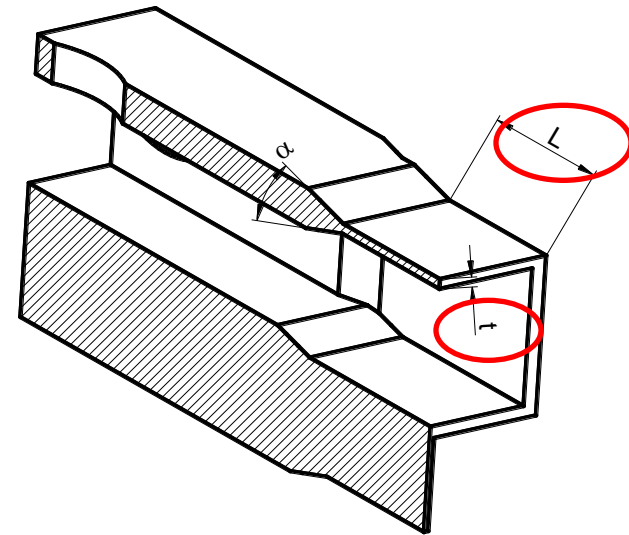
Sensibilidade à imprecisão de maquinagem

Cabeça de extrusão

DieL

DieT

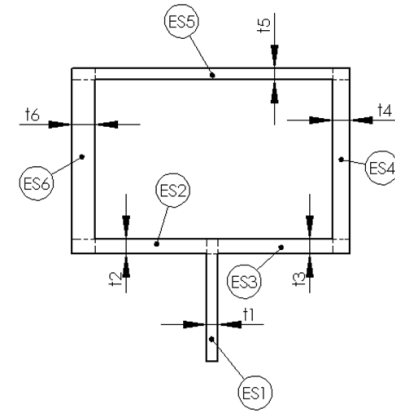
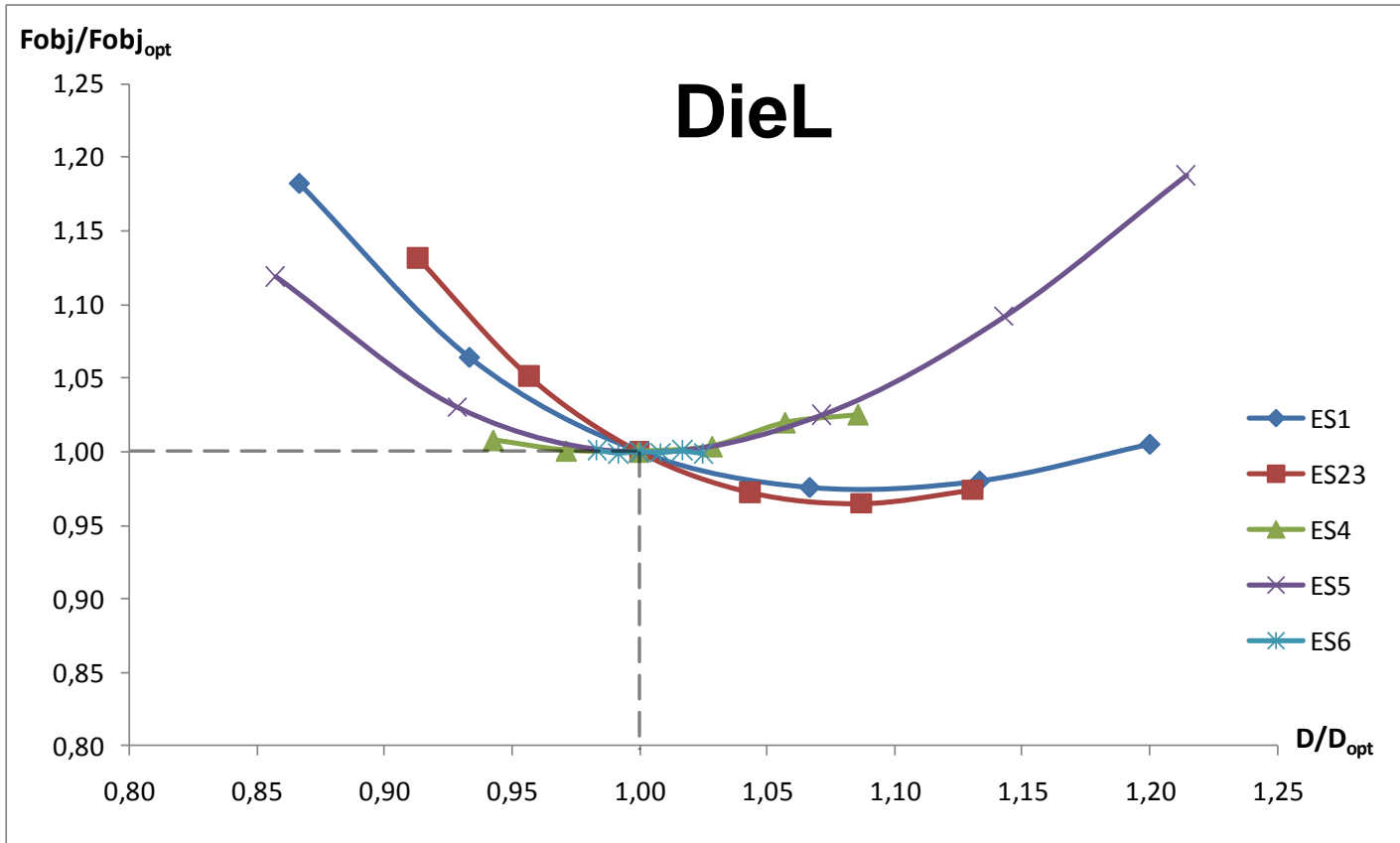
Estudos efetuados



Geometria do Canal de Fluxo

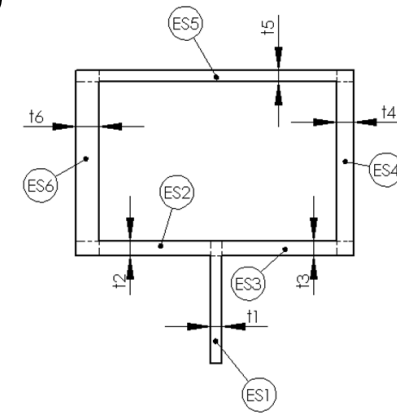
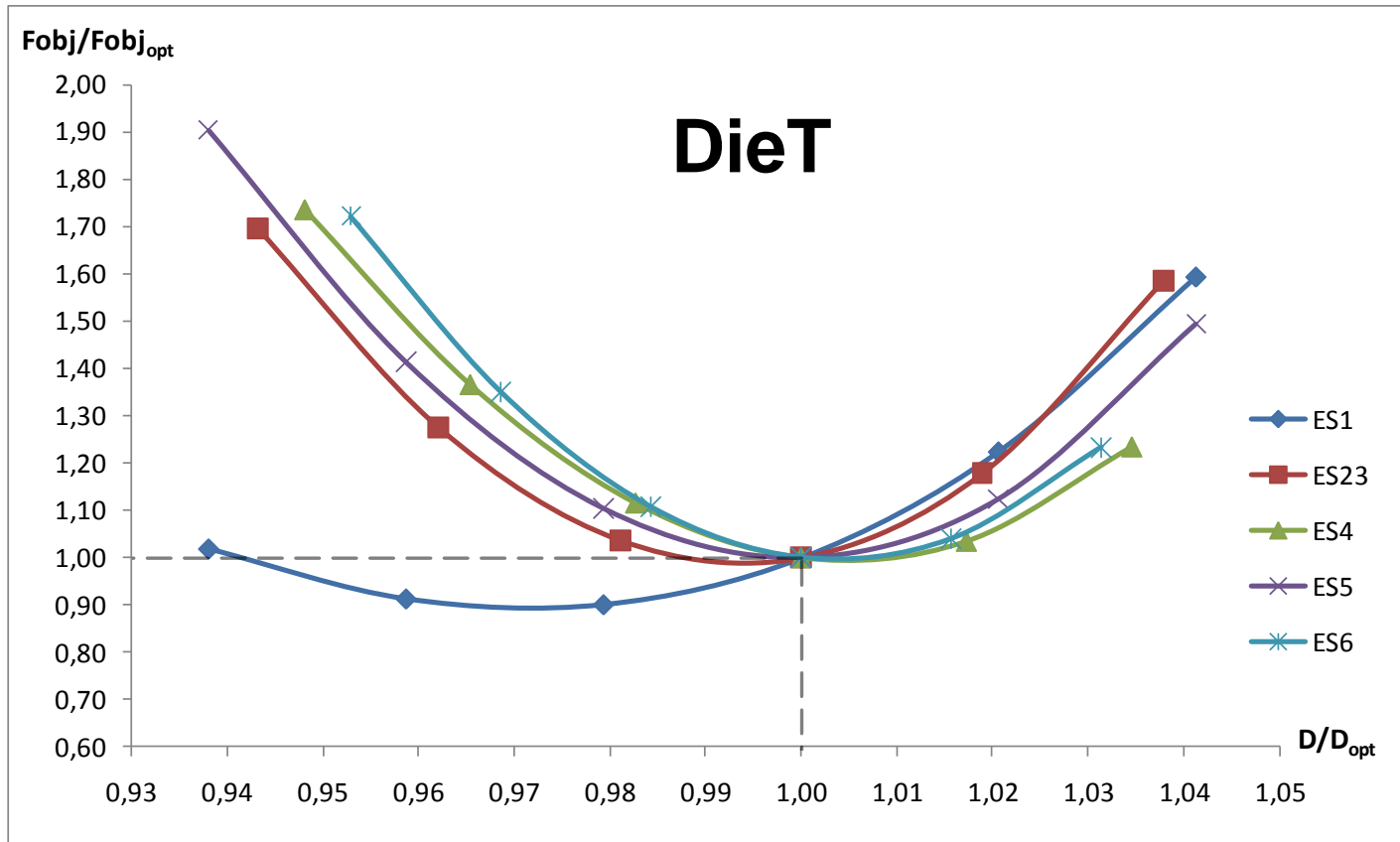
A imprecisão de maquinagem foi simulada (imposta) em ambas as cabeças de extrusão optimizadas

