RDDM

Research Design Development Management

Turbomachinery Lecture Series

Module 00 – Masters Introduction
Gas Turbine Engine Design & Development

Presented to - Présenté at

Polytechnique Montréal
AER4270: Propulsion Aéronautique
MEC6615: Théorie avancée de turbomoteurs
MEC8250: Turbomachines

Carleton University
AERO 4402: Aerospace Propulsion

05 October 2020 – 05 Octobre 2020

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MDIDS-GT Senior research associate
Adjunct Professor at Polytechnique Montreal: AER4270 & MEC6615
Adjunct Professor at Carleton University: AERO 4402

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Some words of wisdom

The most dangerous phrase in the language is, "We've always done it this way."

- Rear Admiral Grace Murray Hopper

Some words of wisdom

"Simple methods with empirical input are still needed for the mean-line design, and it is often emphasized by experienced designers that if the one-dimensional design is not correct then no amount of CFD will produce a good design"

- Denton

Who am I → always busy

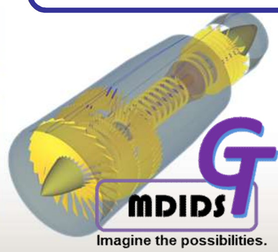
20+ years in Aerospace

Engineering Quality
Project Management
University Lecturer

Gas Turbines
Airplanes
Software

Research & Development
Multi-Disciplinary Engineering
Design & Support

	Aerospace	
	Gas Turbine Domain	Aviation
2000 – 2009	Pratt & Whitney Canada	
2010 – 2019		Bombardier Aerospace
2010 – Present	Polytechnique Montreal	
2019 – Present	Carleton University	
2019 - Present	RDDM Research Design Development Management	Airbus Canada



Turbomachinery Lecture Series

Who am I → always learning

20+ years in Aerospace

Conference papers

Off-Design Prediction of Transonic Axial Compressors: Part 1 - Mean-Line Code and Tuning Factors

Off-Design Prediction of Transonic Axial Compressors: Part 2 - Generalized Mean-Line Loss Modelling Methodology

Education

Bachelor 2000	McGill University
Masters 2008	Concordia University
PhD 2019	Polytechnique Montreal

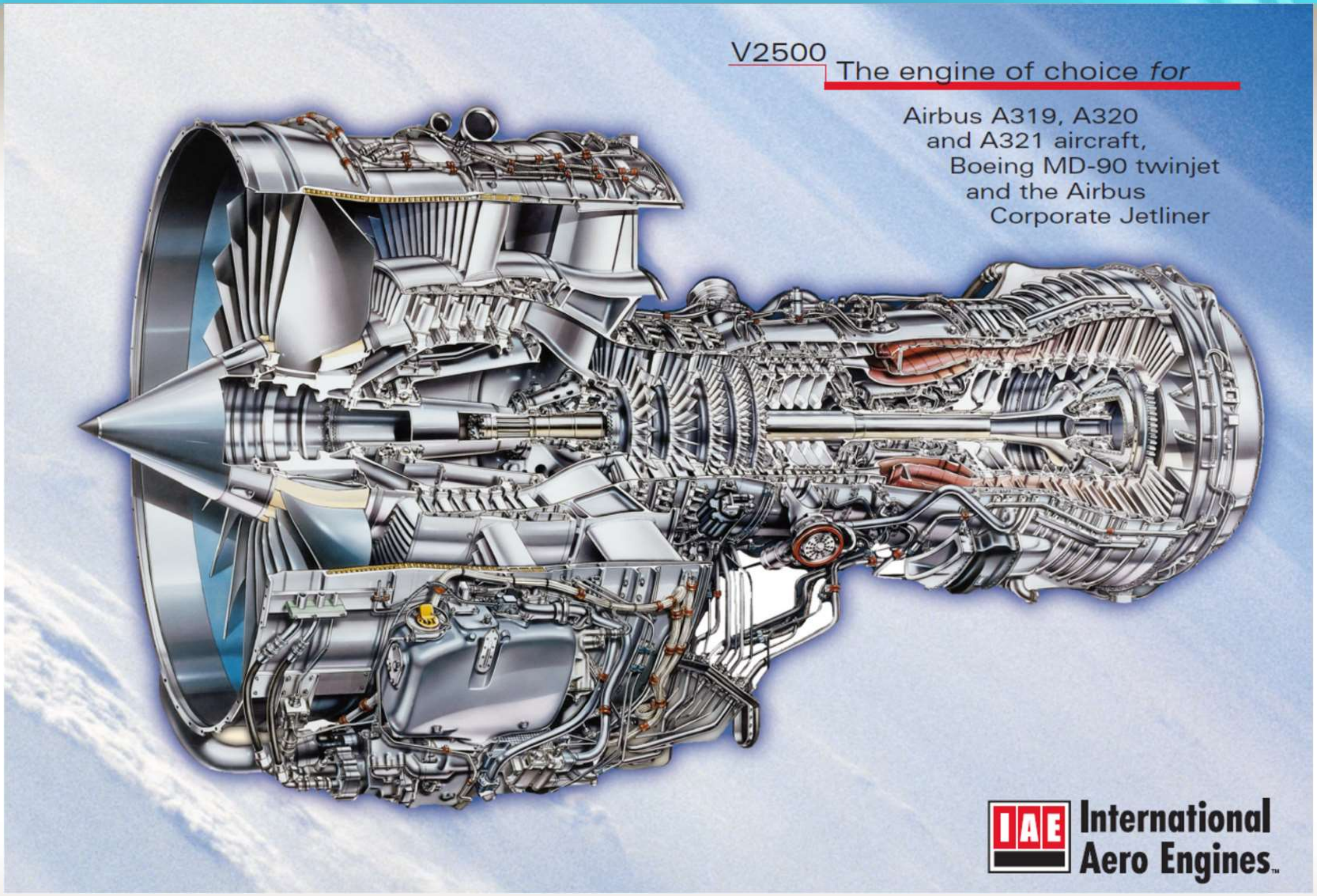
Transonic axial compressors

Thesis: An Off-Design Mean-Line Methodology to Predict the Missing Data of Single-Stage Transonic Axial Compressor Tests

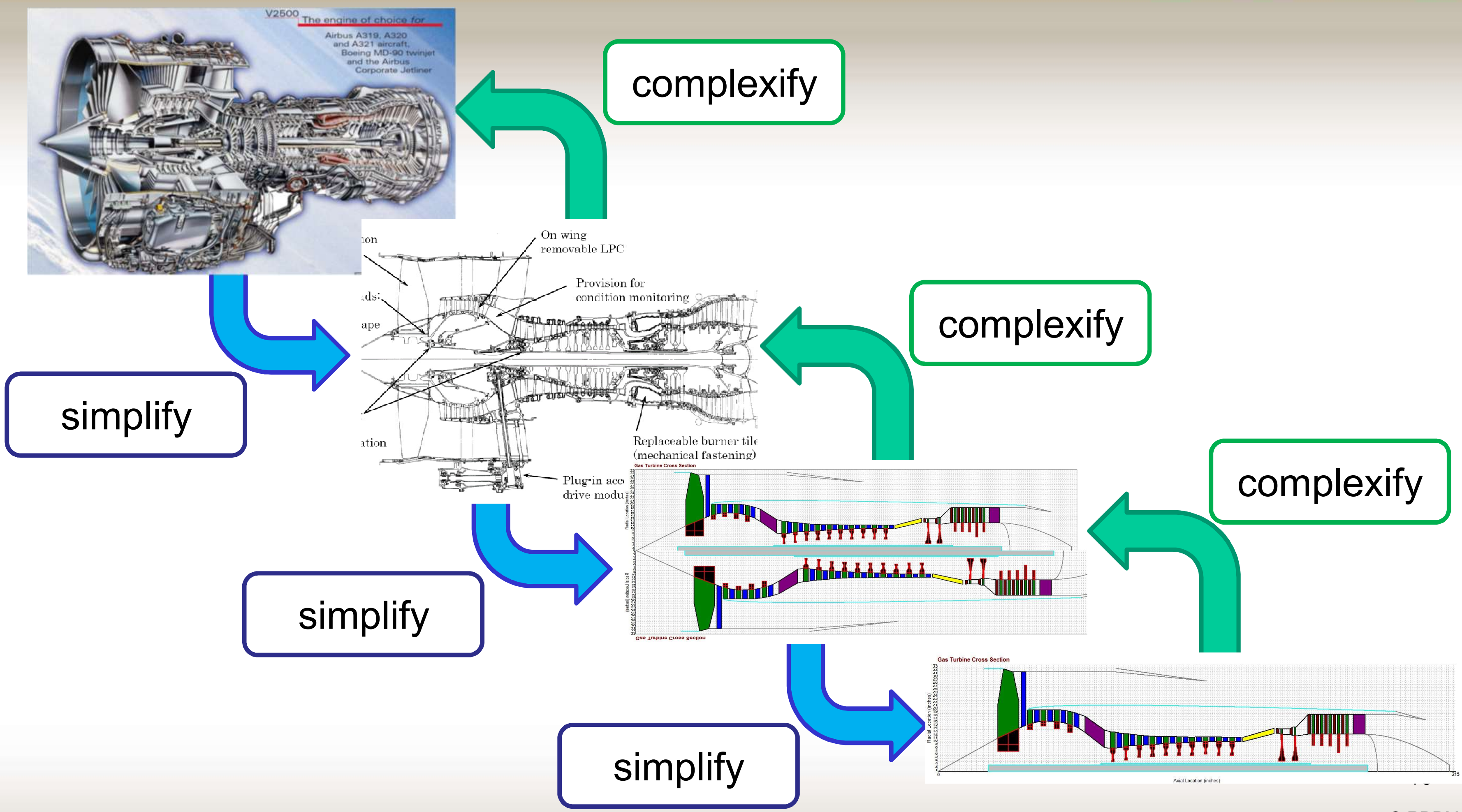
PART ONE

What are we talking about today?

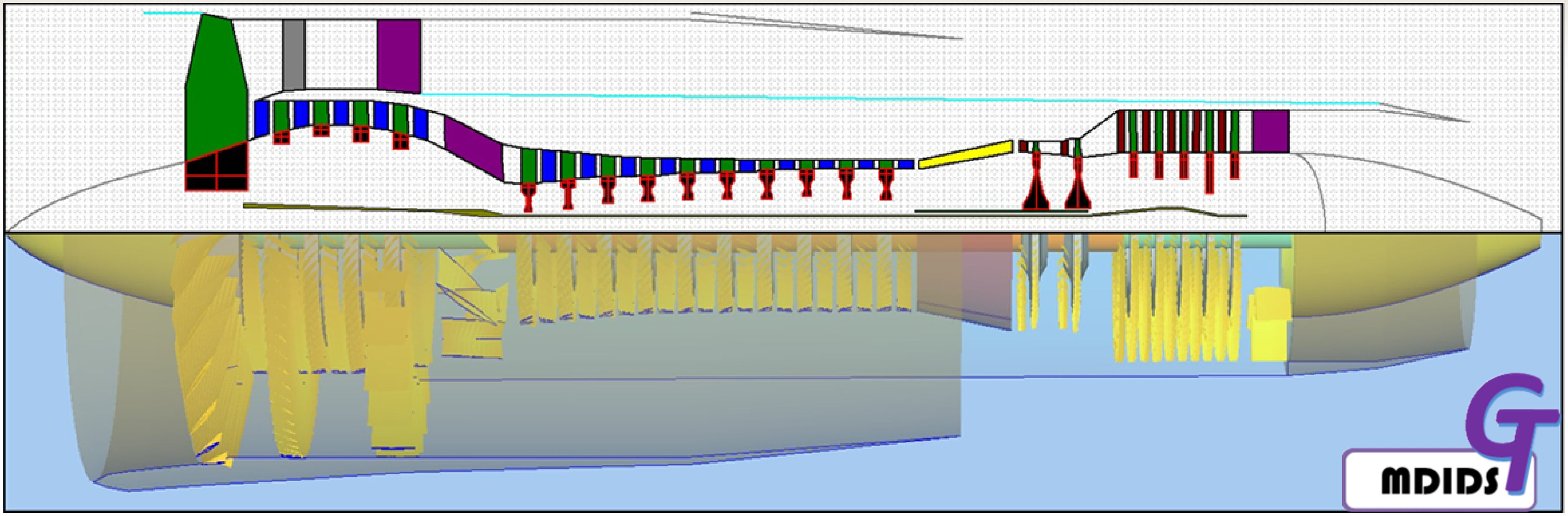
What do we have to do to get to this?



Well, we need to start with the basics



So the idea is to go from a simplified representation to the real thing.



