### Virtual High Performance Machining

#### **Yusuf Altintas, Professor**

M.A.Sc., Ph.D., Hon. Dr. Ing. (Stuttgart), Dr. H.c.(Budapest)

NSERC – P&WC INDUSTRIAL RESEARCH CHAIR PROFESSOR Fellow RSC, CAE, EC, SME, ASME, CIRP, ISNM, Tokyo U., PW&C, AvH

UBC – Manufacturing Automation Laboratory (M.A.L.)

UNIVERSITY OF BRITISH COLUMBIA, VANCOUVER, B.C. CANADA http://www.mal.mech.ubc.ca/







- Machine the part correctly and cost effectively at the first trial
- Replace the physical machining trials by the digital model of the machining operations and machine tools



## Virtual Machining Modules



- 1. Cutter Part Intersection Module (CAD/CAM)
- Machining Process Mechanics & Dynamics Module (UBC-CUTPRO<sup>™</sup> released in 2000)
- 3. Machine Tool Dynamics Kinematics Control (CNC) Modules (UBC-VIRTUAL CNC released in 2004)

1+2+3 = Integrated Virtual Machining System

(UBC-VMS – MACHPRO released in June 2011)



### Tool design for the application



1000 **Cycle Time Reduction: 62%** Simulated Measured BEFORE AFTER Cutting Forces [N] **Taper Helical Ball End Mill** Axial Depth of Cut = 10.0 mm Feed rate = 0.050 mm/tooth - Ti<sub>6</sub>Al<sub>4</sub>V -1000 Speed = 500 rev/min 100 200 300 400 500 600 700 Rotation Angle [deg] 1500 Simulated Measured 1000 Cutting Forces [N] Surface roughness improved by 8.4 fold Impeller Milling **UBC + P&WC NSERC** Chair xial Depth of Cut = 20.0 mn -1000 Feed rate = 0.010 mm/tooth Speed = 500 rev/min -1500 400 100 200 300 500 600 700 Rotation Angle [deg] 



## **Optimal NC Programming**



1. TF Measurement & MALTF



Prediction of torque, power, force, stability lobes, vibrations,..

0.2 Time [sec]



MONTREAL

9.6716e-07

estEREX11 frf

2. Modal Analysis Module

 Mode II
 Shape
 Frequency [H2]
 Damping
 Residue [R4] [m]
 Residue [R6] [m]
 Mode Stiftness
 Mass [Lg]

 1
 N/A
 4.56564-402
 1.1751E-01
 0.0000E+00
 -7.5941E-05
 2.0651E-407
 2.1244

 2
 N/A
 6.53564-402
 5.44986-002
 0.0000E+00
 -8.9437E-05
 2.0521E-407
 2.1244

 3
 N/A
 8.9425E+402
 6.3397E-02
 0.0000E+00
 1.3657E-44
 2.0597E+017
 0.6522

 4
 N/A
 2.1952E-401
 1.6135E-02
 0.0000E+00
 1.3657E-44
 2.0597E+017
 0.6522

Measurement #1

Gives most productive, chatter free cutting conditions to NC Programmer

- O ×

RC





## **Chatter avoidance**









Chatter at 12500 rev/min

Select green zone

Higher productivity at 15000 rev/min. No chatter.





# High Perfromance Machining of Aircraft Parts FORUMEROSPATIALE







- 90% of the material is machined from solid blocks
- Any mistake leads to scrap of costly part
- Any reduction in machining time leads to major savings





# Process Optimization Constraints

#### Chip Load

- Maintain desired feed per tooth despite varying workpiece geometry during machining

#### 2 Cutting Forces

- Avoid excessive cutting forces on the tool

#### **3** Moment on Spindle Bearings

- Avoid spindle bearing failure due to excessive loading

#### Static Tool Deflection

- Control dimensional/form error on the part
- Avoid tool breakage

#### Surface Speed

- Obtain uniform surface finish
- Extend tool life







## MACHPRO: UBC's Virtual Machining Process Simulation and Optimization Platform





### Embedded to NX CAM System



ration Navigator - Program Order			
action natigator - riogram order	Toolcha.	Path Tool	Simulation Plots + ×
GRAM			
nused Items			
PROGRAM			Force (Top) (SVB) Children Children Show All Charts
CRYO_VANE_1			ruices (ruor Csra) Cript caal
FIXED CONTOUR 10 LAY20	8	<ul> <li>T1</li> </ul>	
EIXED CONTOUR 20 LAV20		· 11	Zoom in X Axis Zoom in Y Axis Reset Chart Operations On05-001 v X Axis Time v
EVED CONTOUR 20 LAV20		TI	and a second sec
CENO MANE 2		• 11	Chatter _ p _ p _ p _ p _ p _ p _ p _ p _ p _
- V & ZLEVEL_PROFILE_LAY7-81			
VARIABLE CONTOUR_50_LAY7-81		<ul> <li>10</li> </ul>	
G CKTO_VANE_4			
VARIABLE_CONTOUR_190_LAY7-81		11	
- VARIABLE_CONTOUR_195_LAY7-81		T1	
CRYO_VANE_5	-		
VARIABLE_CONTOUR_300_LAY7-27	8	✓ T2	
g CRYO_VANE_6			
VARIABLE_CONTOUR_400_LAY7-81	8	✓ T3	Lindetermined
g CRYO_VANE_7			
- VARIABLE_CONTOUR_505_LAY7_COPY	8	🖌 T4	1/ 67 117 167
VARIABLE_CONTOUR_505_LAY7		🖌 T4	Time [s]
- VARIABLE_CONTOUR_500_LAY7		🖌 T4	
VARIABLE_CONTOUR_510_LAY7		🖌 T4	
OPT_MACHPRO			
		>	

CAM Machining Operation 'VARIABLE\_CONTOUR\_60\_LAY7-81' selected



## Virtual to real machining









# Virtual Machining of Aerospace Parts



STATOR BLADE FOR A STEAM TURBINE Material: Stainless Steel	MACHpro Productivity Improvement
Blade Roughing – Stage 1	<b>↑</b> 39%
Blade Roughing – Stage 2	<b>↑</b> 31%
Blade Roughing – Stage 3	<b>↑</b> 14%
Semi Finishing – Stage 1	<b>↑</b> 72%
Semi Finishing – Stage 2	<b>1</b> 48%
Overall Productivity Improvement	<b>†</b> 57%







### Impeller Milling UBC + P&WC NSERC Chair



Cycle Time Reduction: <u>62%</u>



Surface roughness improved by 8.4 fold





Research Partnership with Global Aerospace Industry

 Major aerospace companies use our machining process simulation and optimization tool box

(P&WC, P&WA USA, Boeing, Bombardier, ASCO, Embraer, Airbus, GKN, MHI, IHI, Aikoku, Kawasaki, Irkutsk, TAI, TEI, Snecma, AIDC.)

- UBC trains their manufacturing engineers to understand the engineering principles.
- Aero industry raises new problems when they use UBC technology. New problems are brought as research projects to UBC.
- After solving the problem, we integrate the solution to our software and provide it to the industry.





-ORUMINNOVATION

### Technology Transfer from MAL Inc.

- Train manufacturing engineers of the company in one week long course at UBC
- Select an existing aerospace part with high machining time and cost with the company.
- Re-engineer the machining using our Virtual Machining Technology with the manufacturing engineer designated by the company.
- We train the engineer step by step while planning the part machining together.
- We let the company to compare the new and existing methods, and they make their decision with a low cost trial and training.