Sensibilidade à imprecisão de maquinagem



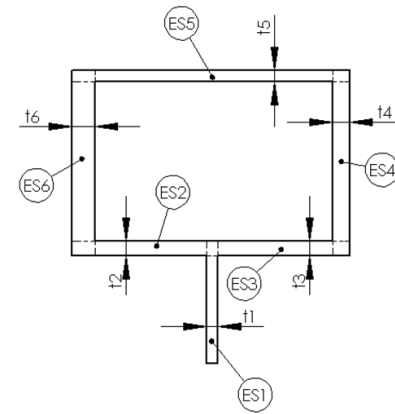
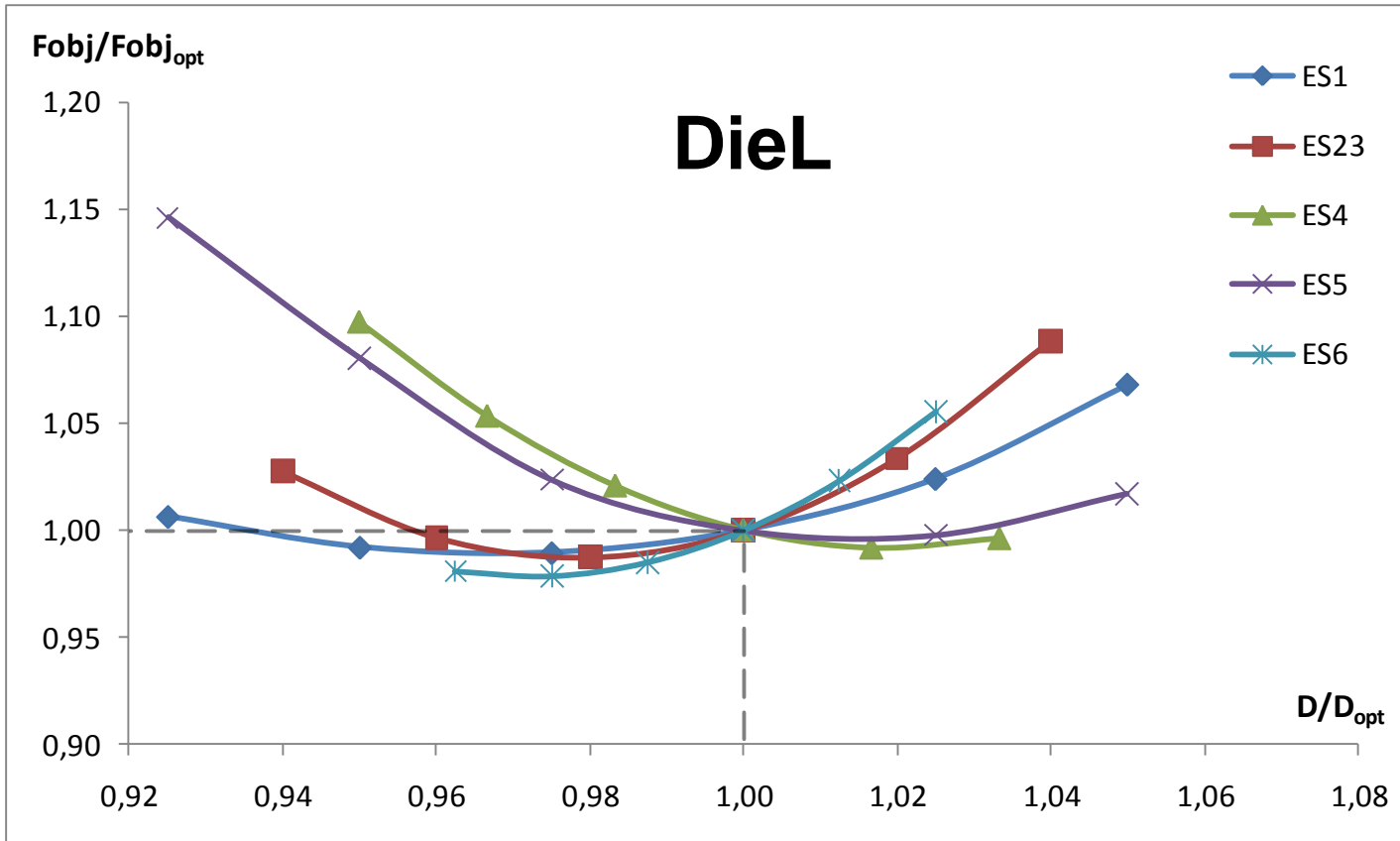
Efeito dos erros no comprimento das secções elementares

Sensibilidade à imprecisão de maquinagem



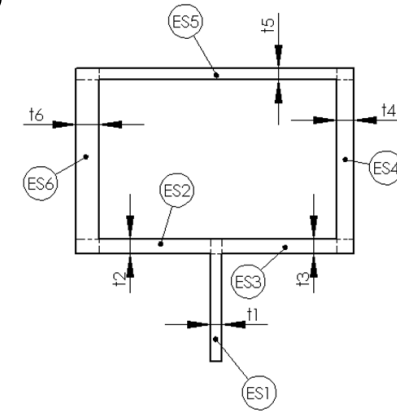
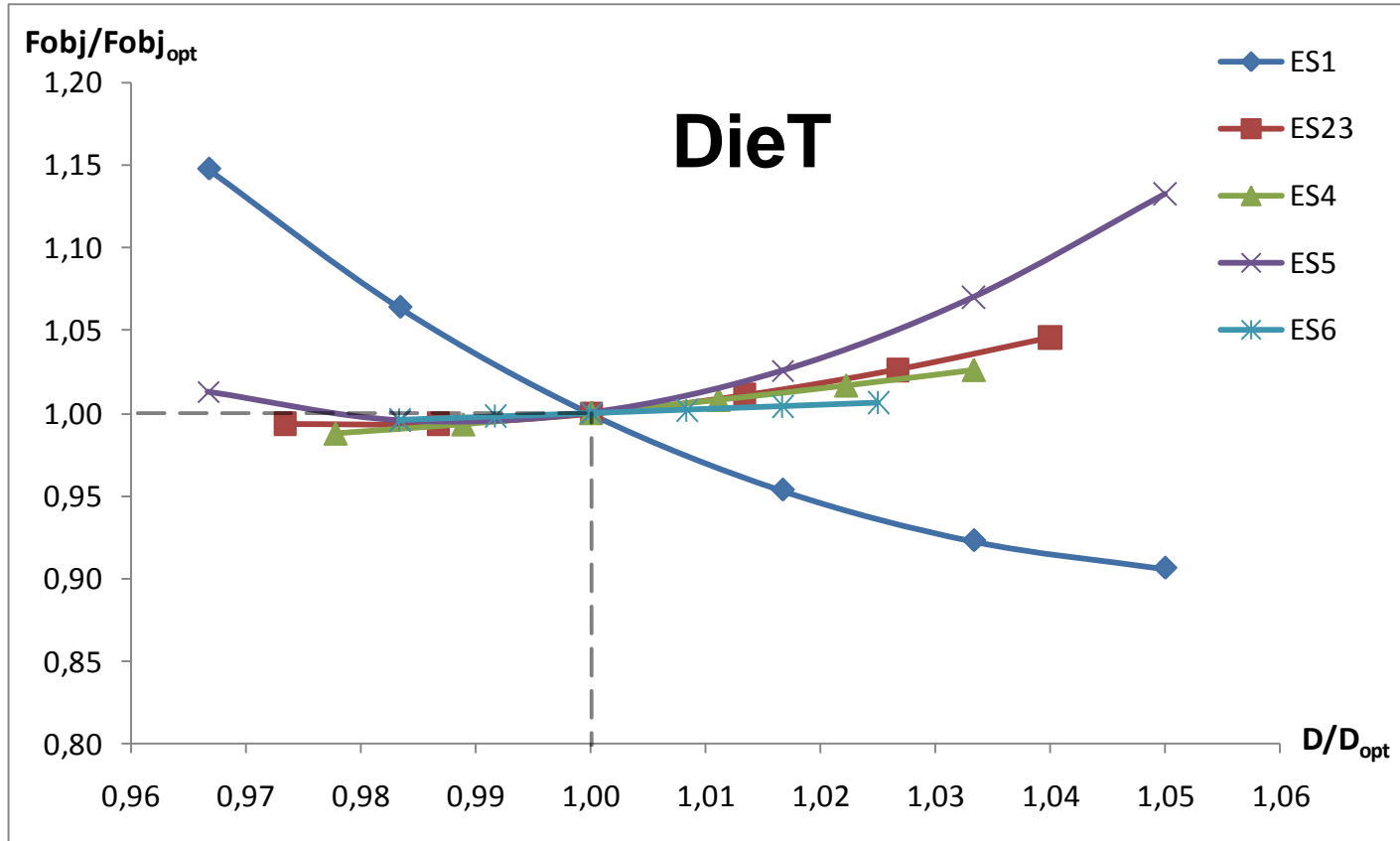
Efeito dos erros na espessura das secções elementares