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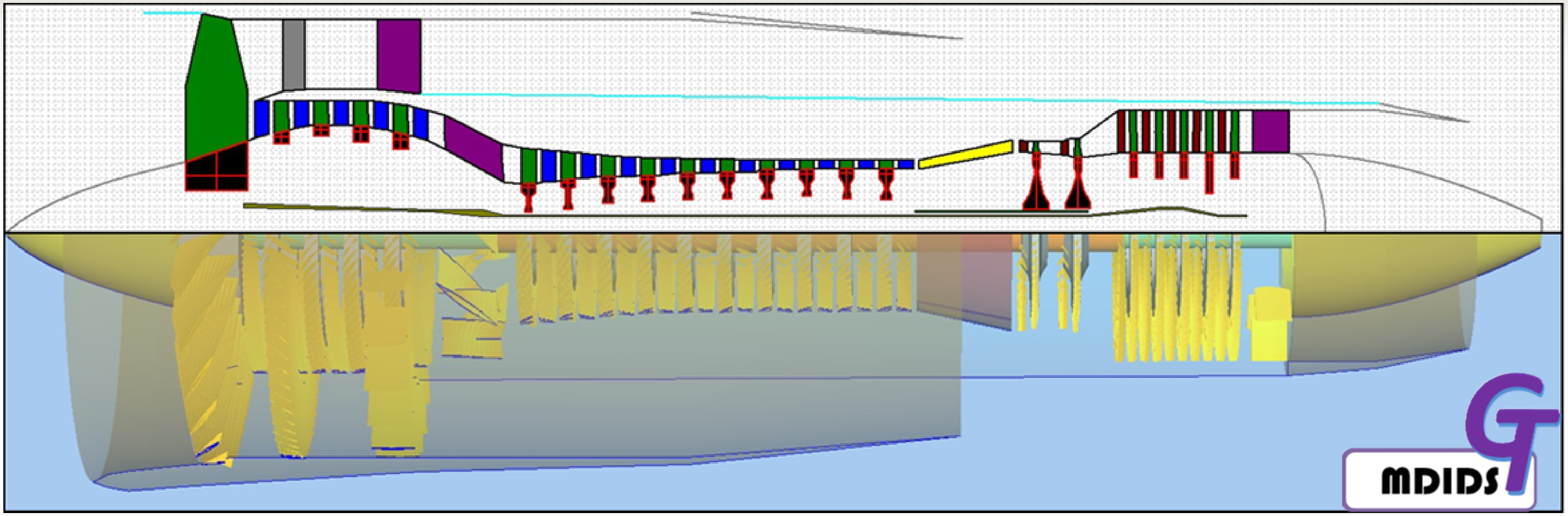
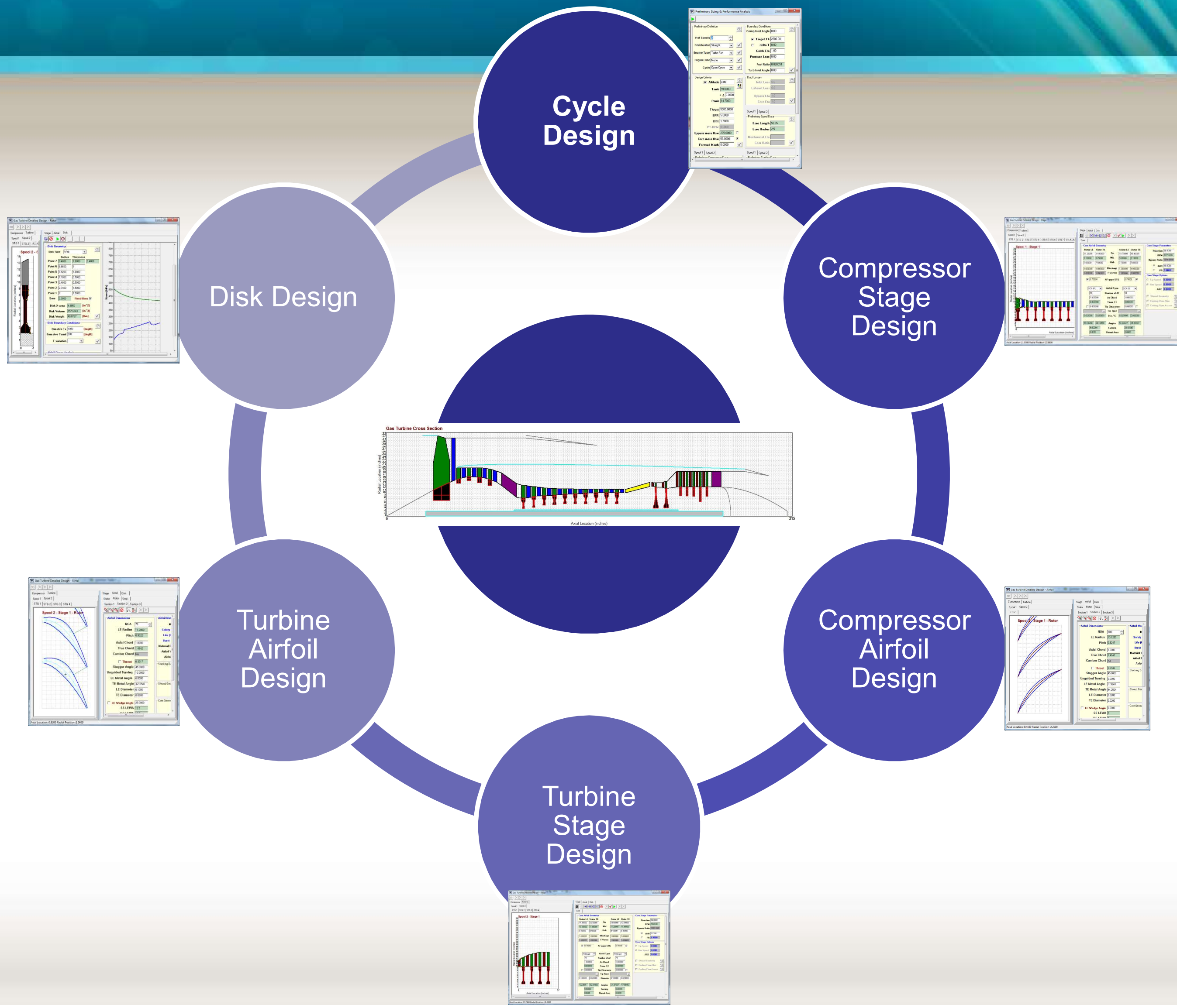
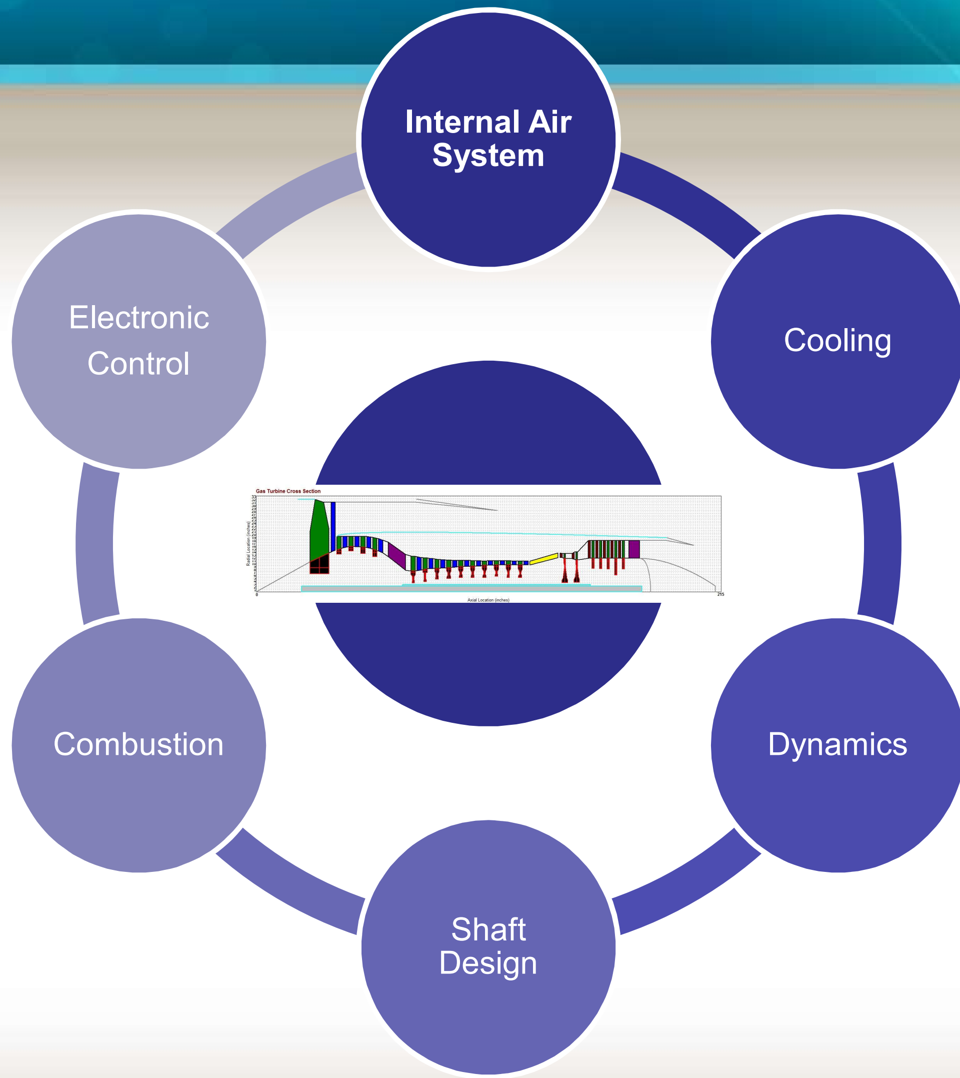


So what do we have to do?

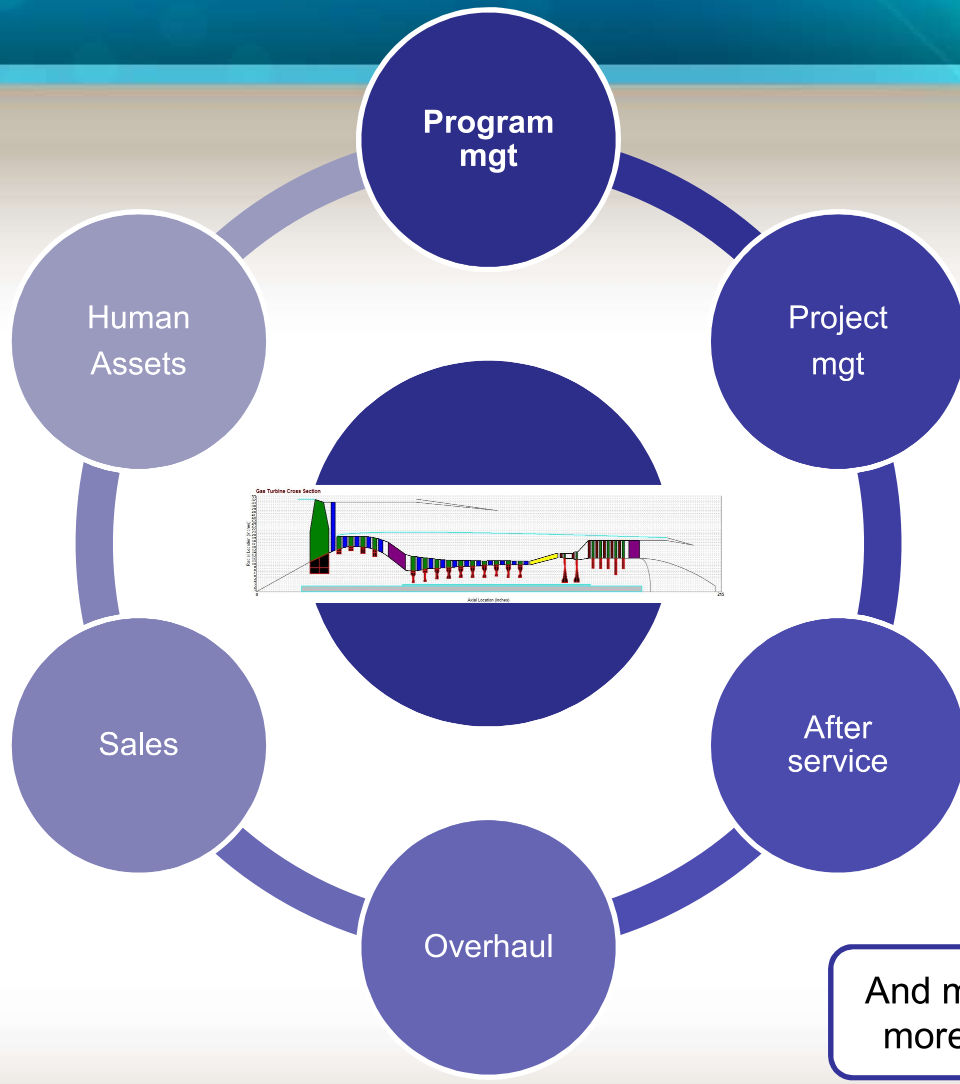
Multi-Disciplinary Design & Optimization



Multi-Disciplinary Design & Optimization (con't)

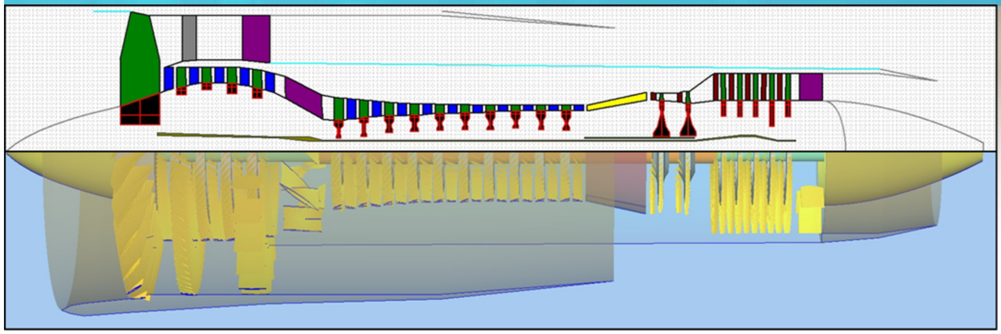


Multi-Disciplinary Design & Optimization (con’t)

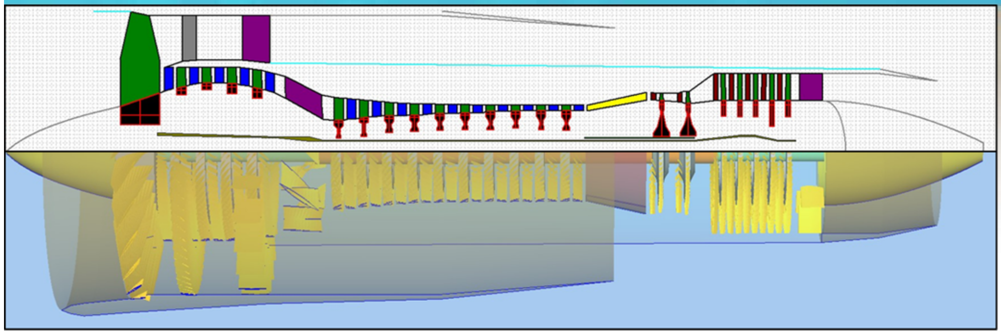


And much more …

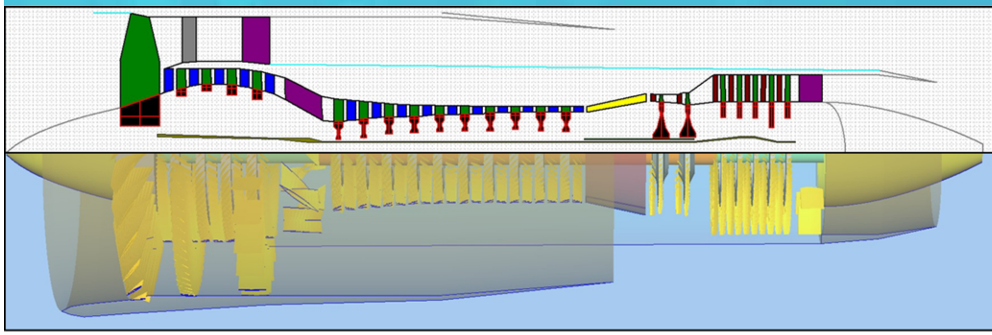
What are the 2 driving constraints?



What are the 2 driving constraints?