Sensibilidade à imprecisão de maquinagem



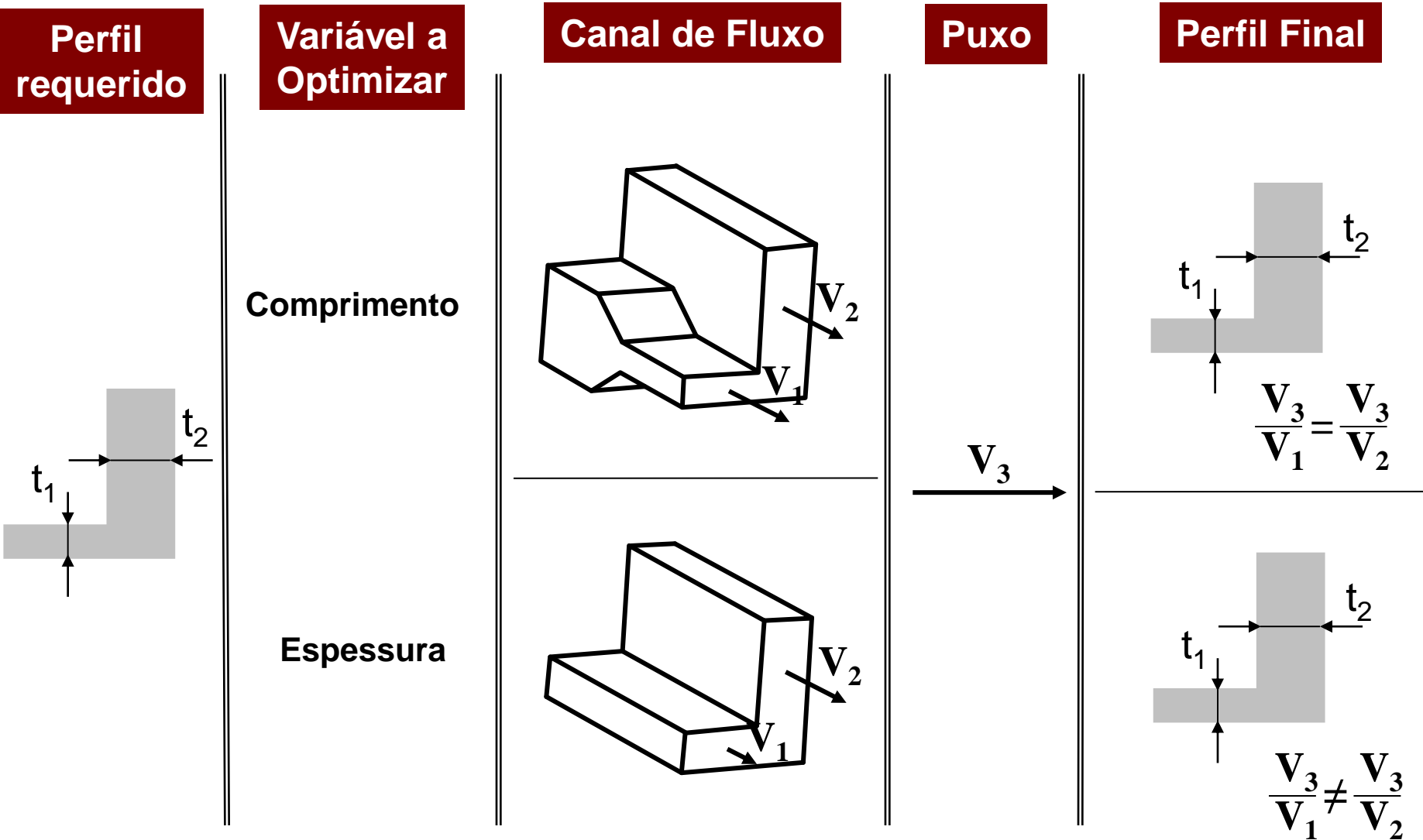
Efeito dos erros na **espessura** das secções elementares

Sensibilidade à imprecisão de maquinagem



Efeito dos erros no comprimento das secções elementares

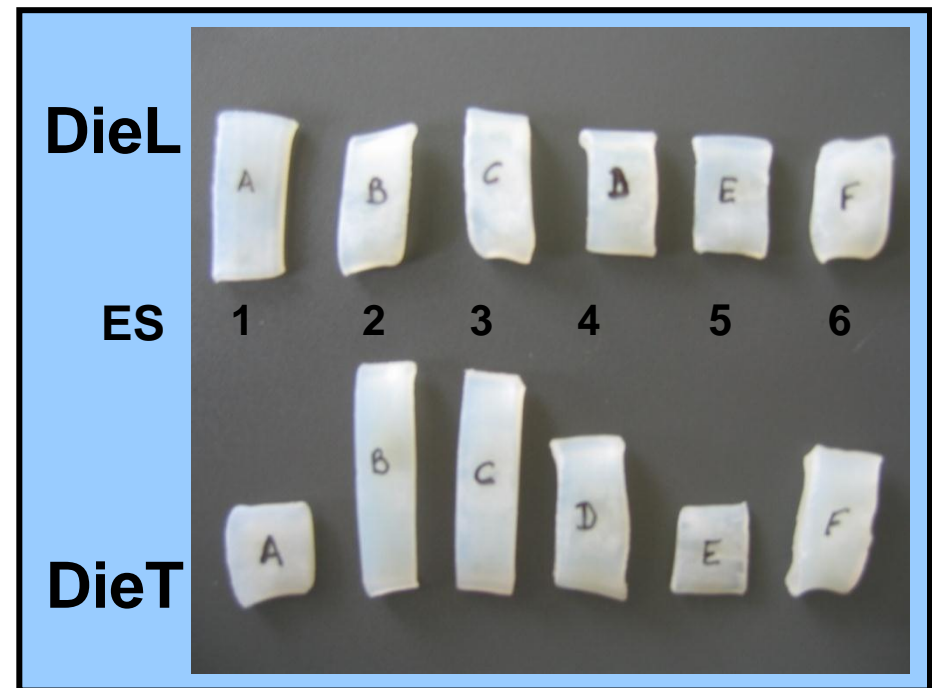
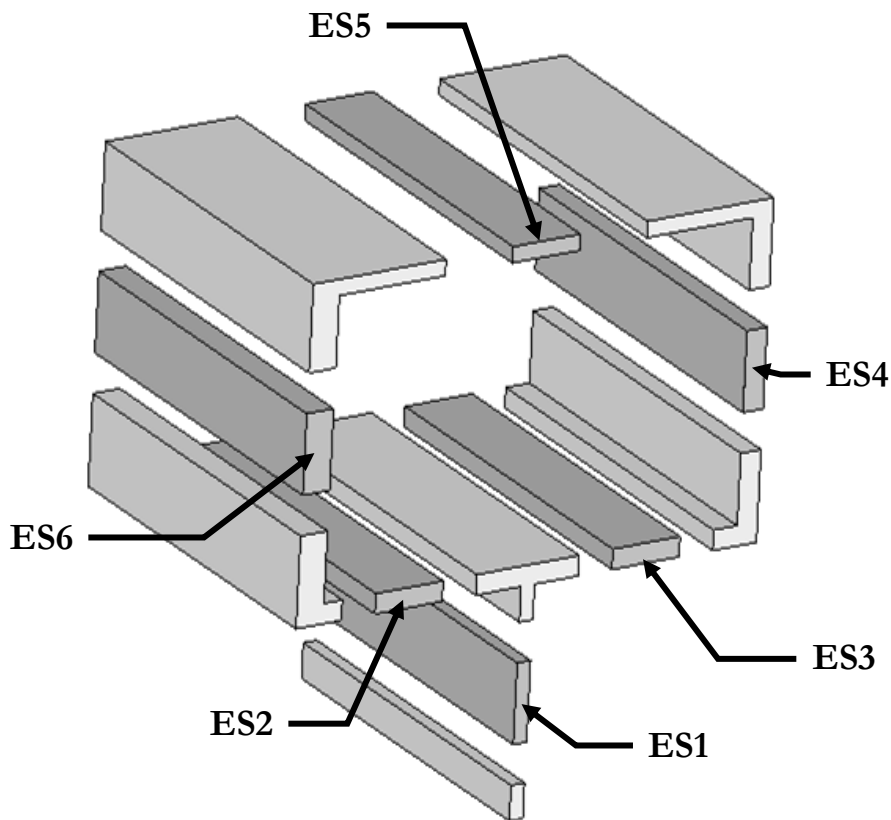
Cabeças de Extrusão – Comprimento vs Espessura











Cabeças de Extrusão – Comprimento vs Espessura

Razão \bar{V}_{max} / \bar{V}

Geometria	ES1	ES2	ES3	ES4	ES5	ES6
DieINI	6.20	3.72	3.39	2.18	7.46	1.00
DieL	1.08	1.15	1.03	1.12	1.15	1.00
DieT	1.68	1.38	1.33	1.24	1.56	1.00

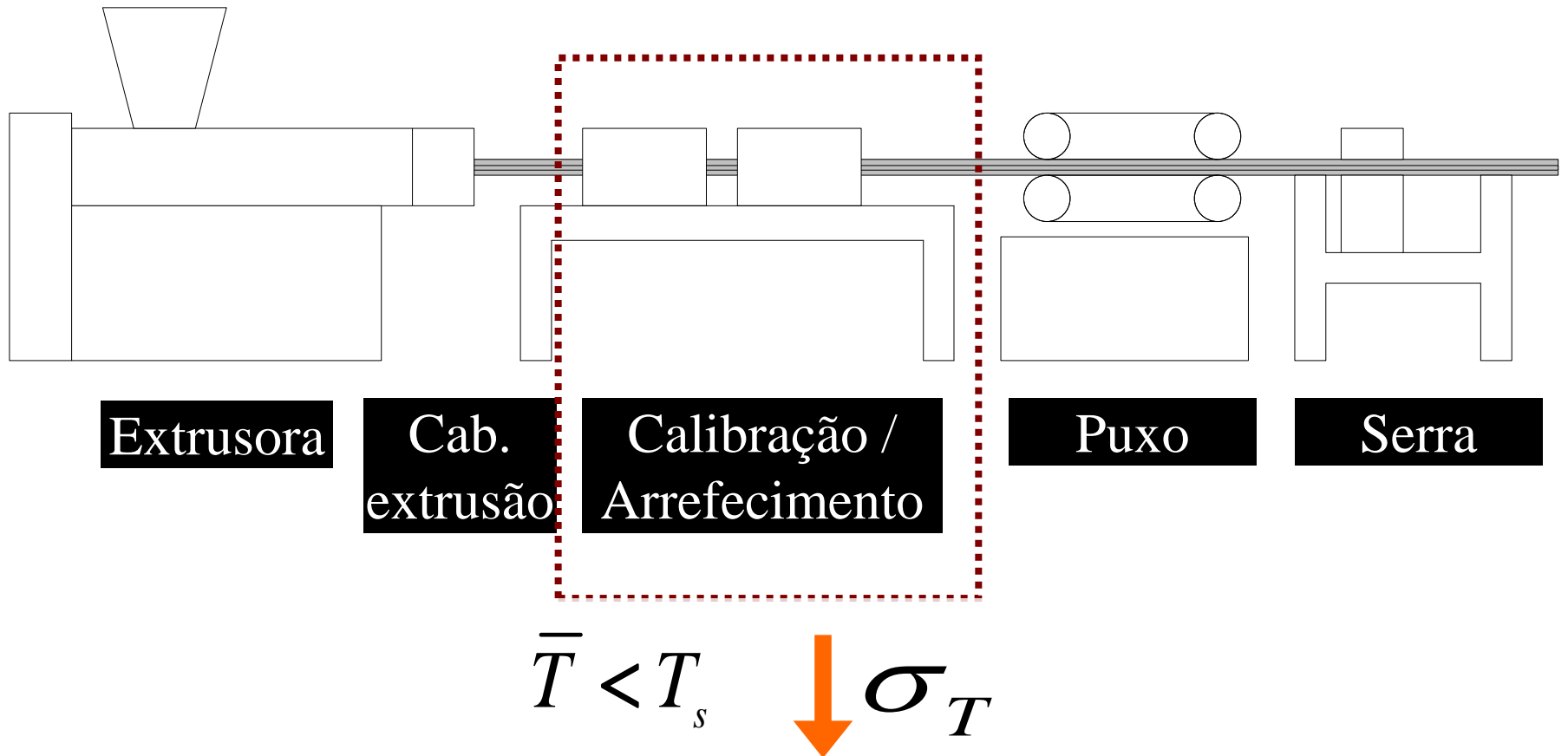


- Código numérico validado experimentalmente
- Optimização automática testada com sucesso
- Comparação das estratégias de projeto:

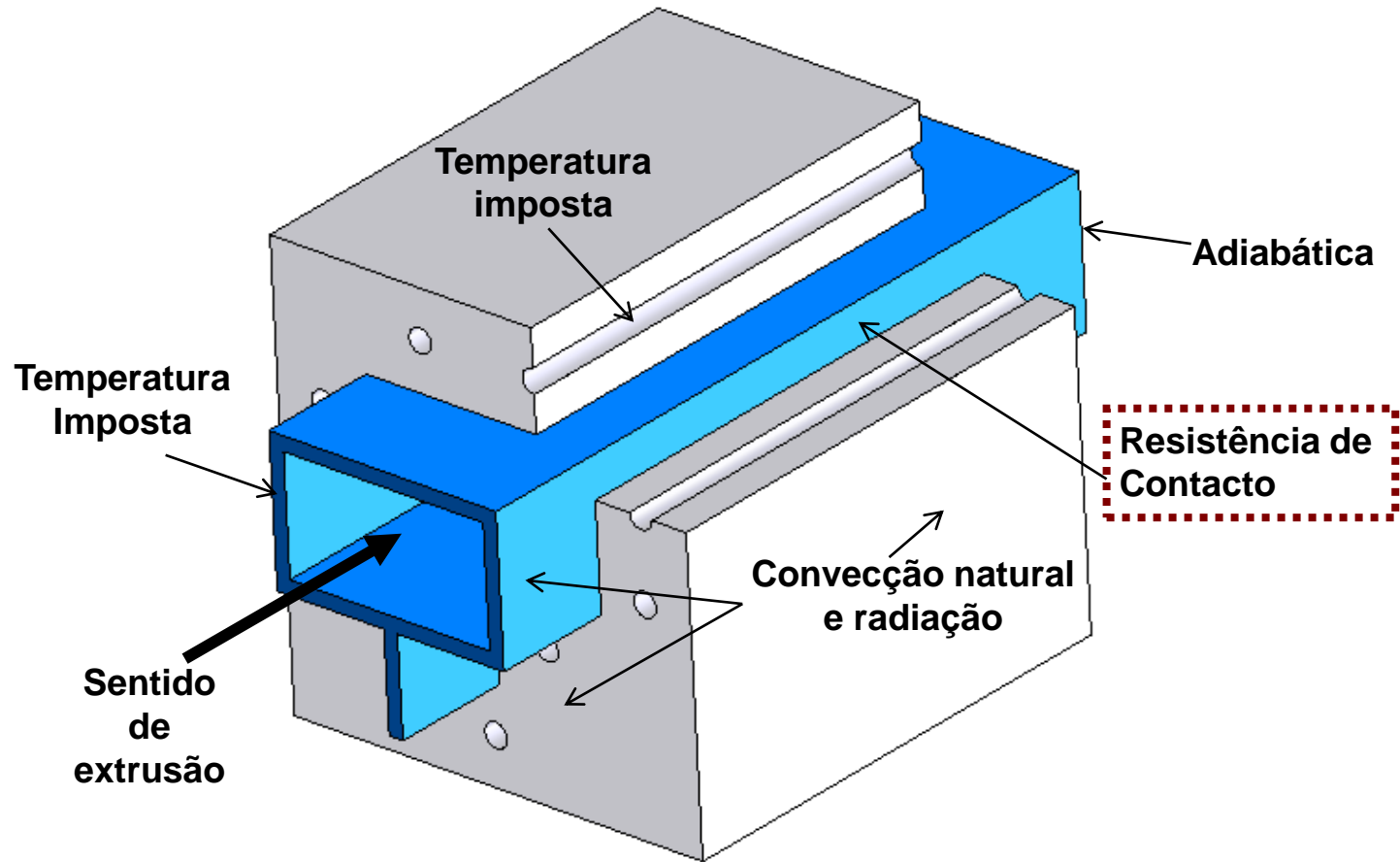
Estratégia	Sensibilidade			Requisitos de modelação	Estabilidade Dimensional
	Parâmetros do Processo	Propriedades da Matéria-prima	Imprecisão de Maquinagem		
Comprimento	=			3D 	
Espessura	=			2D 	

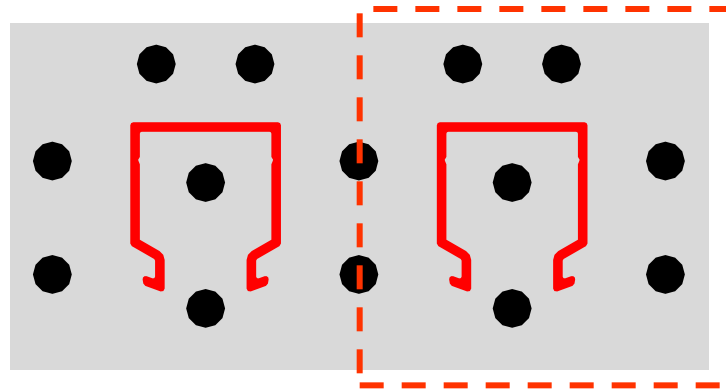
- A Modelação numérica suporta a compreensão do processo

Calibradores - Introdução

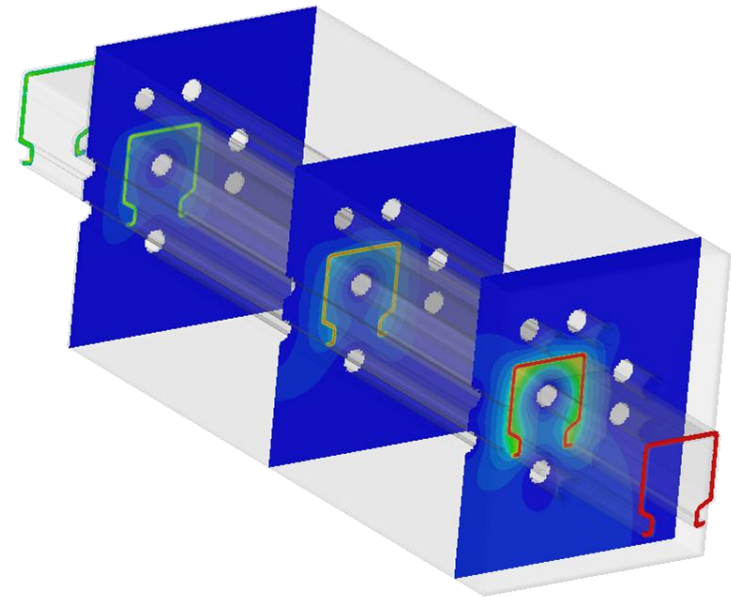
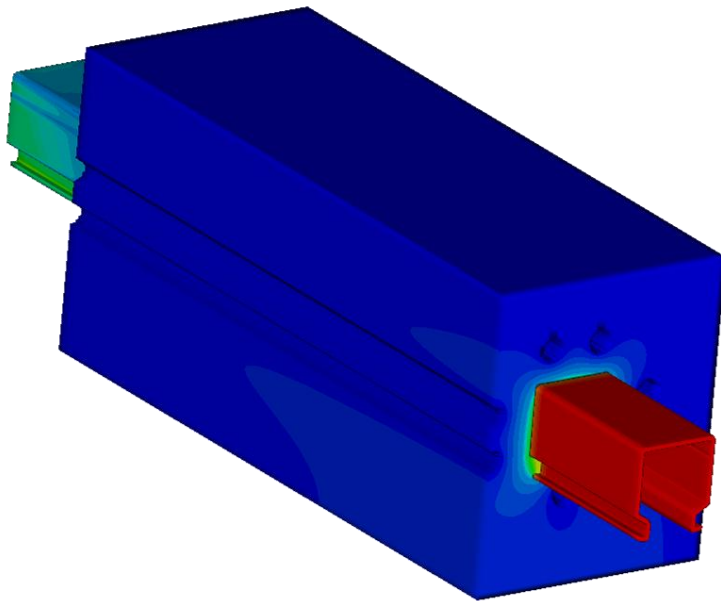


Calibradores – Condições de Fronteira





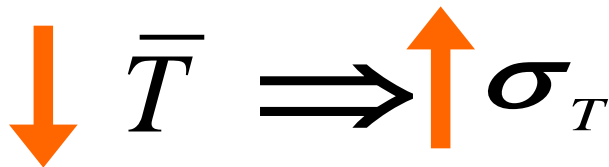
Cálculo 3D da distribuição de temperaturas



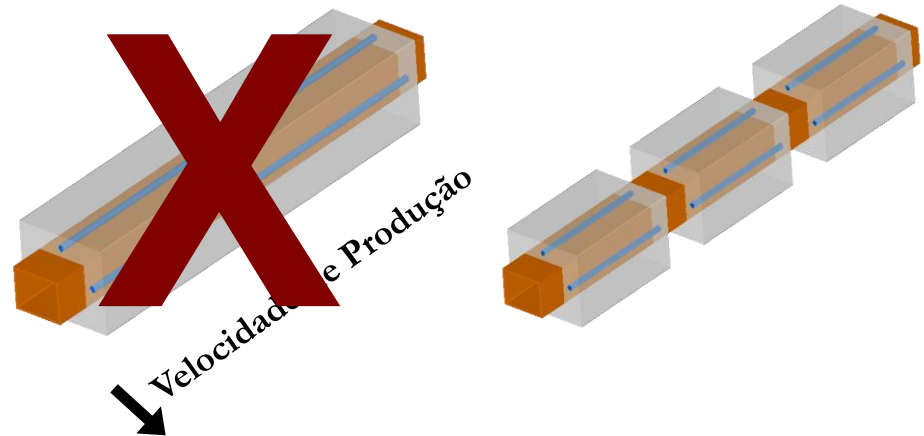
Estudo da influência dos parâmetros do processo, condições fronteira e layout de calibração no desempenho do sistema

Conclusão:

Em general

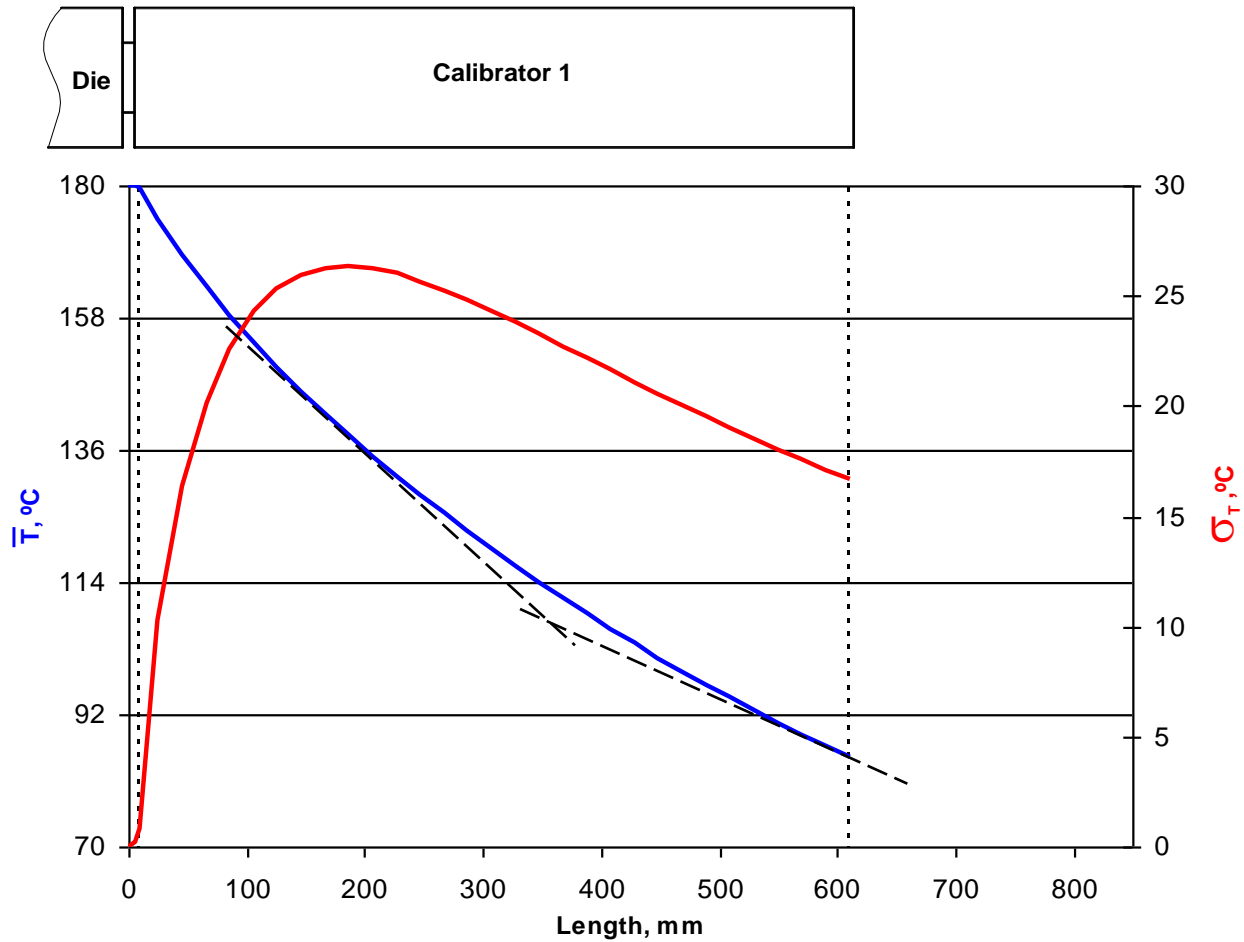


Excepções

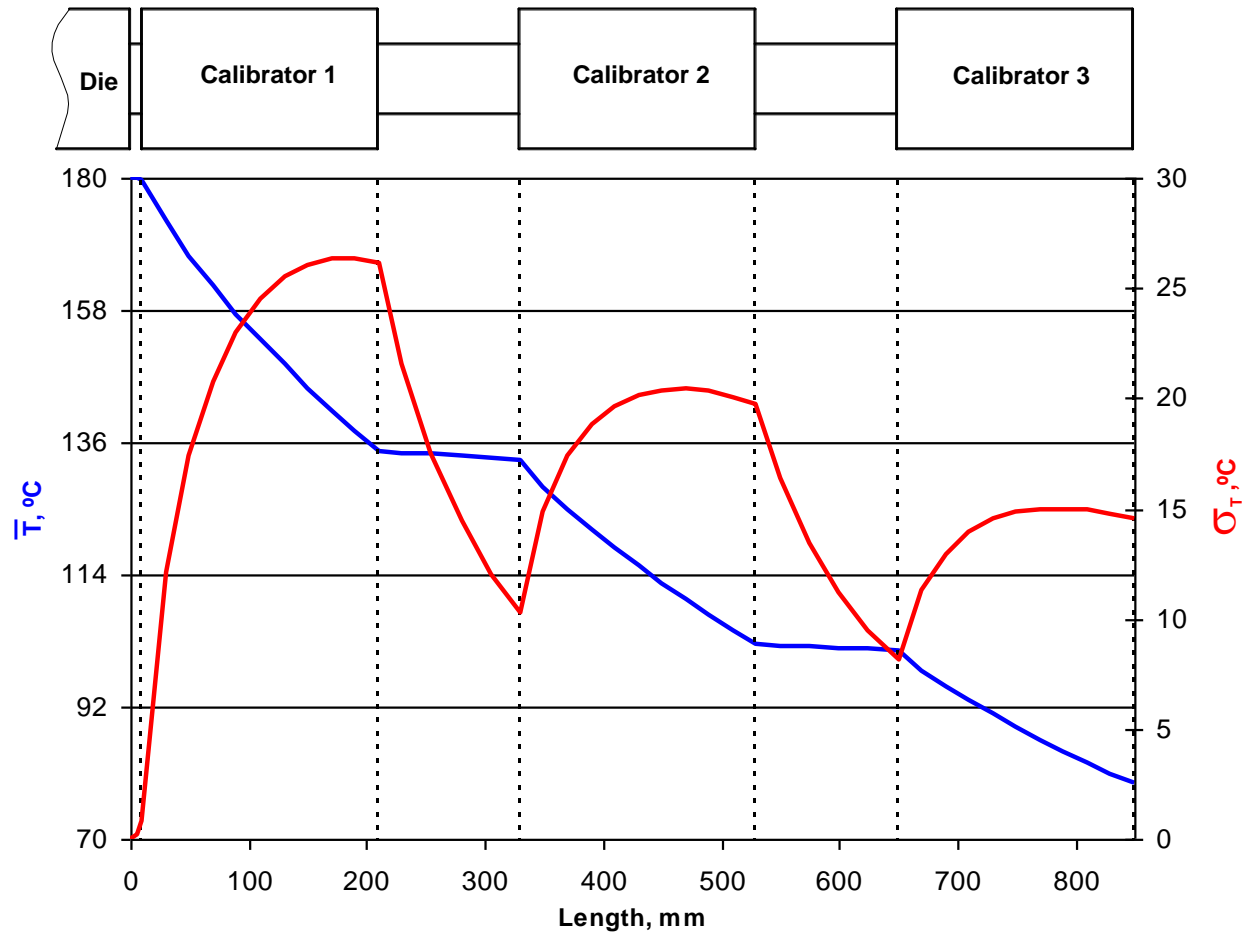


Polym Eng Sci, 44 (2004), p.2216-2228

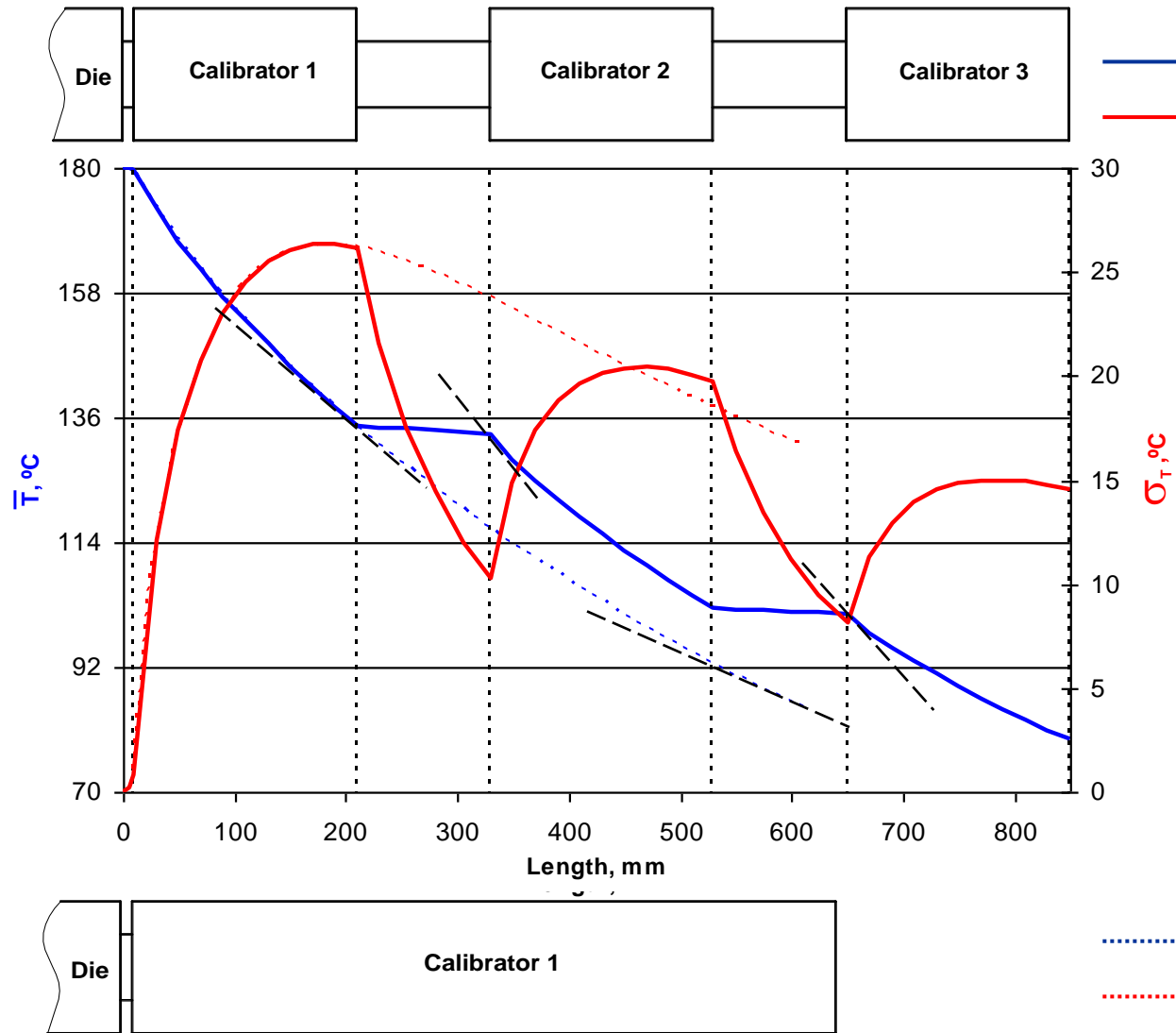
Calibradores – Comportamento do Sistema



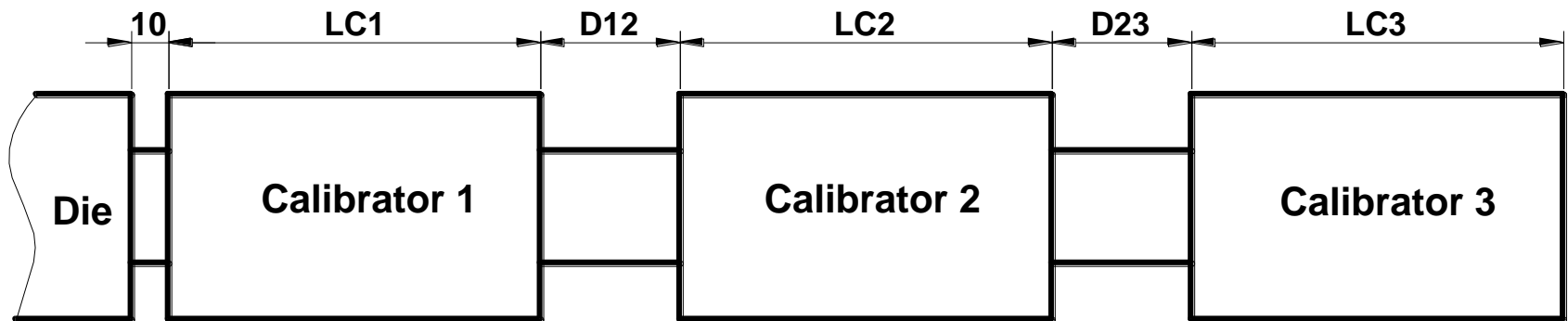
Calibradores – Comportamento do Sistema



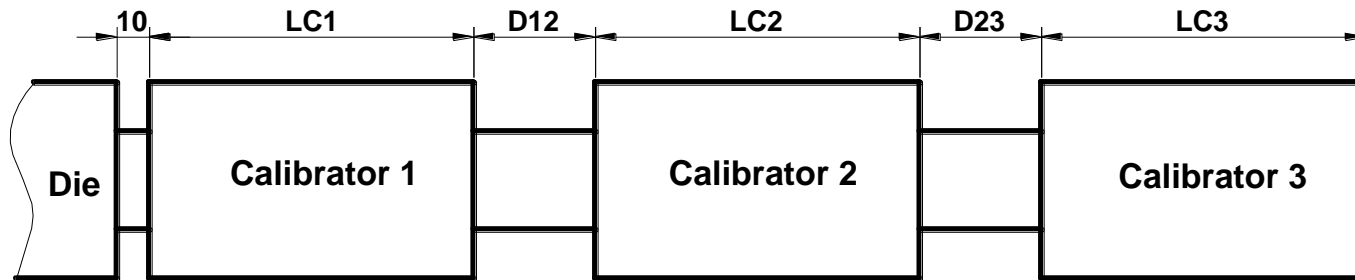
Calibradores – Comportamento do Sistema



Influência da Distribuição de Comprimentos LCi and Dij



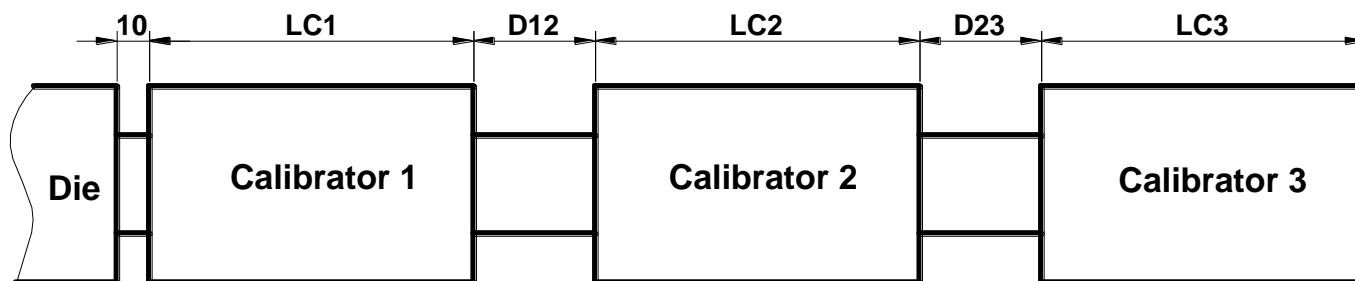
Calibradores – Comportamento do Sistema



LC _i	LC1 [mm]	LC2 [mm]	LC3 [mm]
→	600	-	-
→	300	300	-
→	200	200	200
→	200	200	200
→	200	200	200
↘	300	200	100
↗	100	200	300
↘	300	200	100
↘	300	200	100
↗	100	200	300
↗	100	200	300

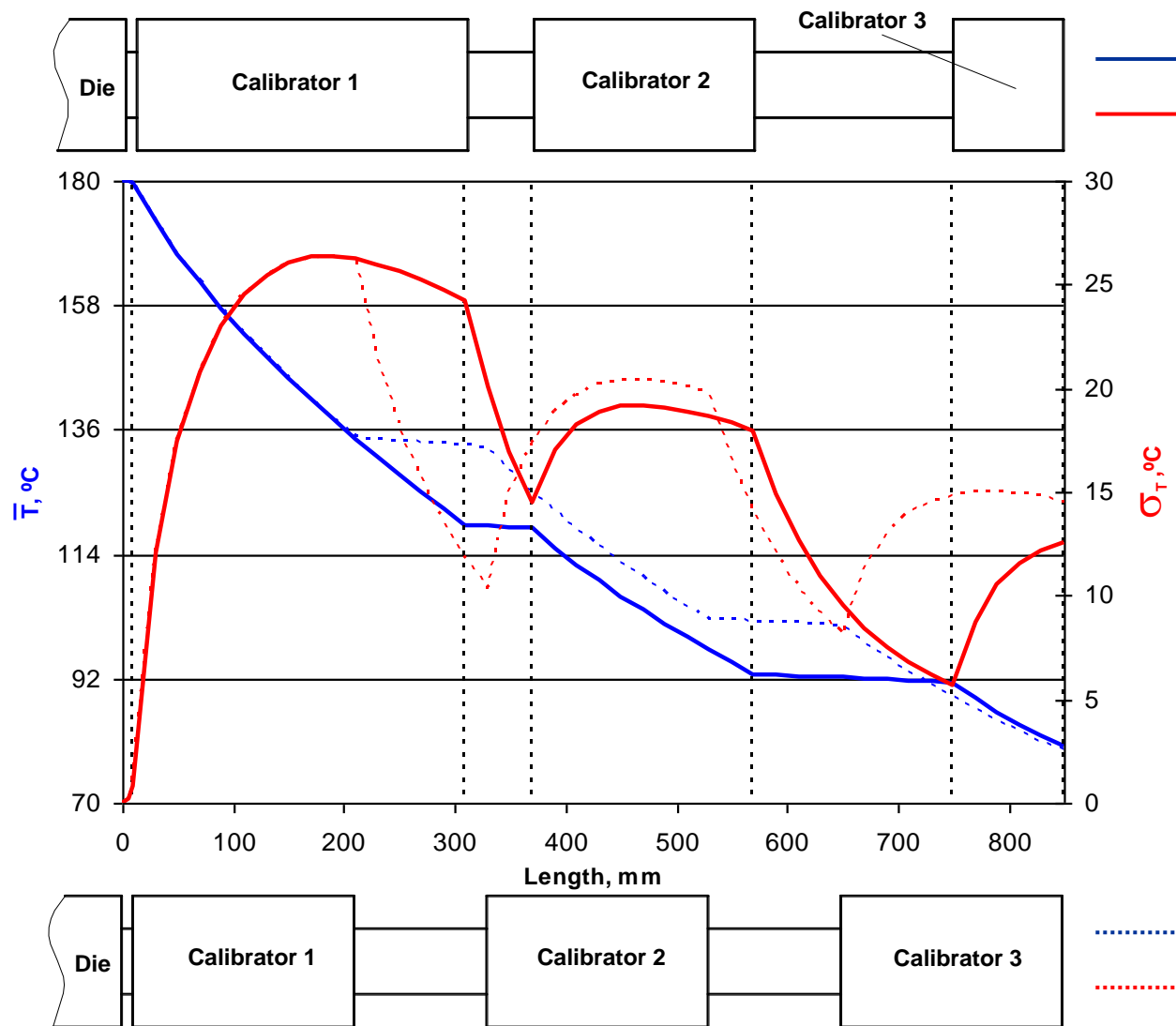
D _{ij}	D12 [mm]	D23 [mm]
	-	-
→	240	-
→	120	120
↗	60	180
↘	180	60
→	120	120
→	120	120
↘	180	60
↗	60	180
↘	180	60
↗	60	180