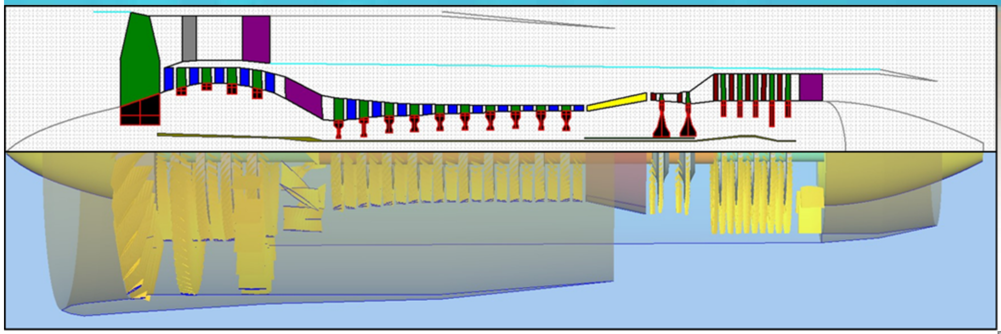
And what is the driving design parameter for a Turbofan?



The driving parameter of Turbofan

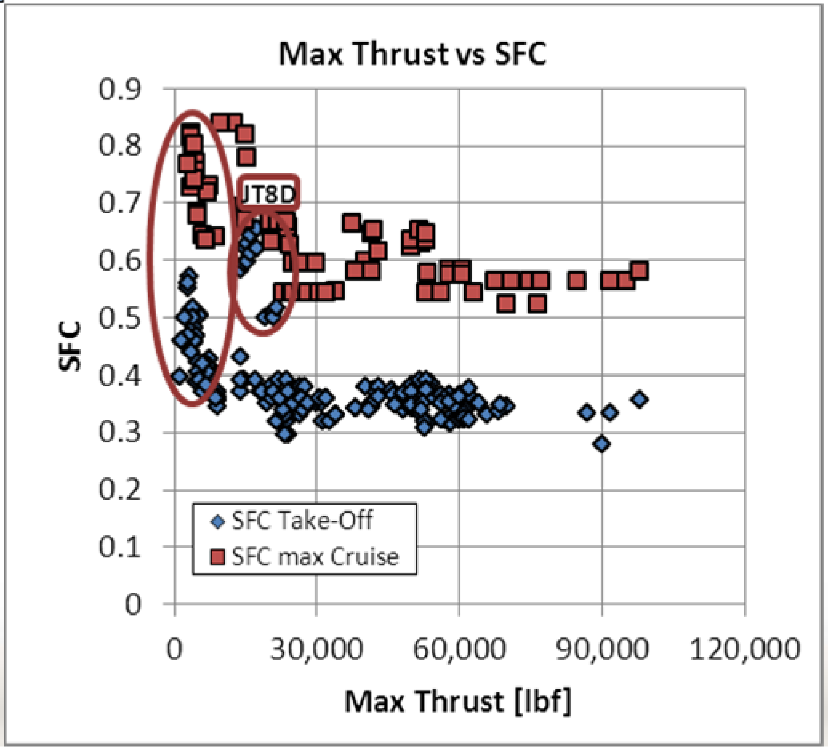
THRUST
IN CONTEXT WITH 60 YEARS OF DATA

It's all about "Thrust"

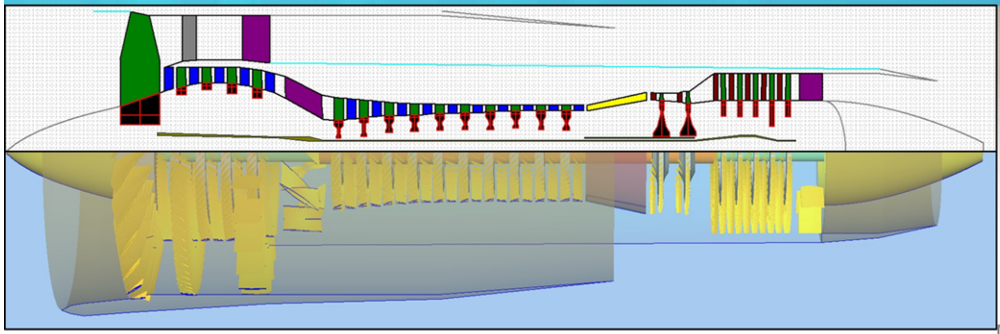


Specific Fuel Consumption (SFC)

Our target to achieve or do better

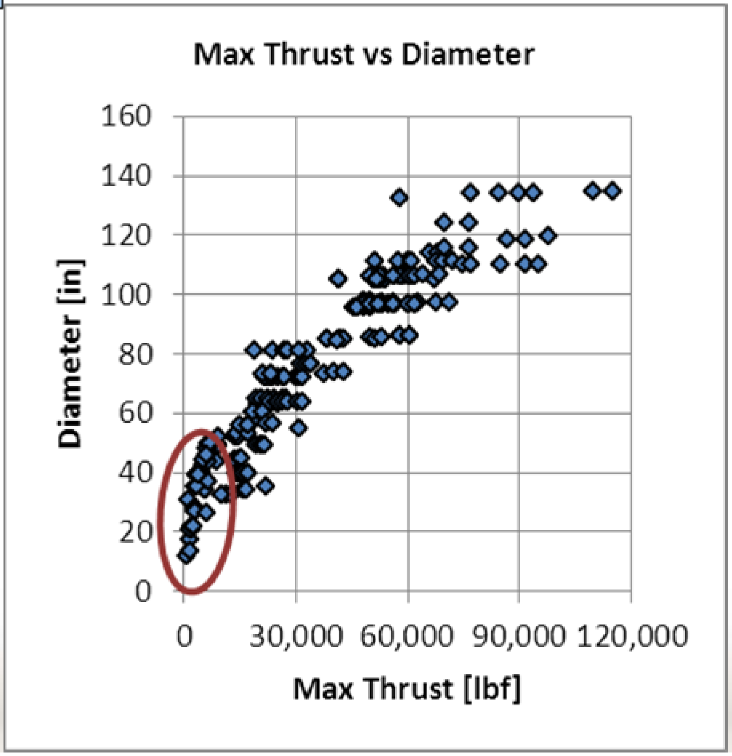


It's all about "Thrust" (con't)

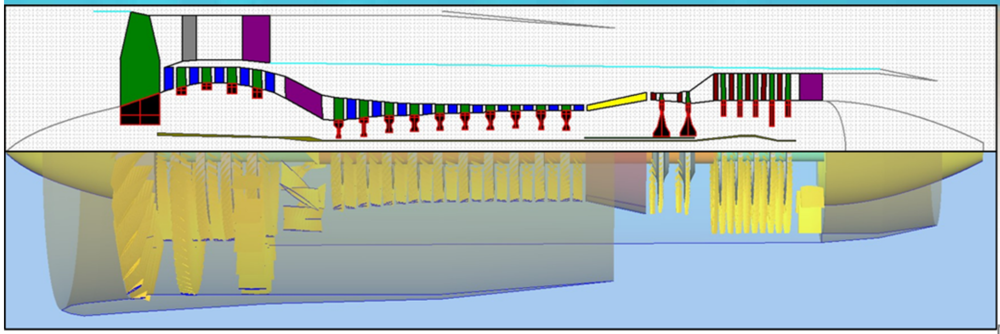


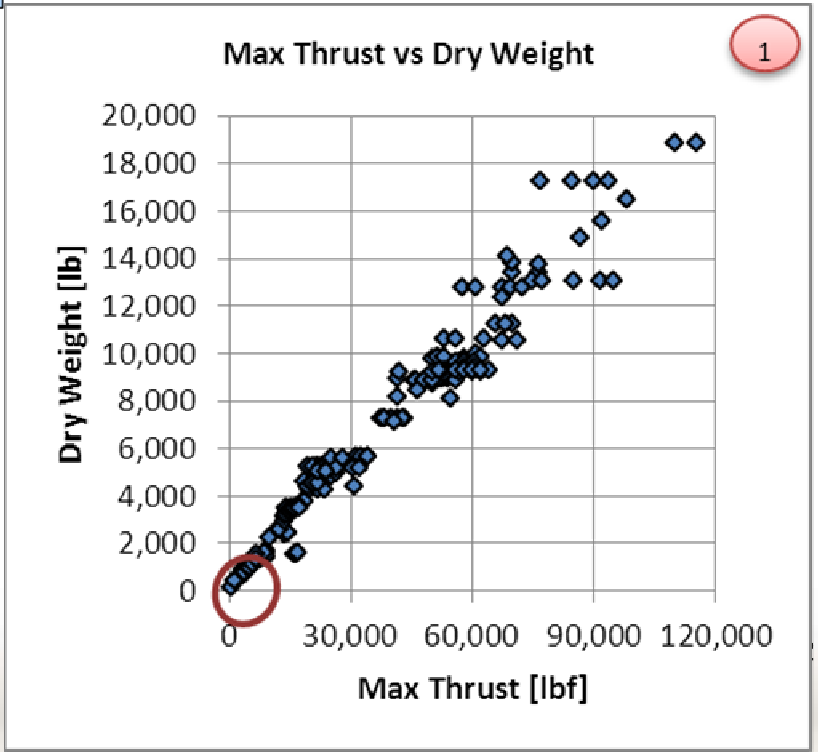
Fan diameter

Size
Weight



It’s all about “Thrust” (con’t)

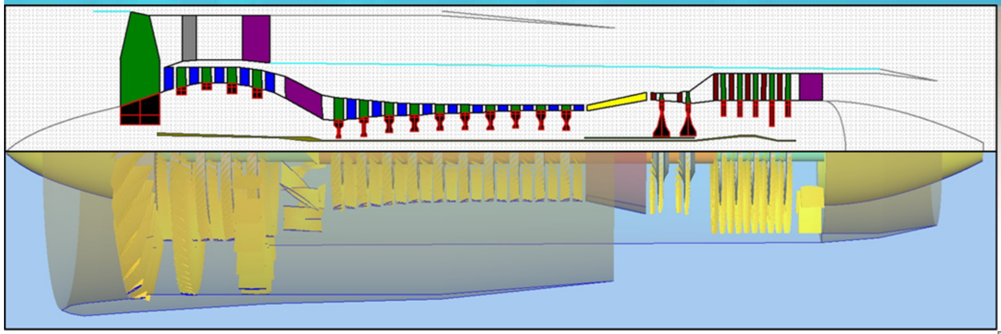




Weight

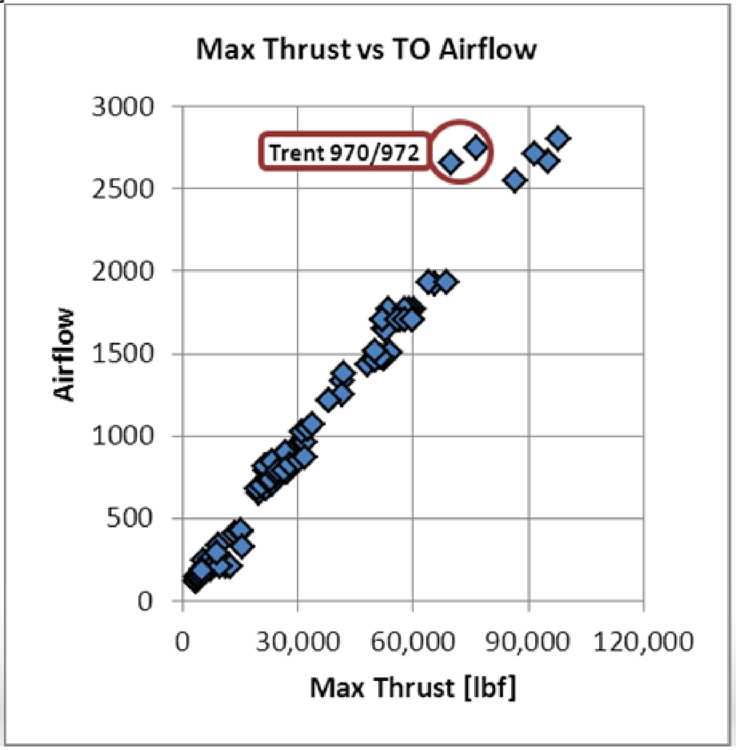
Time for a diet
and
Stay on target

It's all about "Thrust" (con't)

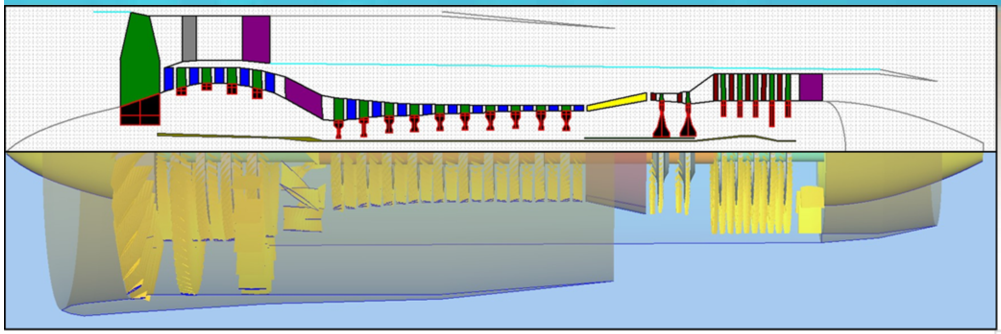


Air flow

The driving fluid Performance

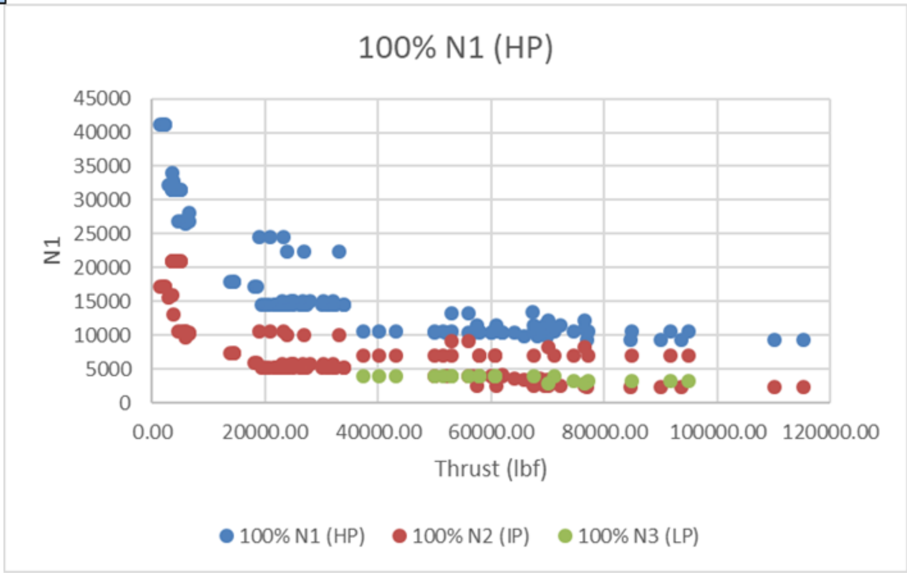


It’s all about “Thrust” (con’t)

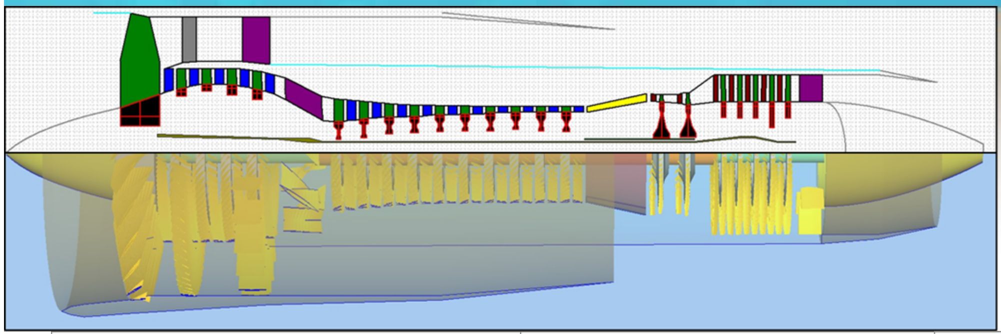


RPM

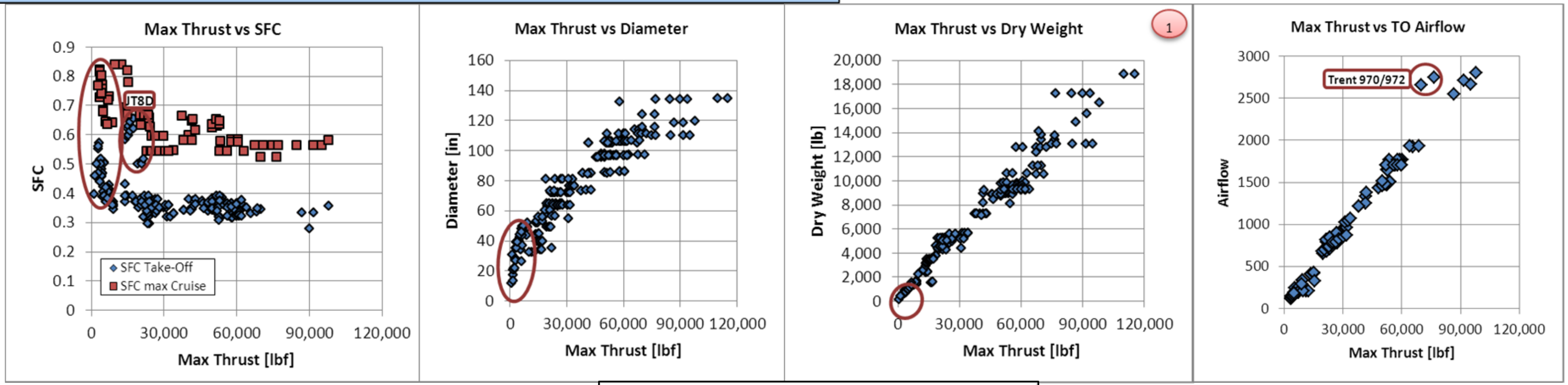
Stress
Material selection
Performance
Cost

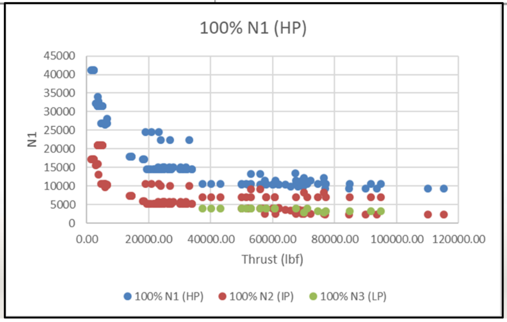


It's all about "Thrust" (con't)



Gas turbine preliminary sizing limit & trade-off curves





The basic cross sections

CHOOSING THE ENGINE CONFIGURATION

Choosing a configuration

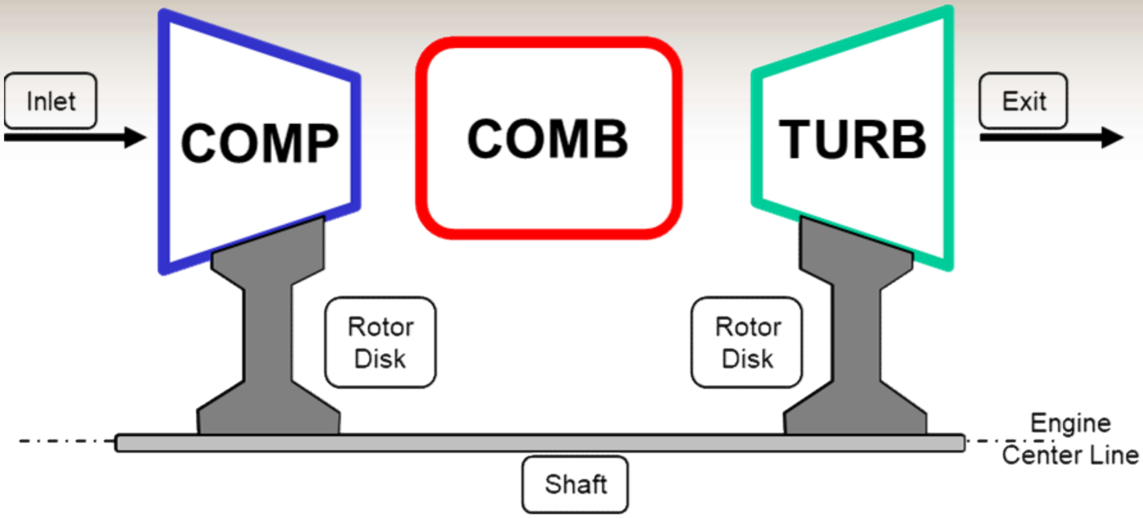
Three ingredients are required

1) a knowledge of different engine configurations

2) a historical background of existing engines

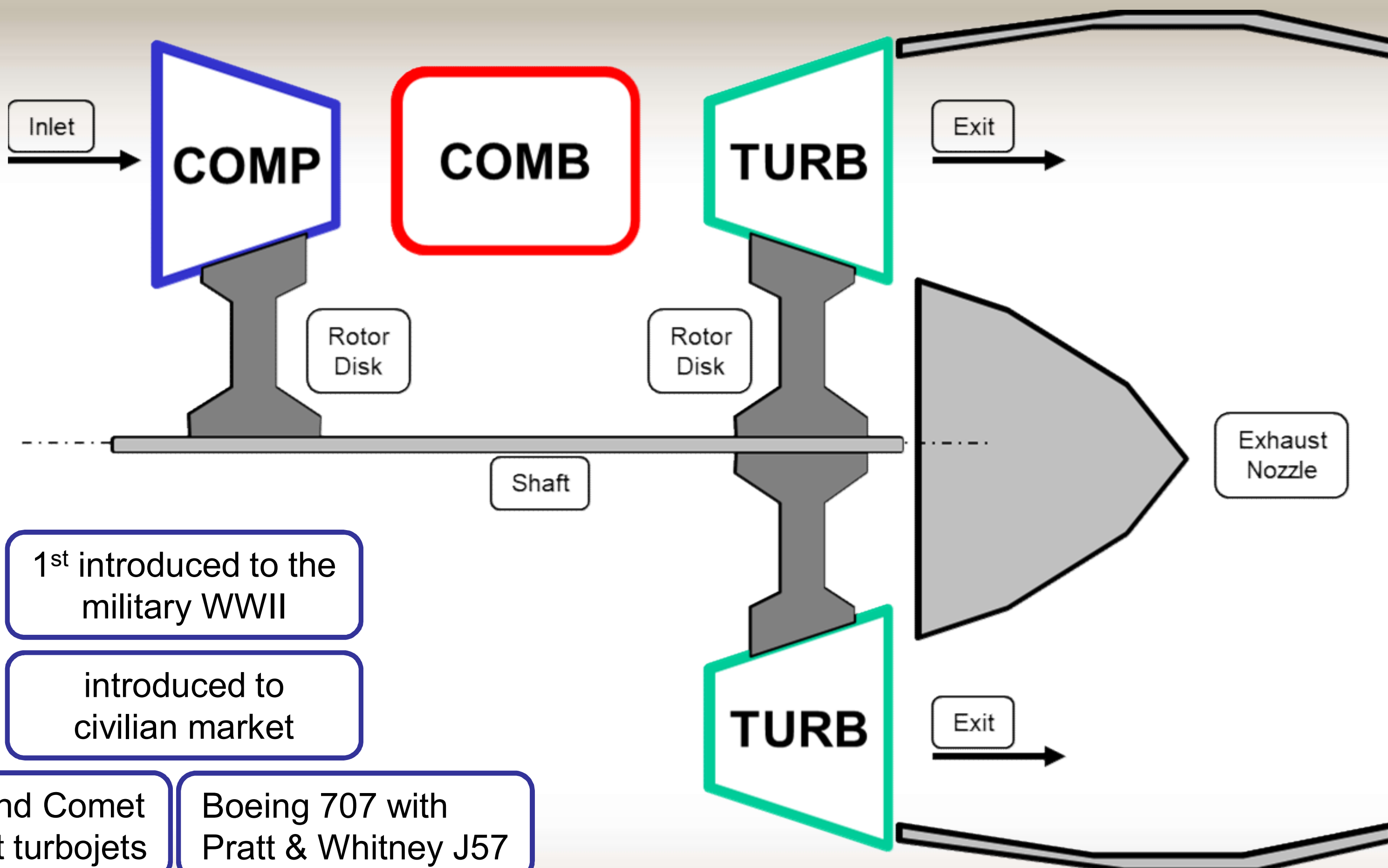
3) lots and lots of simulation models

The “core”



Inlet
COMP
COMB
TURB
Exit
Rotor Disk
Rotor Disk
Engine Center Line
Shaft

The "Grandpa to all"