Calibradores – Comportamento do Sistema

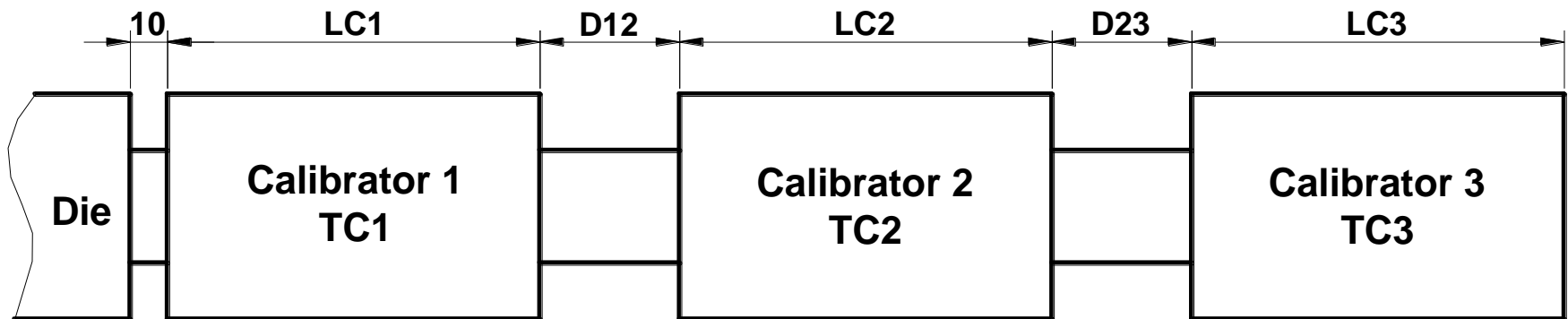


LCi	LC1	LC2	LC3	Dij	D12	D23	\bar{T}		σ_T	
	[mm]	[mm]	[mm]		[mm]	[mm]	[°C]	[%]	[°C]	[%]
→	600	-	-		-	-	84.9	0.0%	16.6	0.0%
→	300	300	-	→	240	-	80.3	-5.5%	15.2	-8.6%
→	200	200	200	→	120	120	79.2	-6.7%	14.5	-12.6%
→	200	200	200	↗	60	180	79.5	-6.4%	14.5	-13.1%
→	200	200	200	↘	180	60	79.4	-6.5%	14.8	-10.8%
↘	300	200	100	→	120	120	79.5	-6.4%	13.0	-22.1%
↗	100	200	300	→	120	120	79.4	-6.5%	15.1	-9.3%
↘	300	200	100	↘	180	60	79.6	-6.3%	13.8	-17.3%
↘	300	200	100	↗	60	180	79.9	-5.9%	12.6	-24.3%
↗	100	200	300	↘	180	60	79.7	-6.1%	15.2	-8.4%
↗	100	200	300	↗	60	180	79.5	-6.3%	15.1	-9.4%

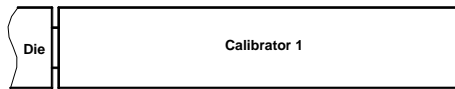
Calibradores – Comportamento do Sistema



Influência da Temperatura de Arrefecimento **TC_i**



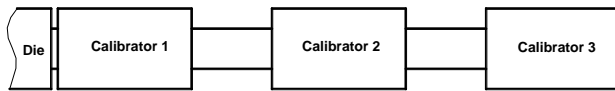
Calibradores – Comportamento do Sistema



TCi	TC1 [°C]	TC2 [°C]	TC3 [°C]
-----	-------------	-------------	-------------



18 - -



18 18 18



10 10 10



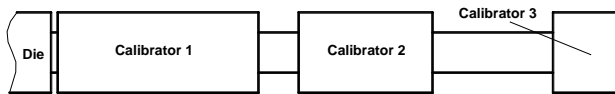
26 26 26



26 18 10



10 18 26



18 18 18



10 10 10



26 26 26



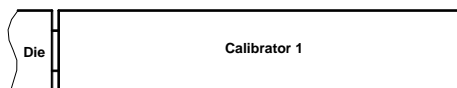
26 18 10



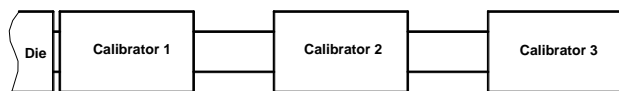
10 18 26

$10^{\circ}\text{C} \leq \text{TCi} \leq 26^{\circ}\text{C}$

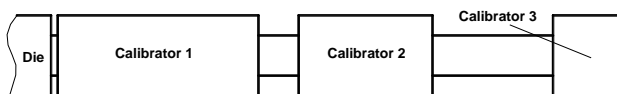
Calibradores – Comportamento do Sistema



TCi	TC1	TC2	TC3	\bar{T}		σ_T	
	[°C]	[°C]	[°C]	[°C]	[%]	[°C]	[%]
→	18	-	-	84.9	-	16.6	-



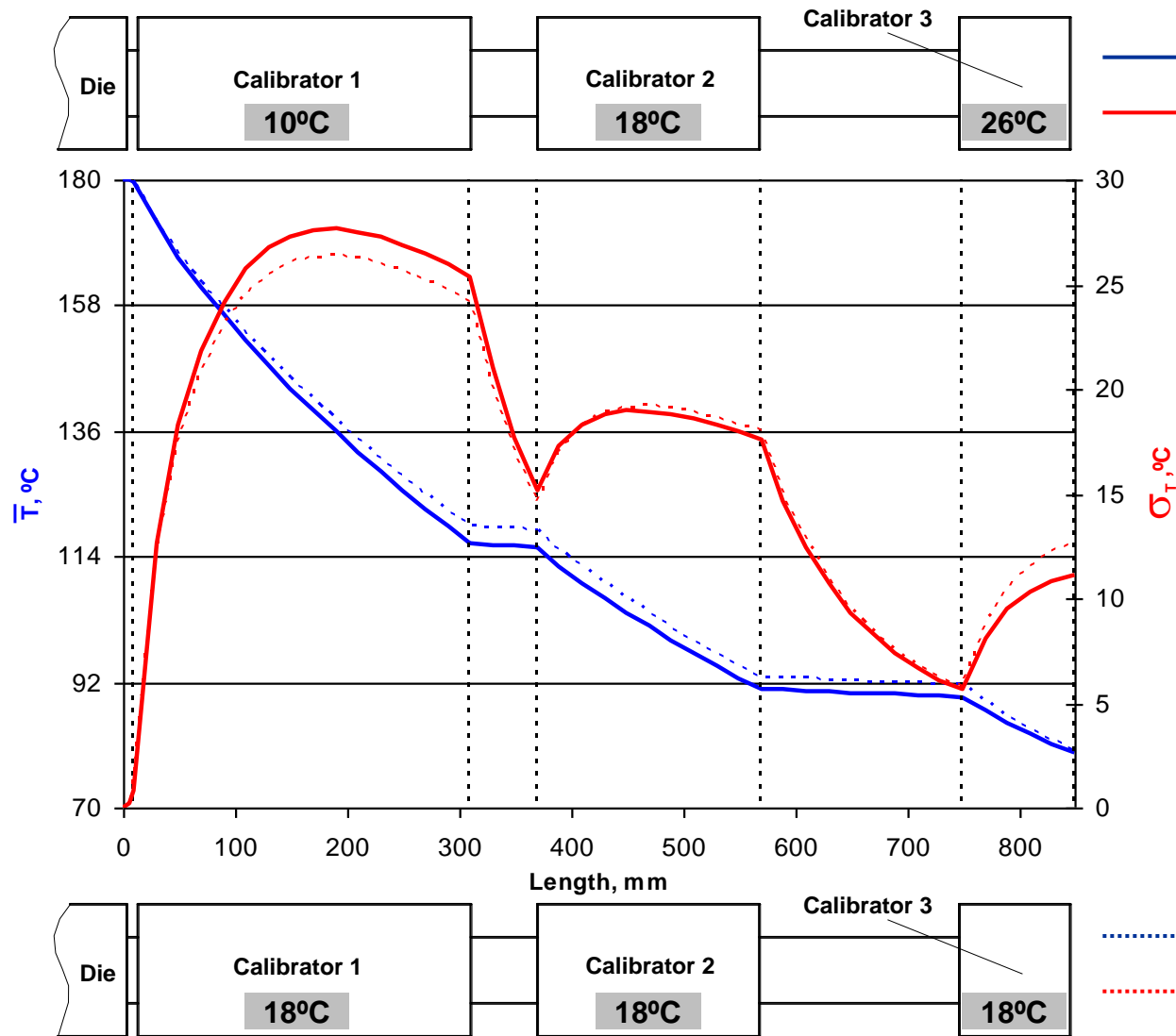
→	18	18	18	79.2	-6.7%	14.5	-12.6%
→	10	10	10	74.4	-12.3%	15.3	-8.2%
→	26	26	26	83.9	-1.1%	13.8	-17.0%
↘	26	18	10	78.0	-8.1%	16.0	-3.6%
↗	10	18	26	80.3	-5.4%	13.0	-21.7%



→	18	18	18	79.9	-5.9%	12.6	-24.3%
→	10	10	10	75.2	-11.4%	13.2	-20.7%
→	26	26	26	84.6	-0.4%	12.0	-28.0%
↘	26	18	10	80.2	-5.5%	14.1	-15.5%
↗	10	18	26	79.5	-6.3%	11.1	-33.1%