1st introduced to the military WWII

introduced to civilian market

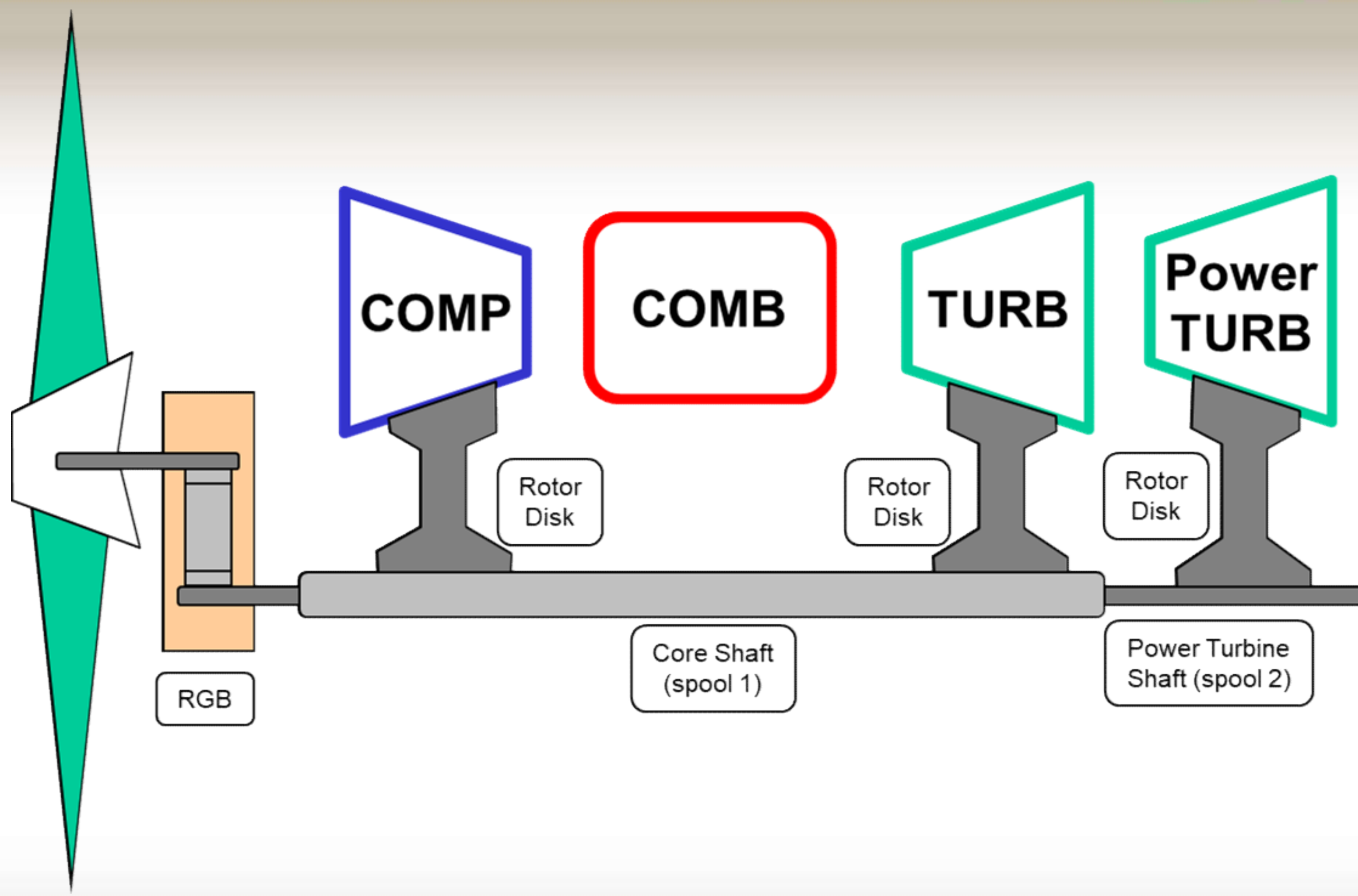
de Havilland Comet with Ghost turbojets

1949 / 1952

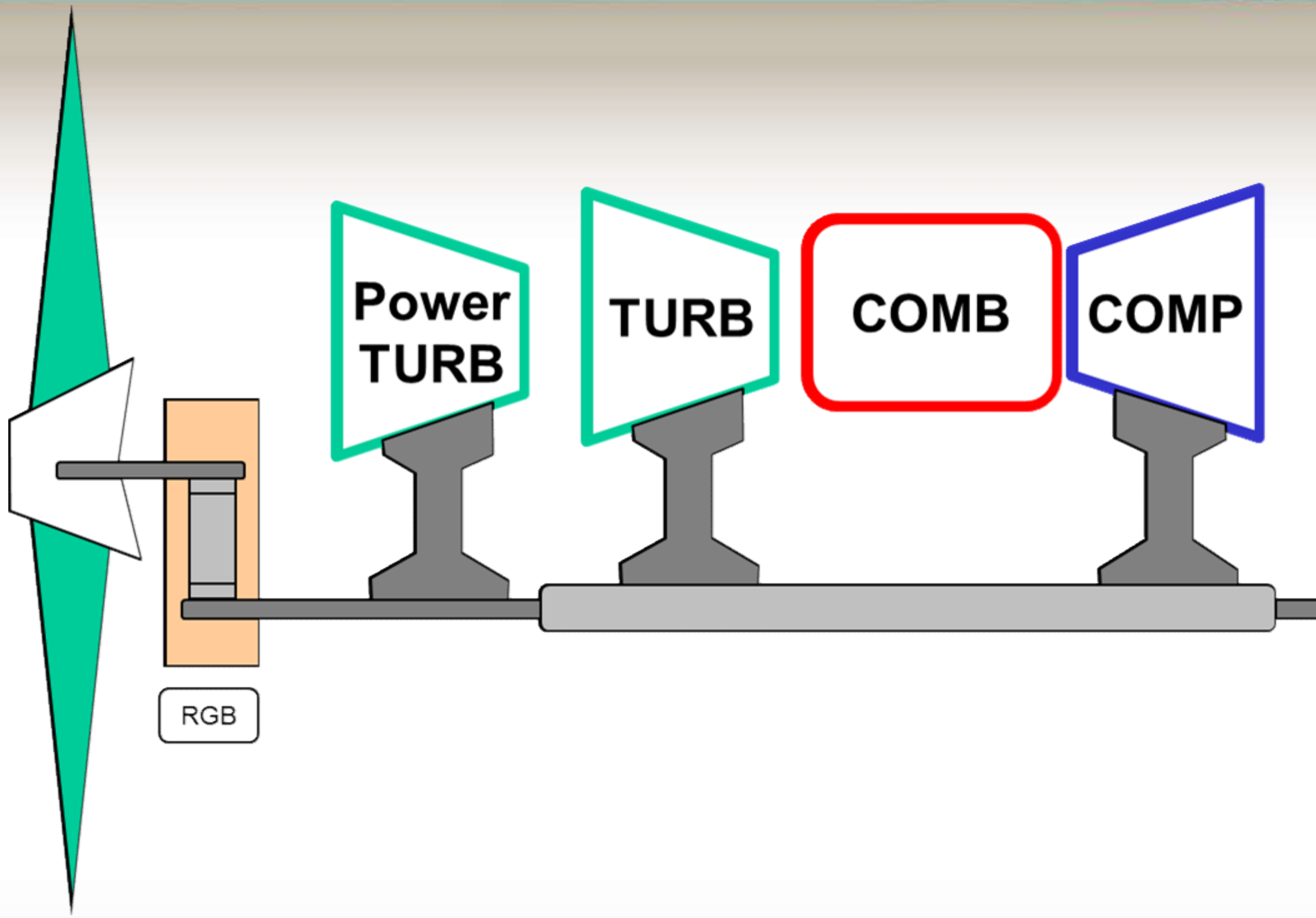
Boeing 707 with Pratt & Whitney J57

1957 / 1958

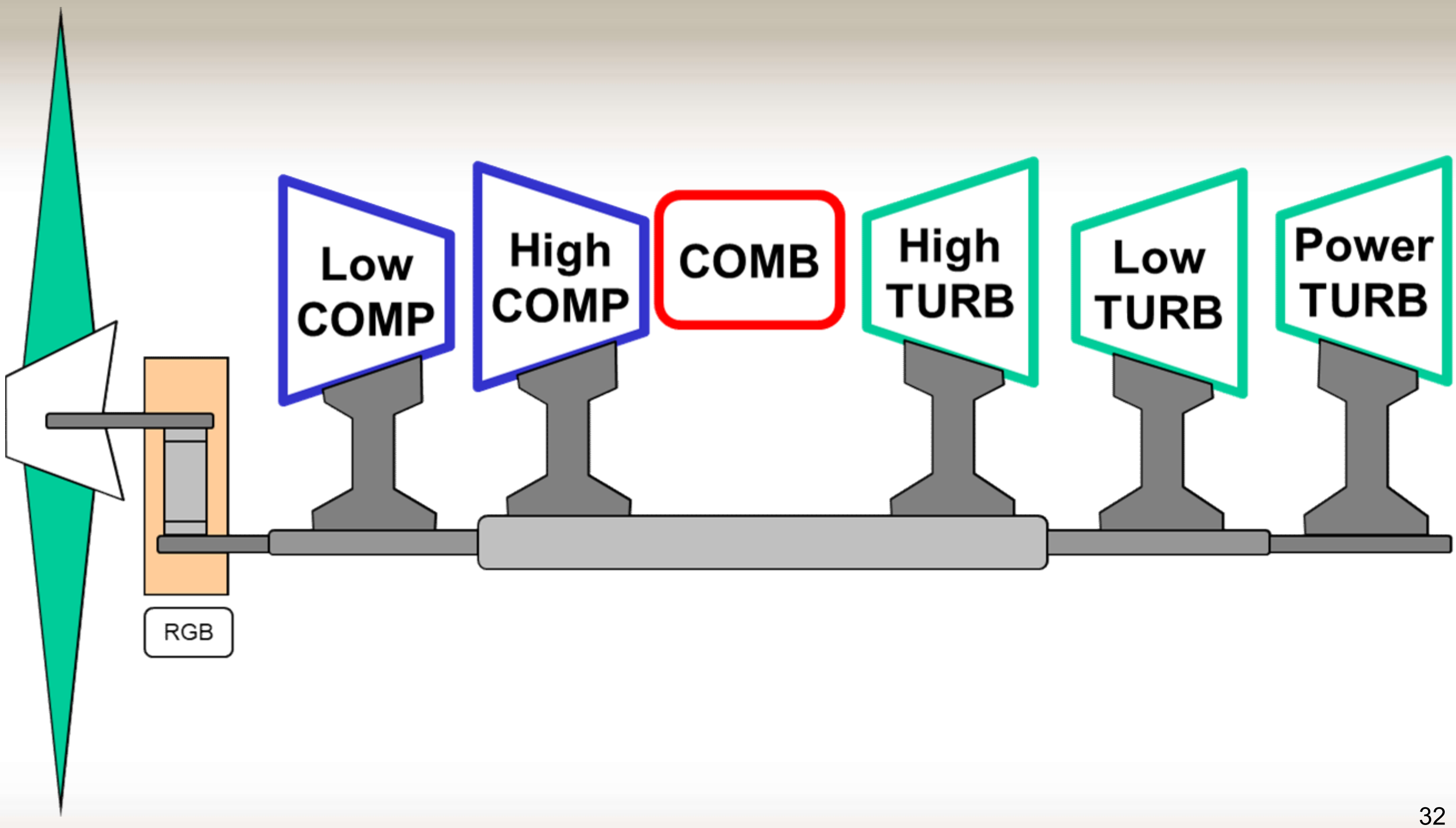
2 Spool Turbo-Prop



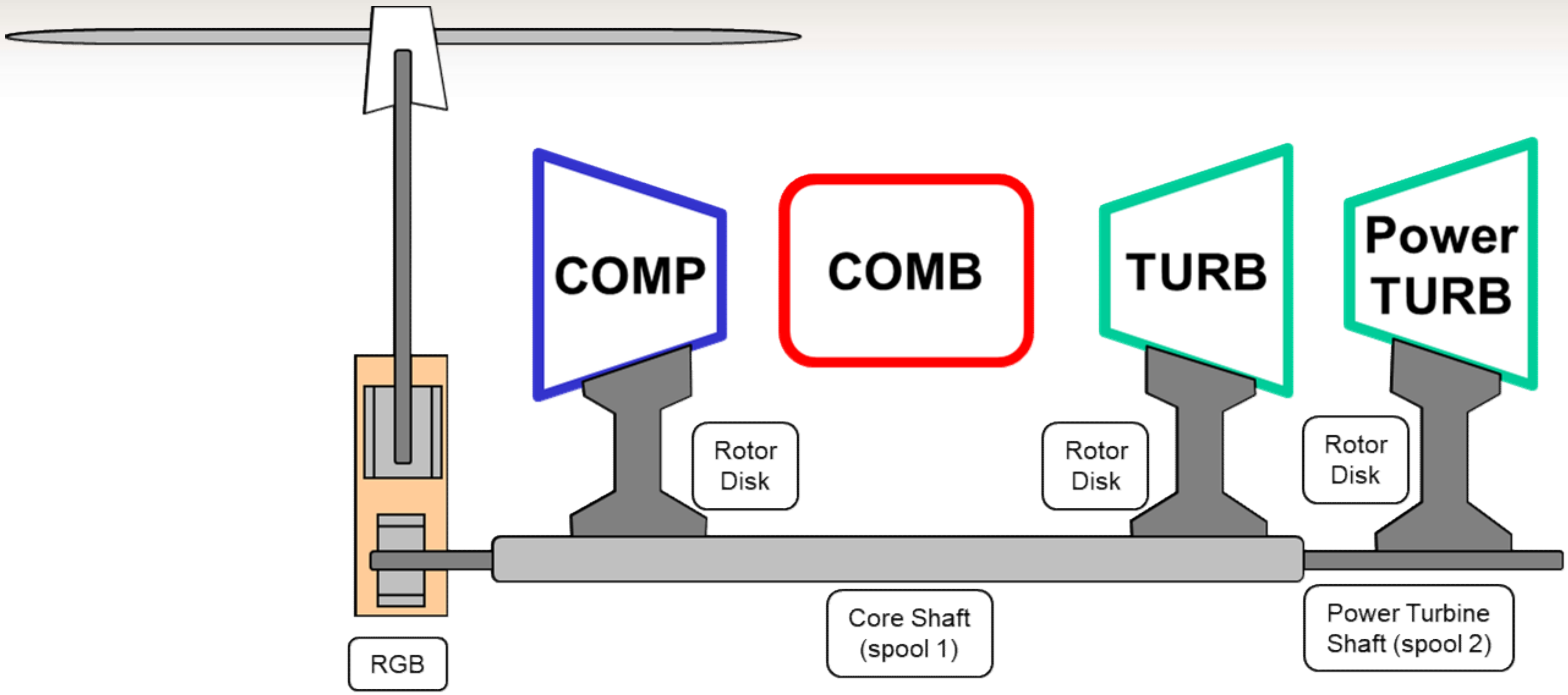
2 Spool Turbo-Prop reversed RGB



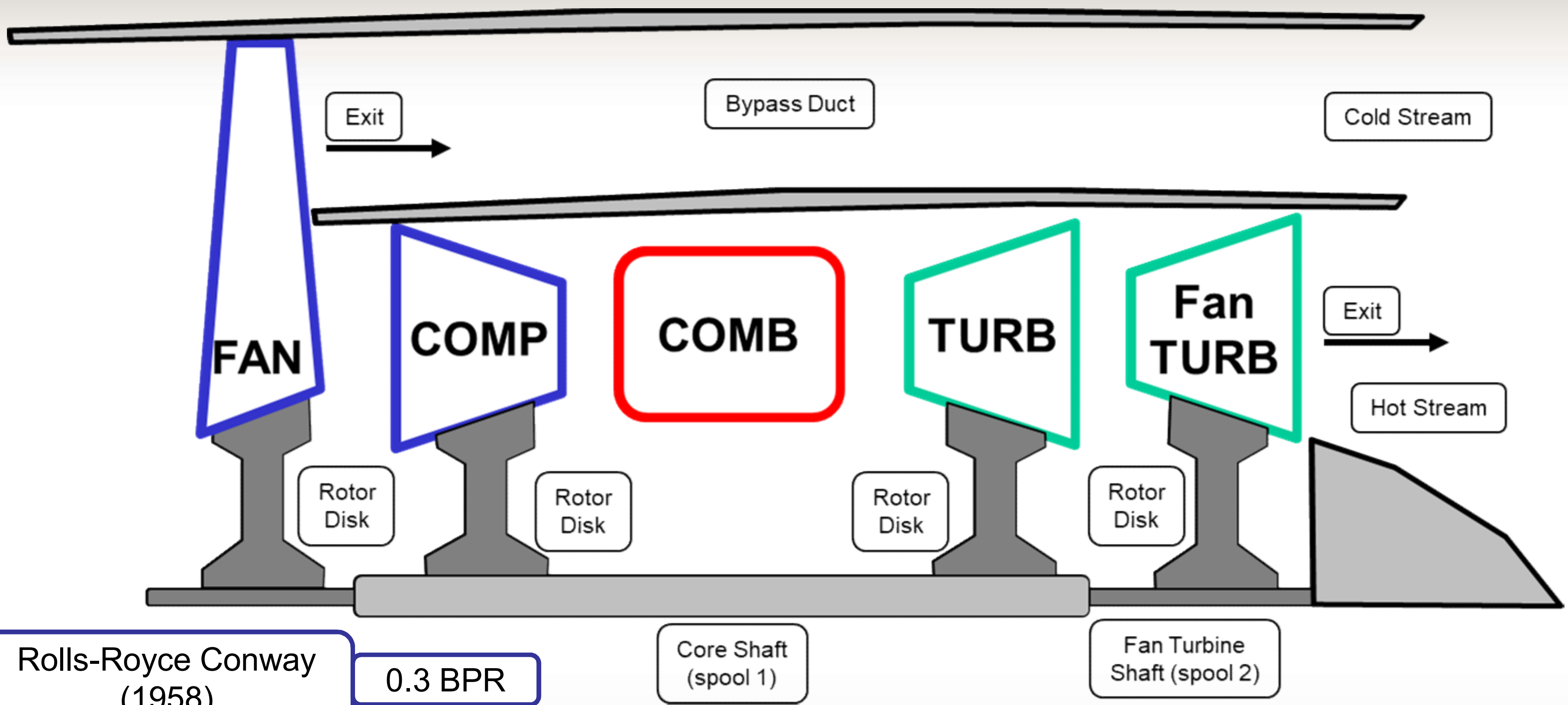
3 Spool Turbo-Prop



2 Spool Turbo-Shaft

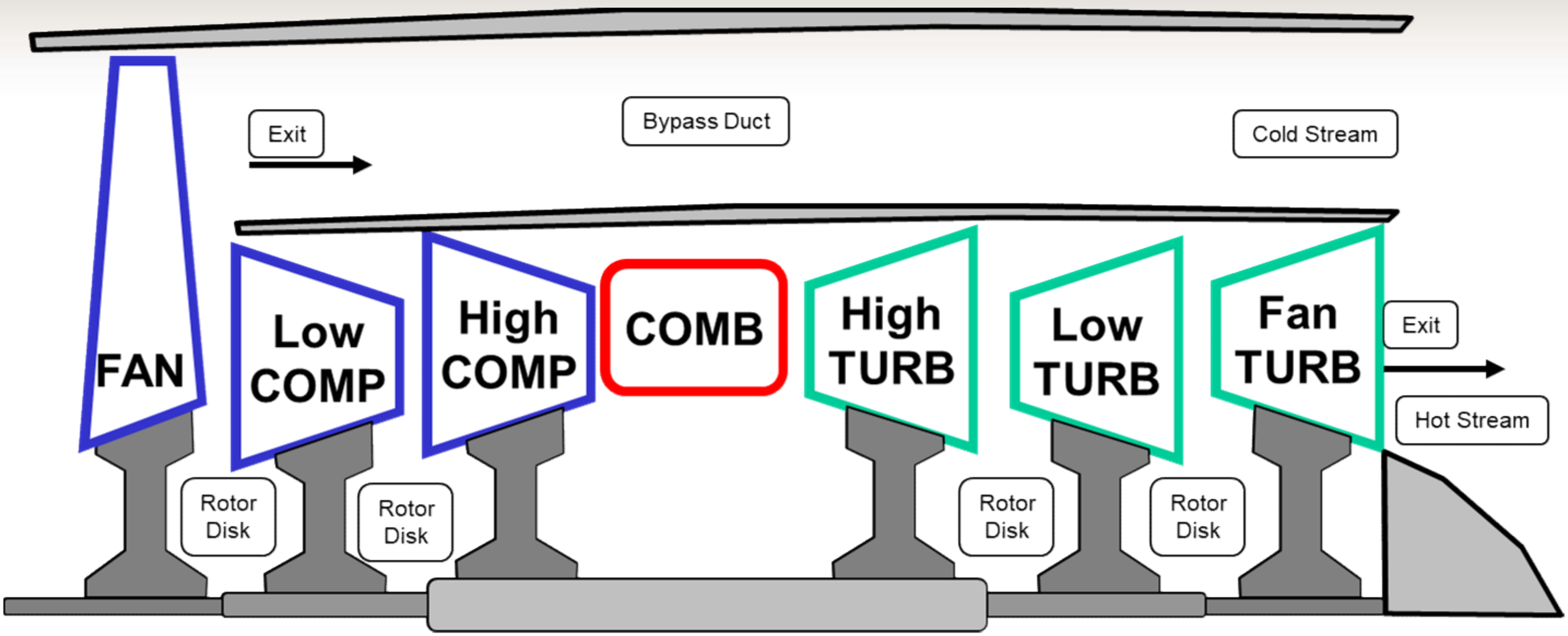


2 Spool Turbo-Fan