10°C ≤ TCi ≤ 26°C

Calibradores – Comportamento do Sistema

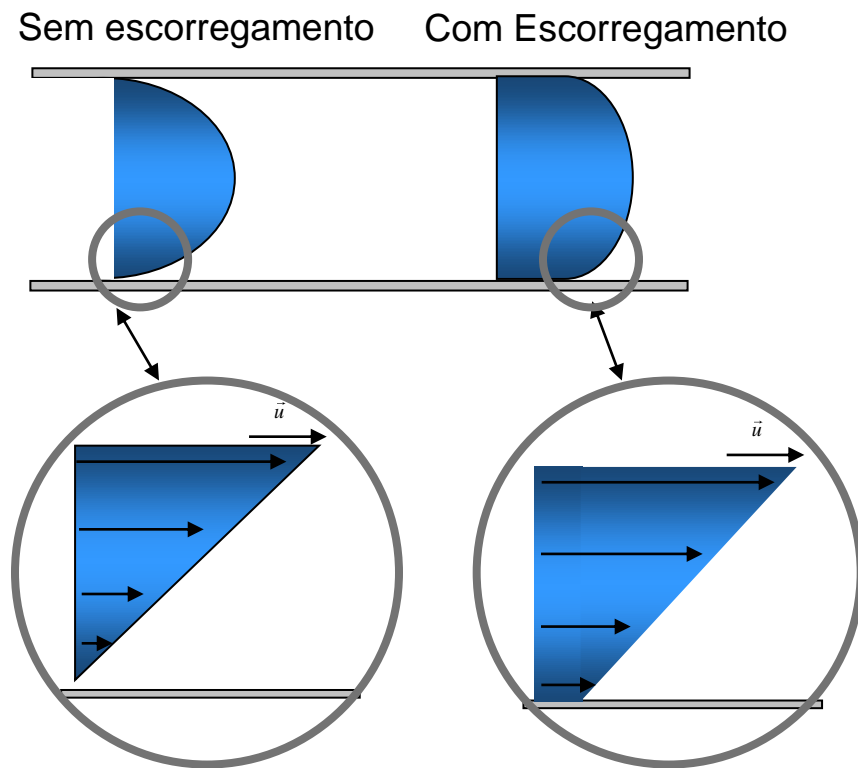


- Sistemas de Calibração com
 - comprimentos **decrecentes** das **unidades de calibração**;
 - comprimentos **crecentes** dos **espaçamentos**;
 - **temperaturas** de arrefecimento **crecentes**;apresentam um desempenho superior;
- A Modelação numérica suporta a compreensão do processo.

Implementação de novas condições de fronteira

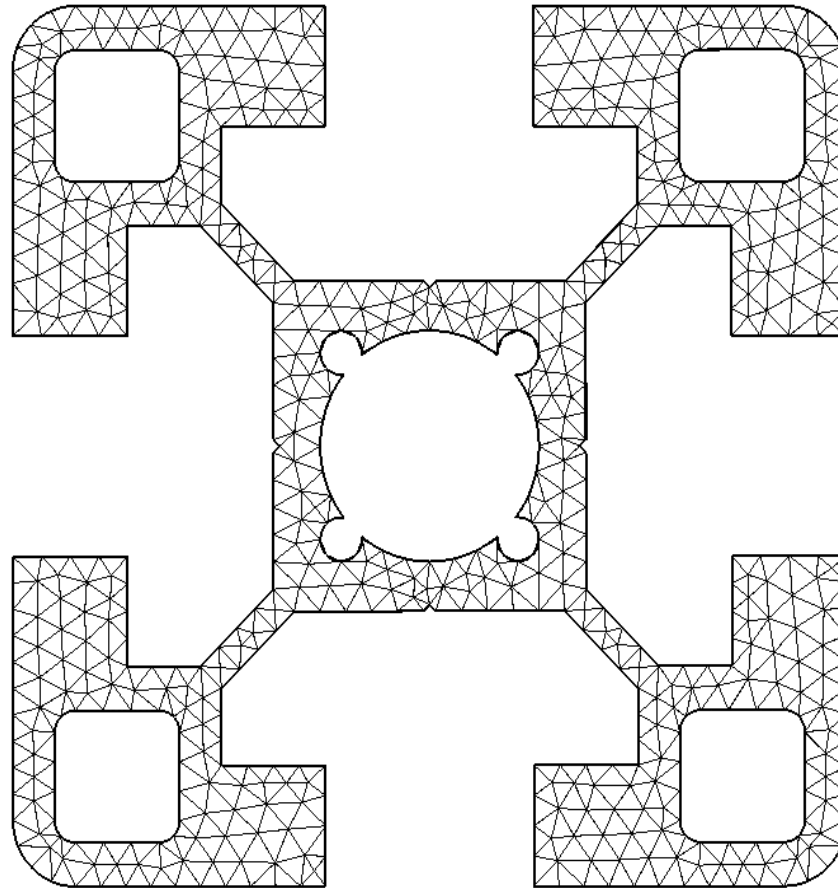


Superfície-livre

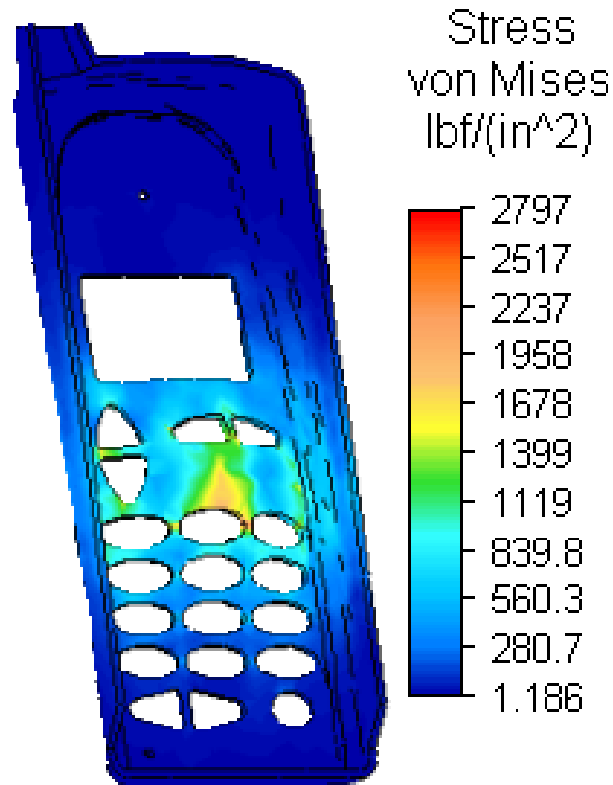


Escorregamento na parede

Desenvolvimento de código numérico para geometrias complexas

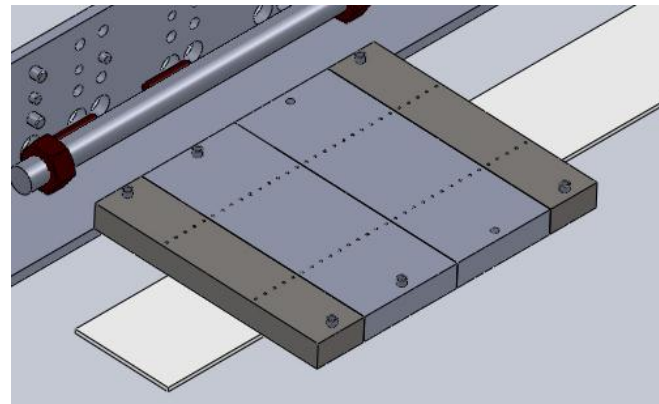
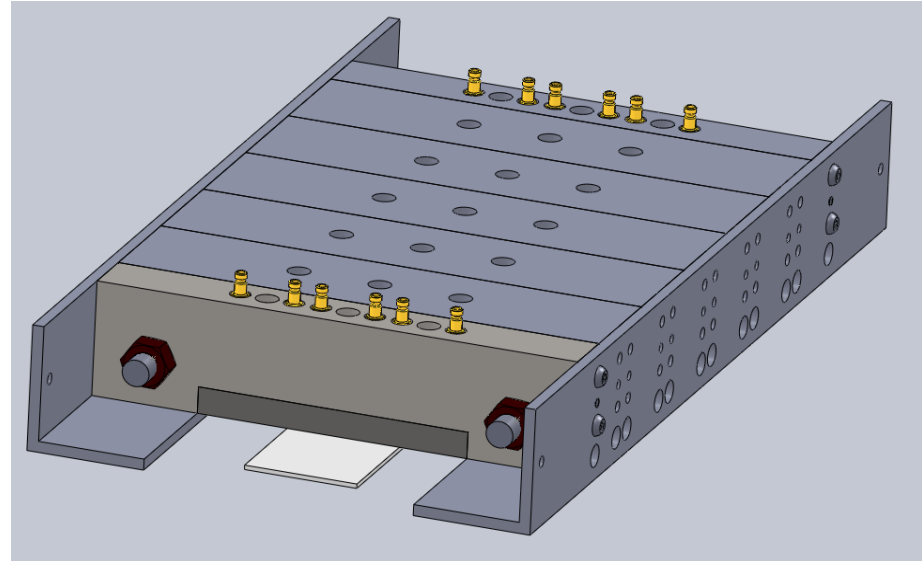
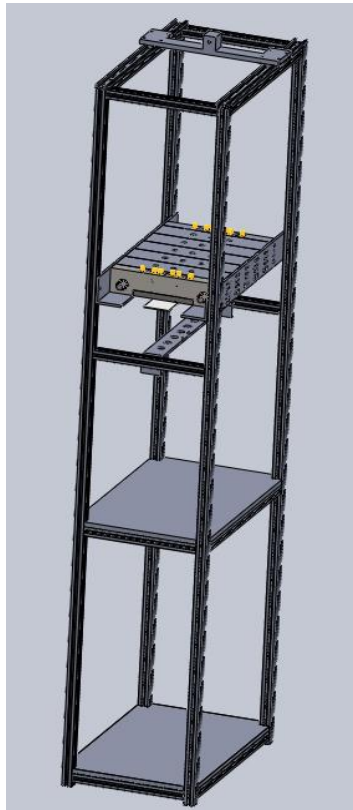


Implementação da previsão das tensões residuais desenvolvidas durante o arrefecimento



<http://wikihelp.autodesk.com>

Caraterização experimental da resistência de contacto em calibração





Obrigado pela Atenção!

Questões?