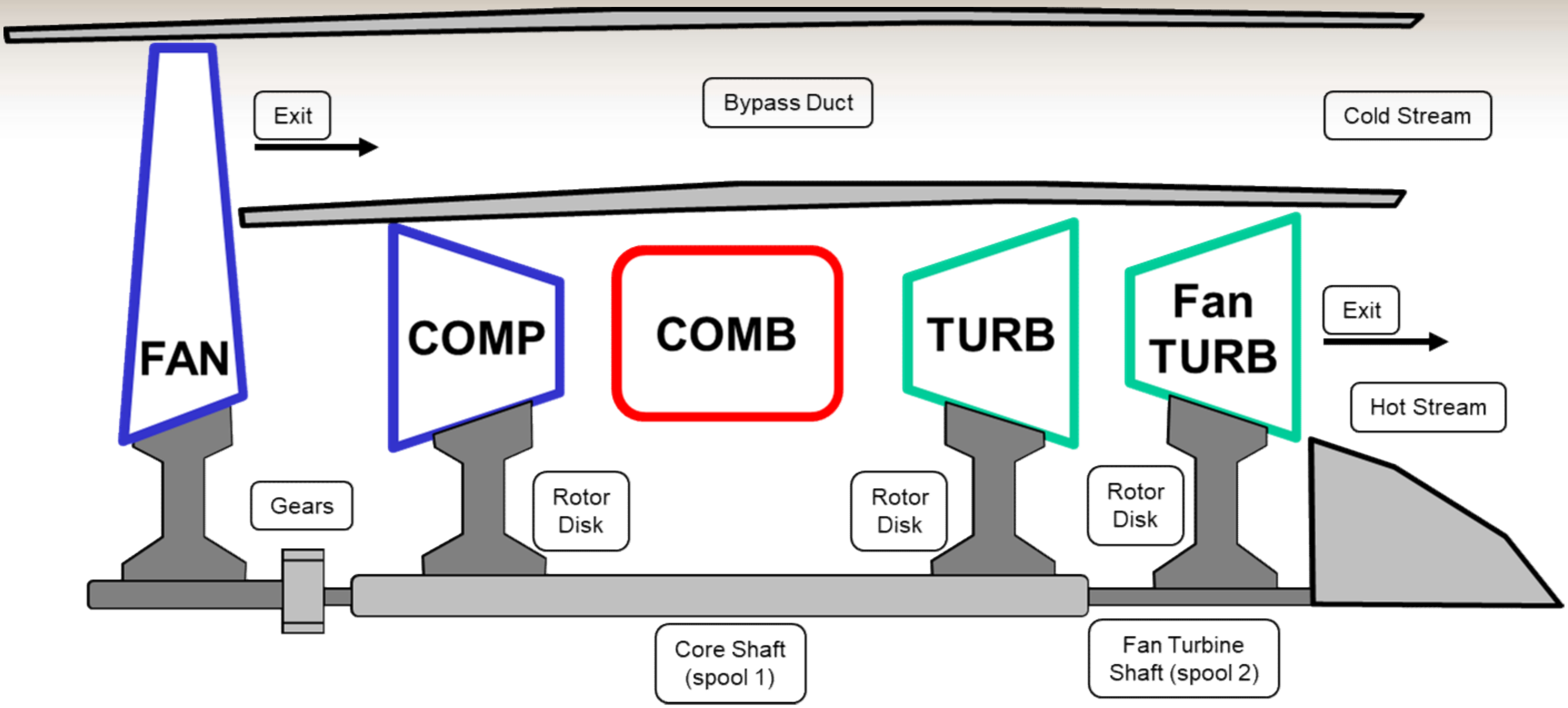


Rolls-Royce Conway (1958)	0.3 BPR
Pratt & Whitney JT3D (1959)	1.42 BPR

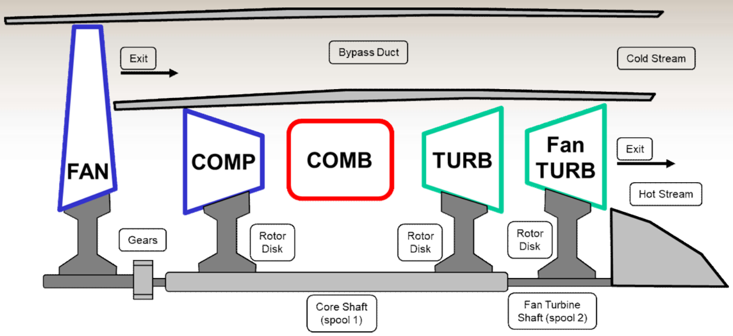
3 Spool Turbo fan



2 Spool Geared Turbo-Fan



2 Spool Geared Turbo-Fan

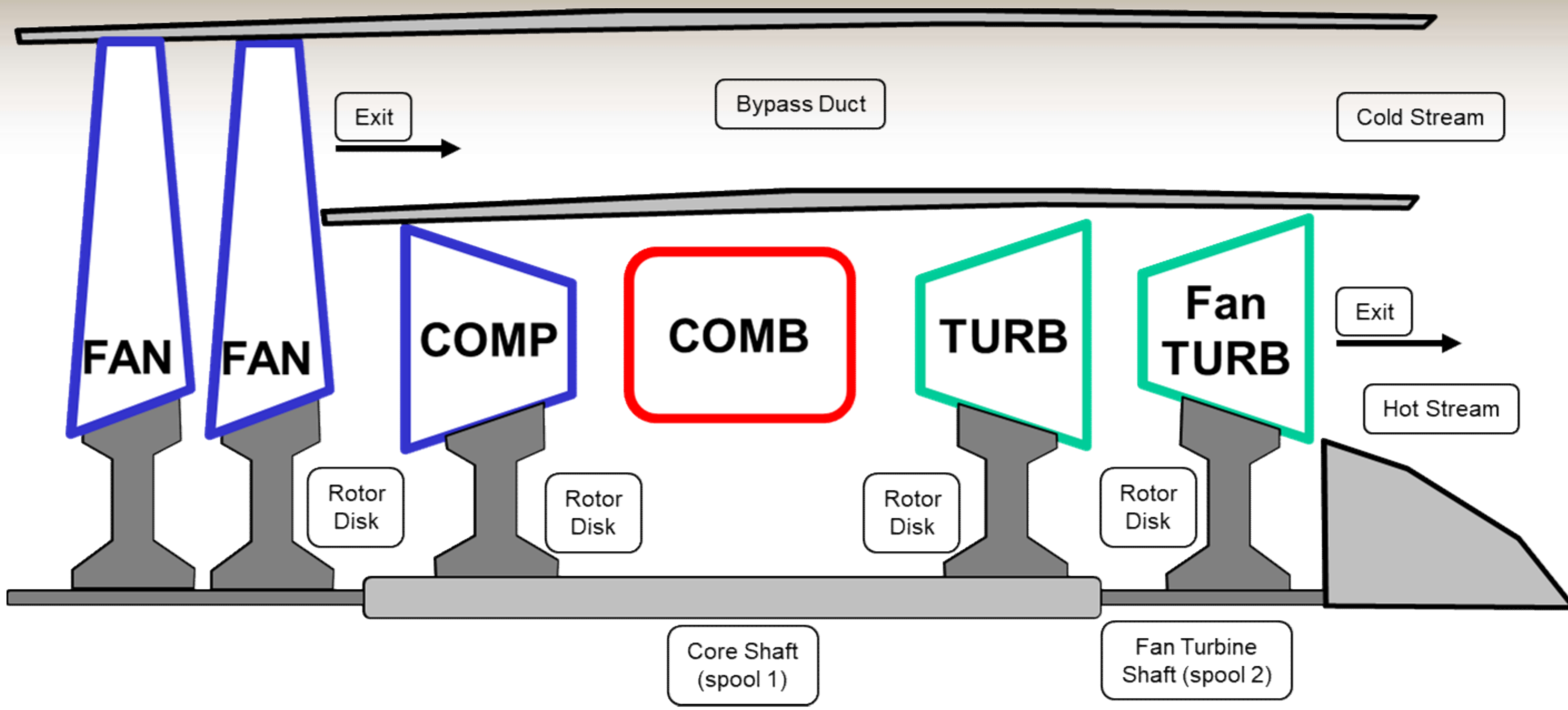


COMPANY	ENGINE	TIMEFRAME	COMMENT
Honeywell	TFE731	1972	
GE	QCSEE	1974	NASA design contract
Honeywell	ALF 502/507	1980	
IAE	SuperFan	1986	Engineering study only
Pratt & Whitney	PW1000G	2012	
United Engine Corporation	PD-30	TBD	
Rolls-Royce	UltraFan	TBD	

Is the UltraFan a reincarnation of the SuperFan? … I wonder …

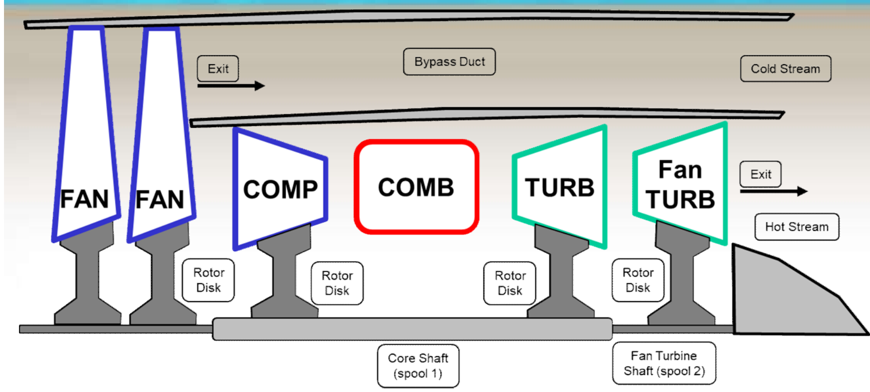
2 Spool Double-Fan Turbo-Fan

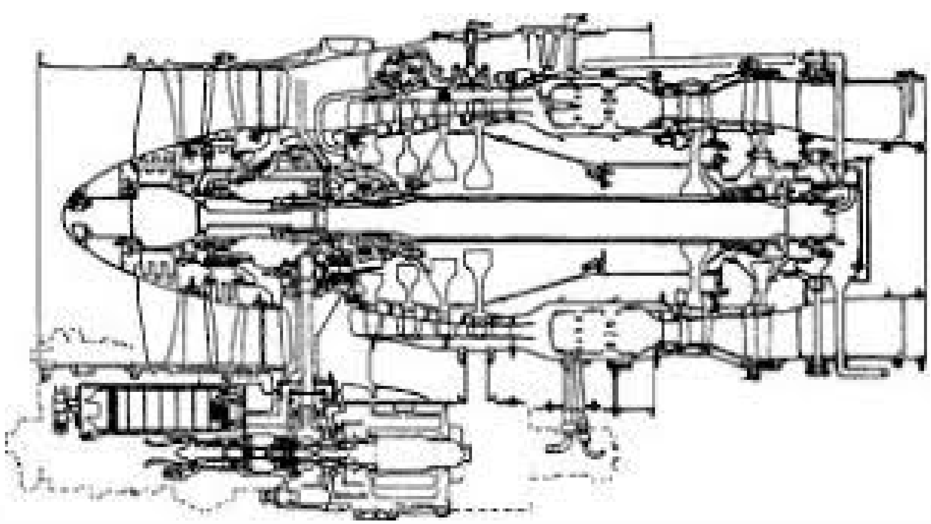
NEW in 2018 By GE



2 Spool Double-Fan Turbo-Fan

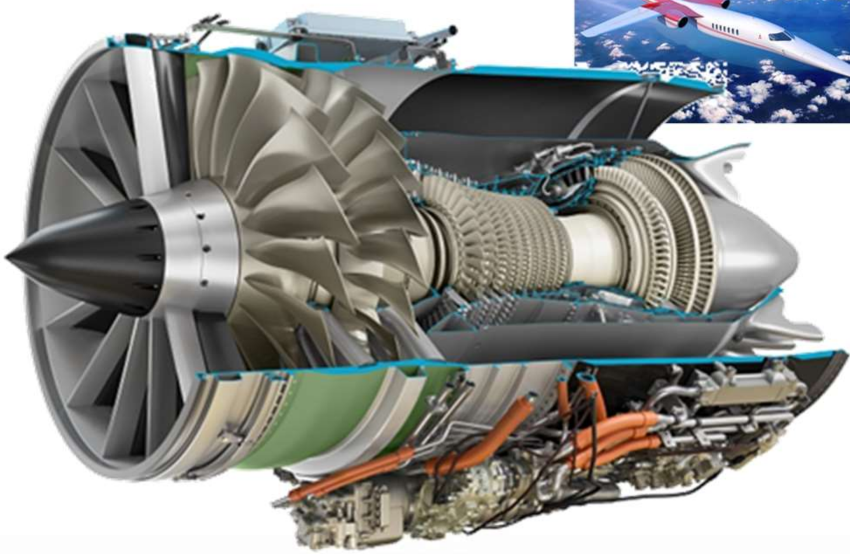
NEW in 2018
By GE





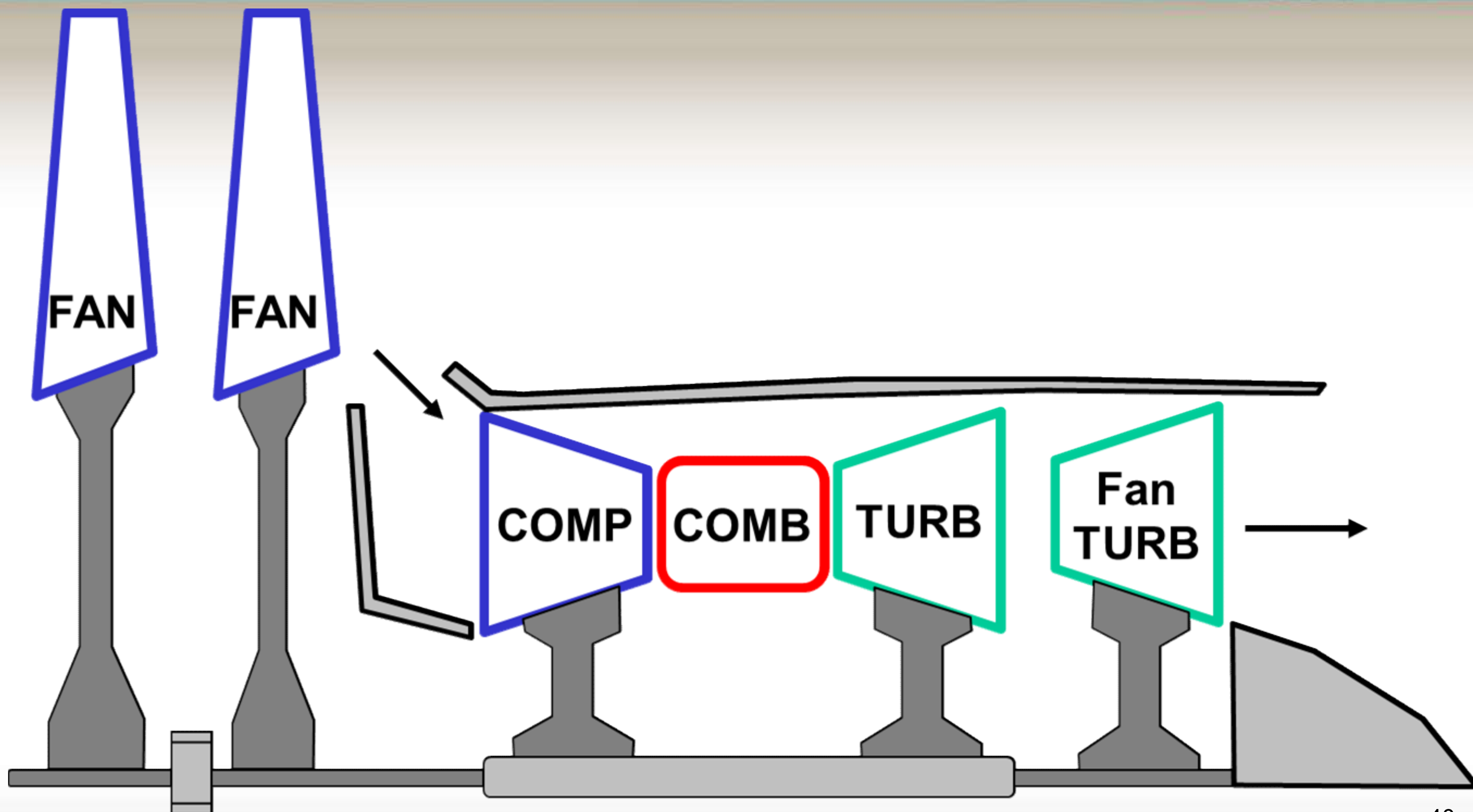
SAFRAN Larzac 04 (military)

1969, 1982, 1984



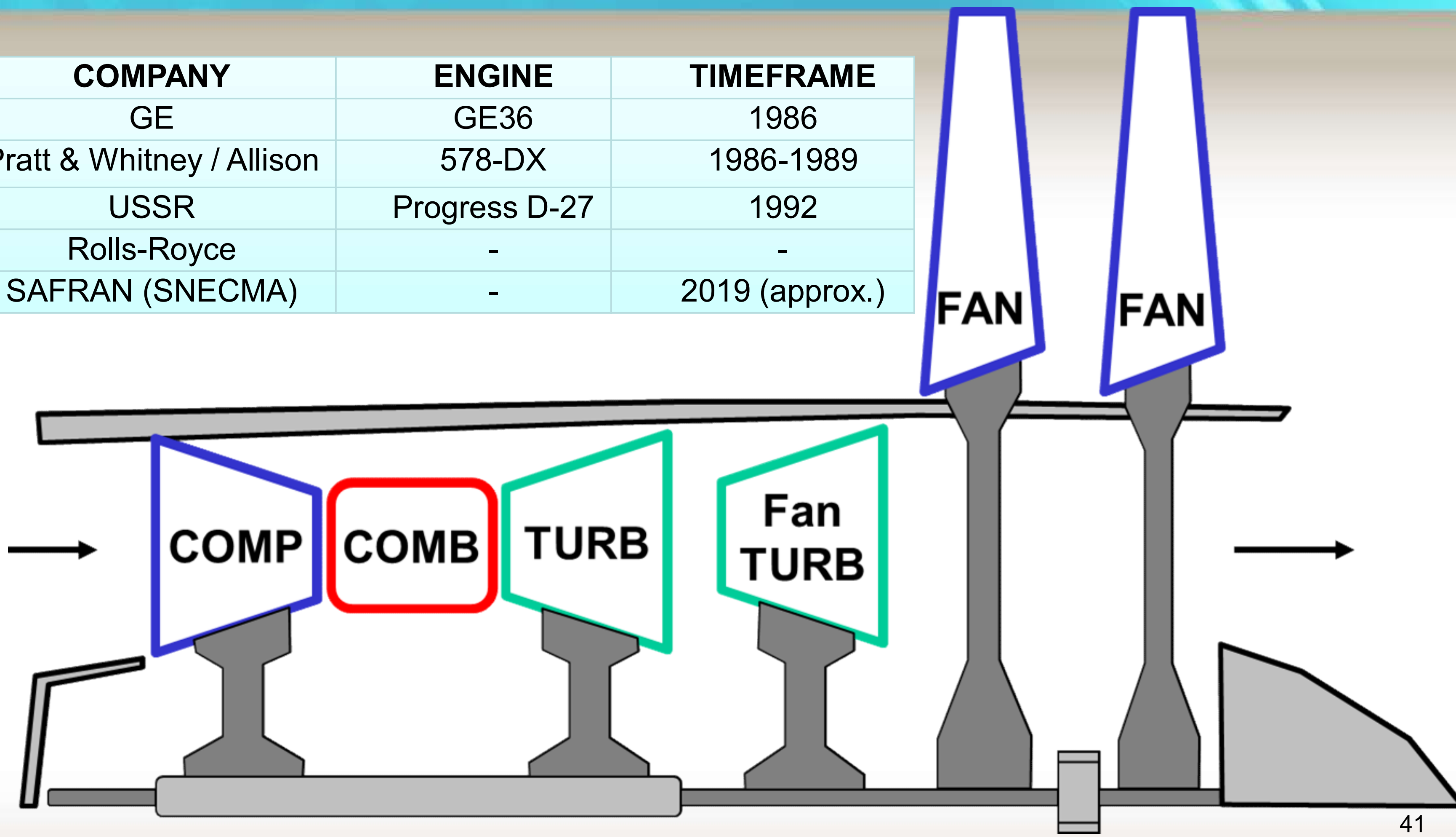
GE Affinity (Civilian supersonic)

Open Rotor Forward Fan



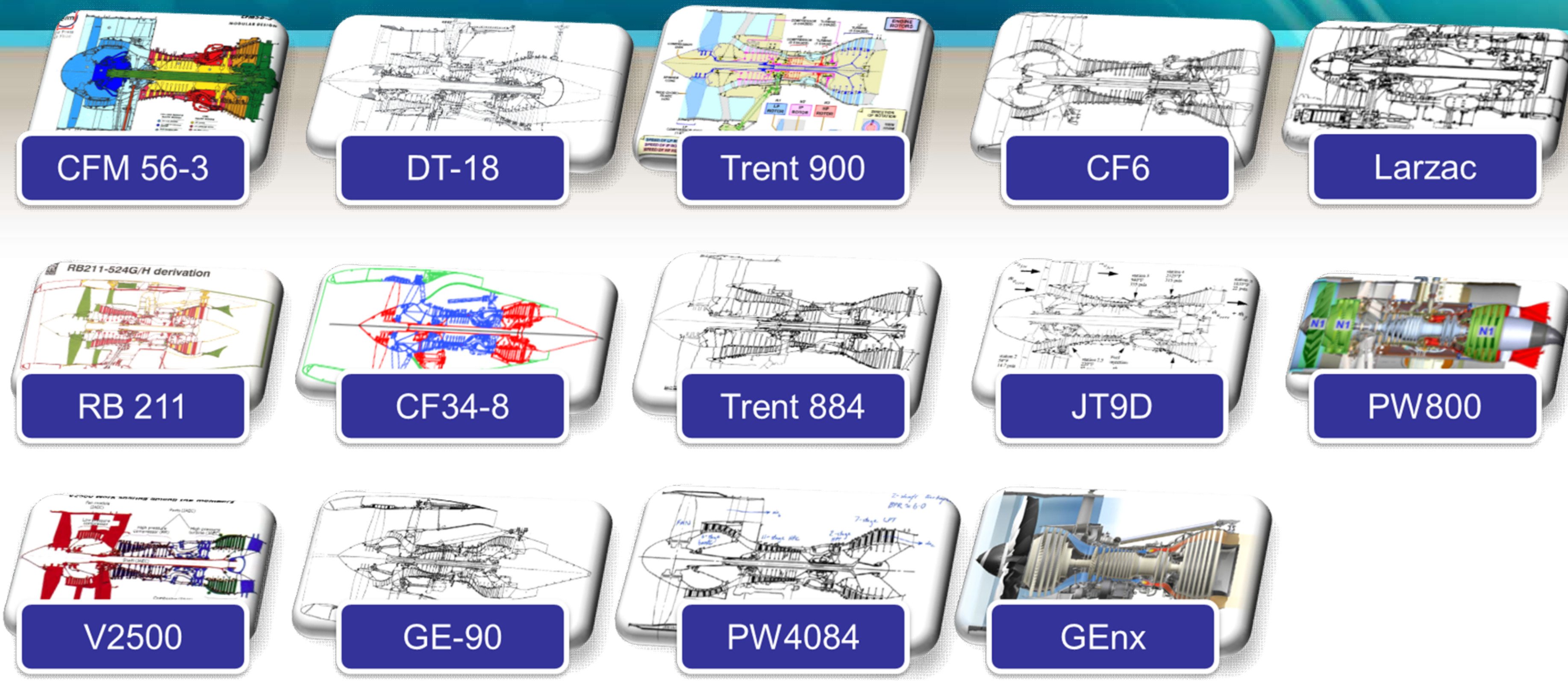
Open Rotor Rear Fan

COMPANY	ENGINE	TIMEFRAME
GE	GE36	1986
Pratt & Whitney / Allison	578-DX	1986-1989
USSR	Progress D-27	1992
Rolls-Royce	-	-
SAFRAN (SNECMA)	-	2019 (approx.)



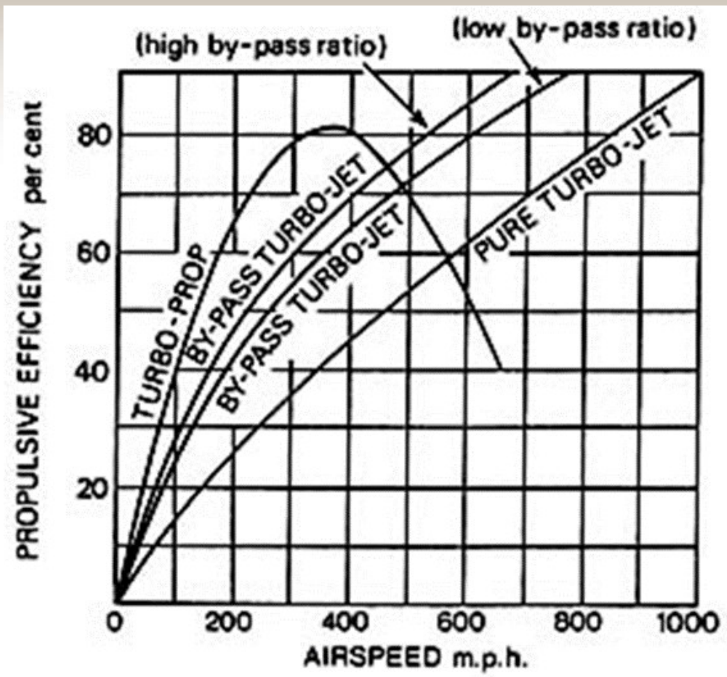
How do we choose which configuration?

Database of engines



Successful production engine data	"biased" clean sheets and derivatives	Model & simulation validation	Incorporation of new or improved technologies

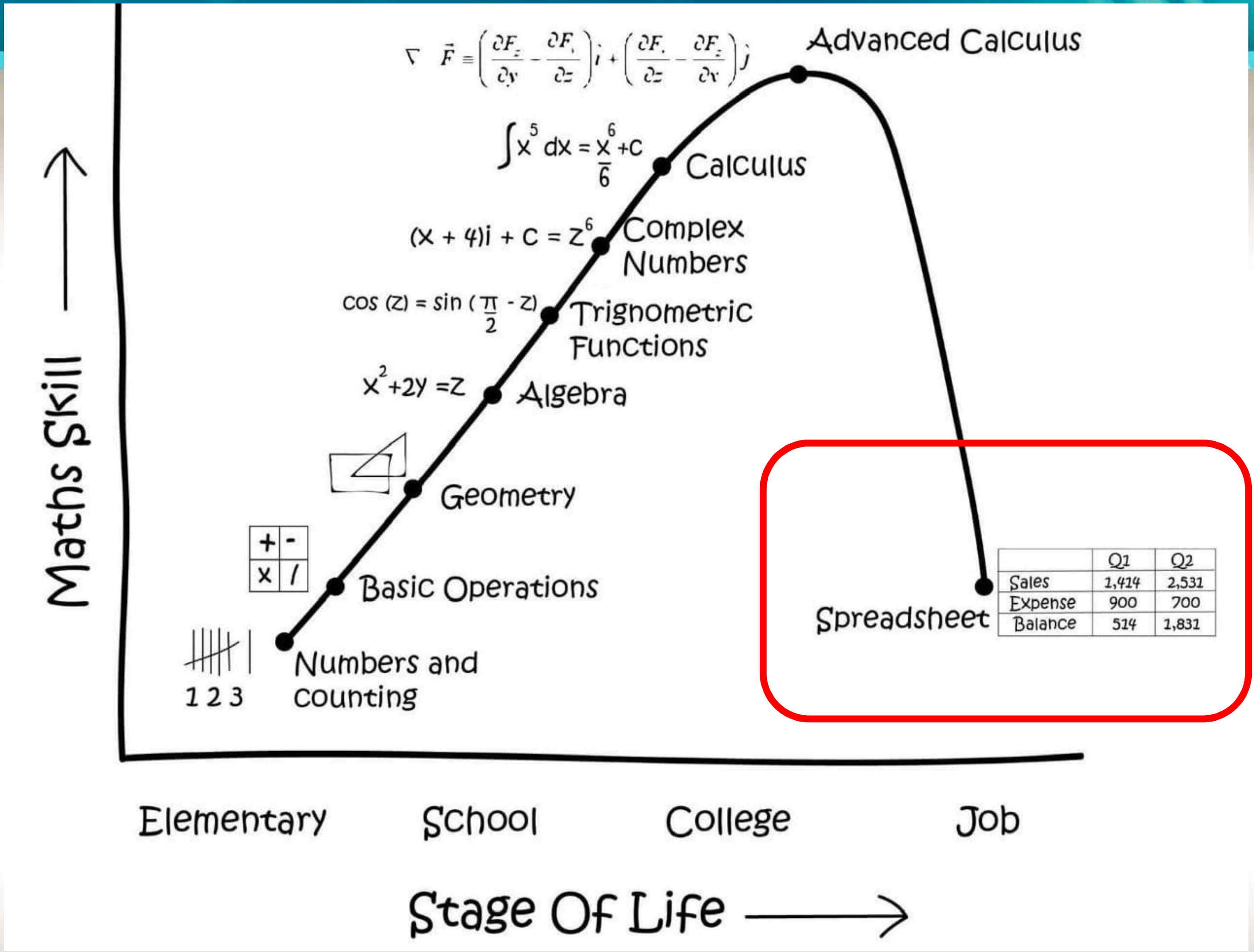
How do we choose which configuration?



- $f(x)$
- EI
- NI
- Mgt
- Next slide

EI: Emotional Intelligence
NI: Natural Intelligence

And lots of sophisticated spreadsheets

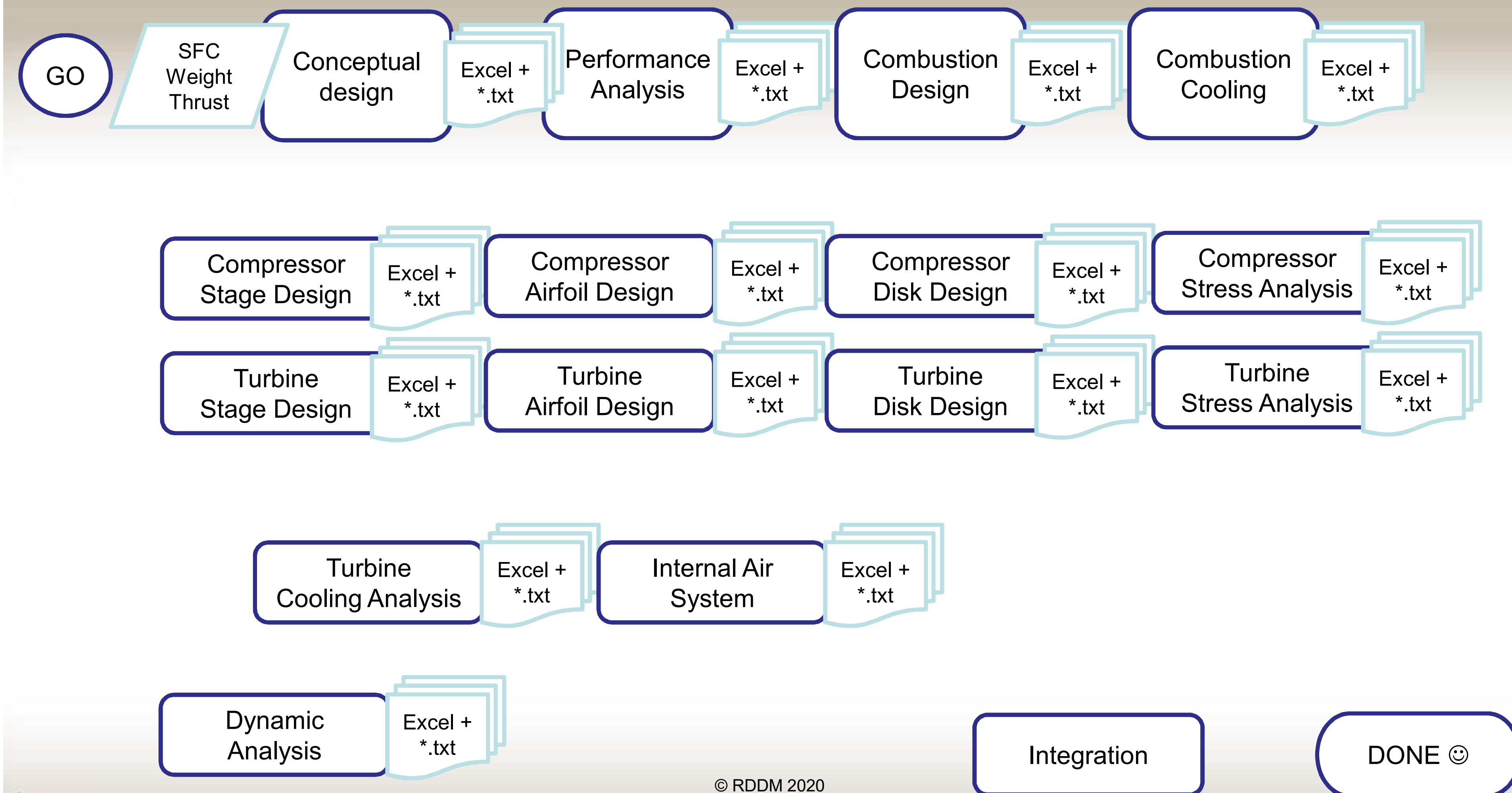


"It is common sense to take a method and try it. If it fails, admit it frankly and try another. But above all, try something."- **Franklin D. Roosevelt**

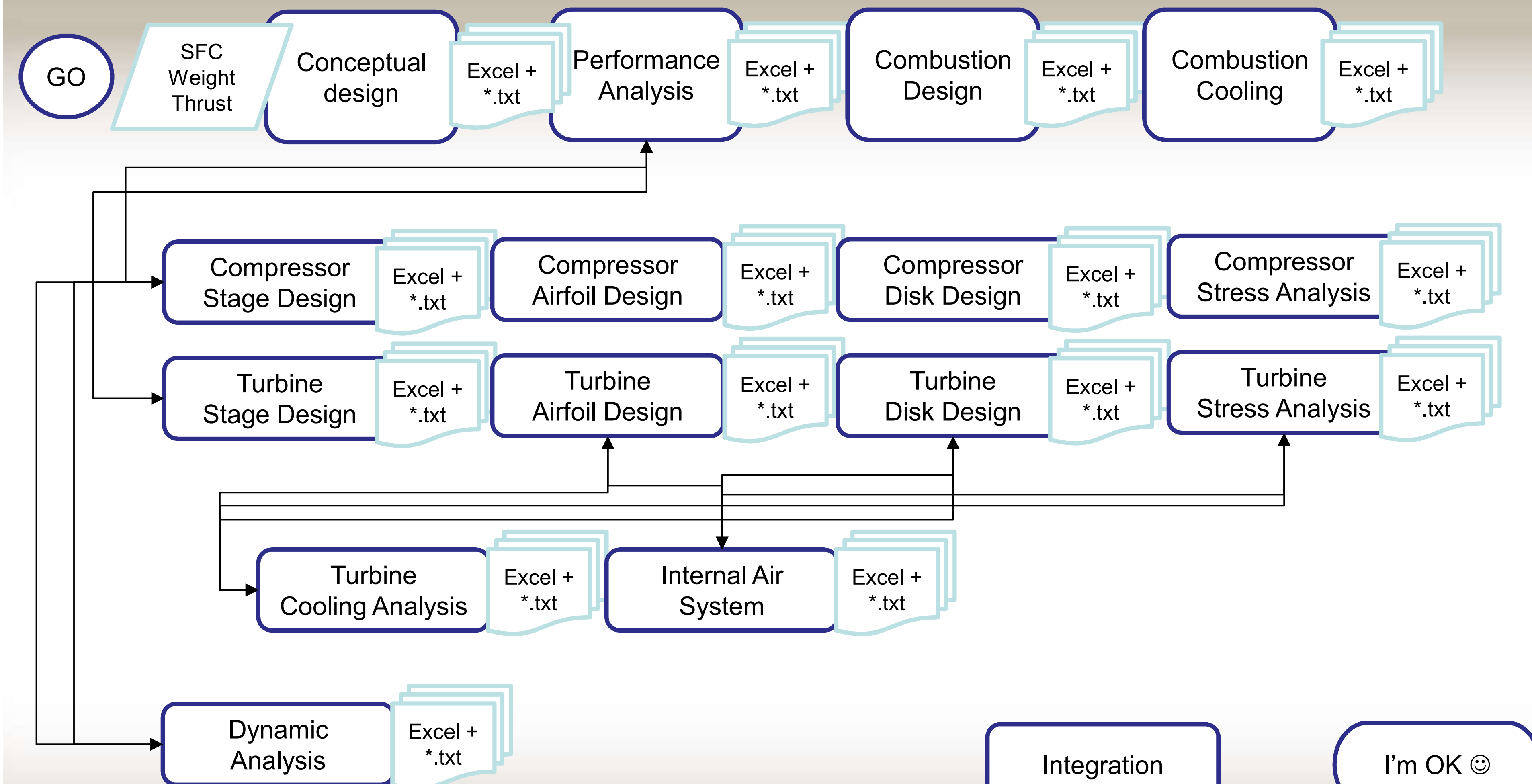
The (disastrous) design process

MULTI-DISCIPLINARY (INTEGRATED) DESIGN (& OPTIMIZATION) SYSTEM

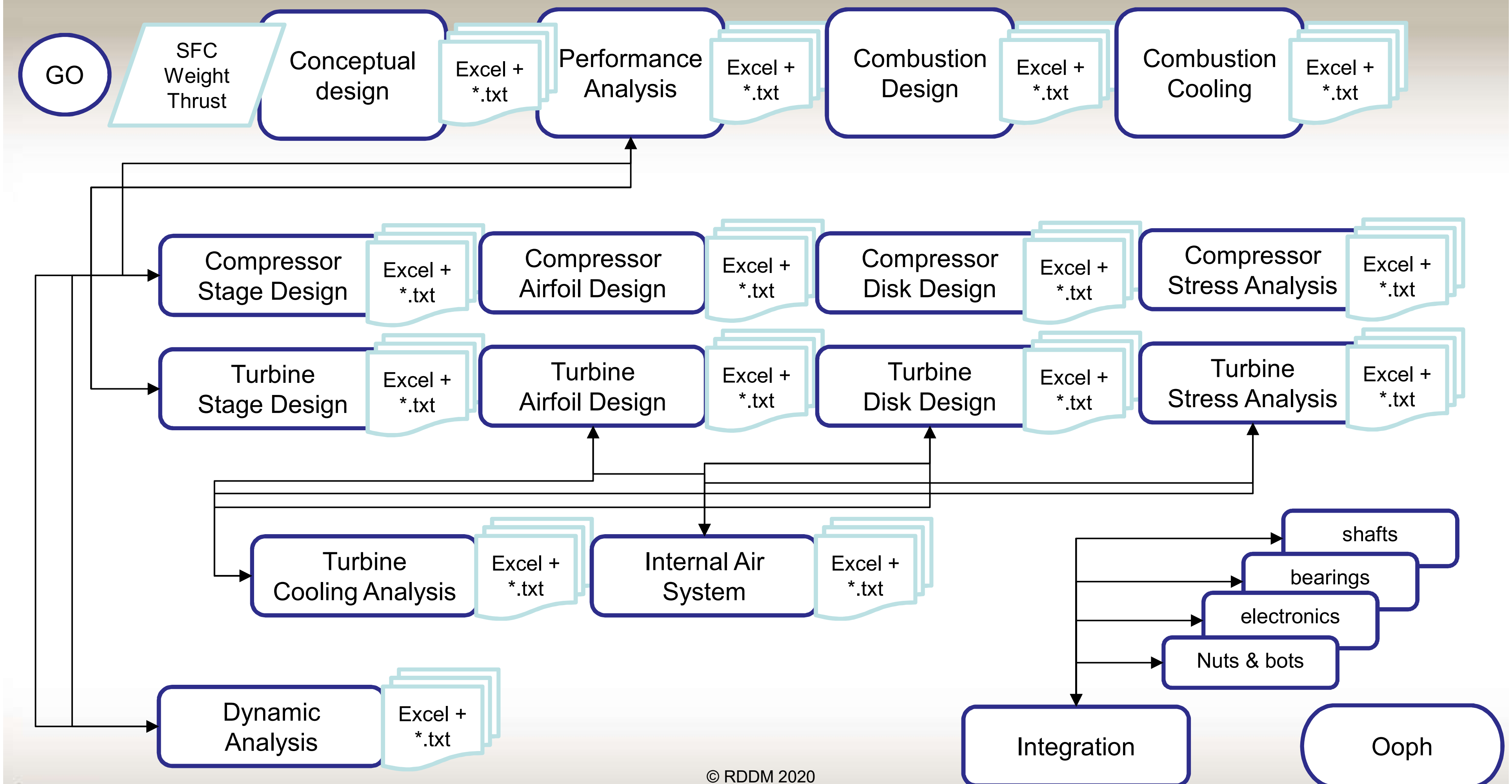
A simplified value stream



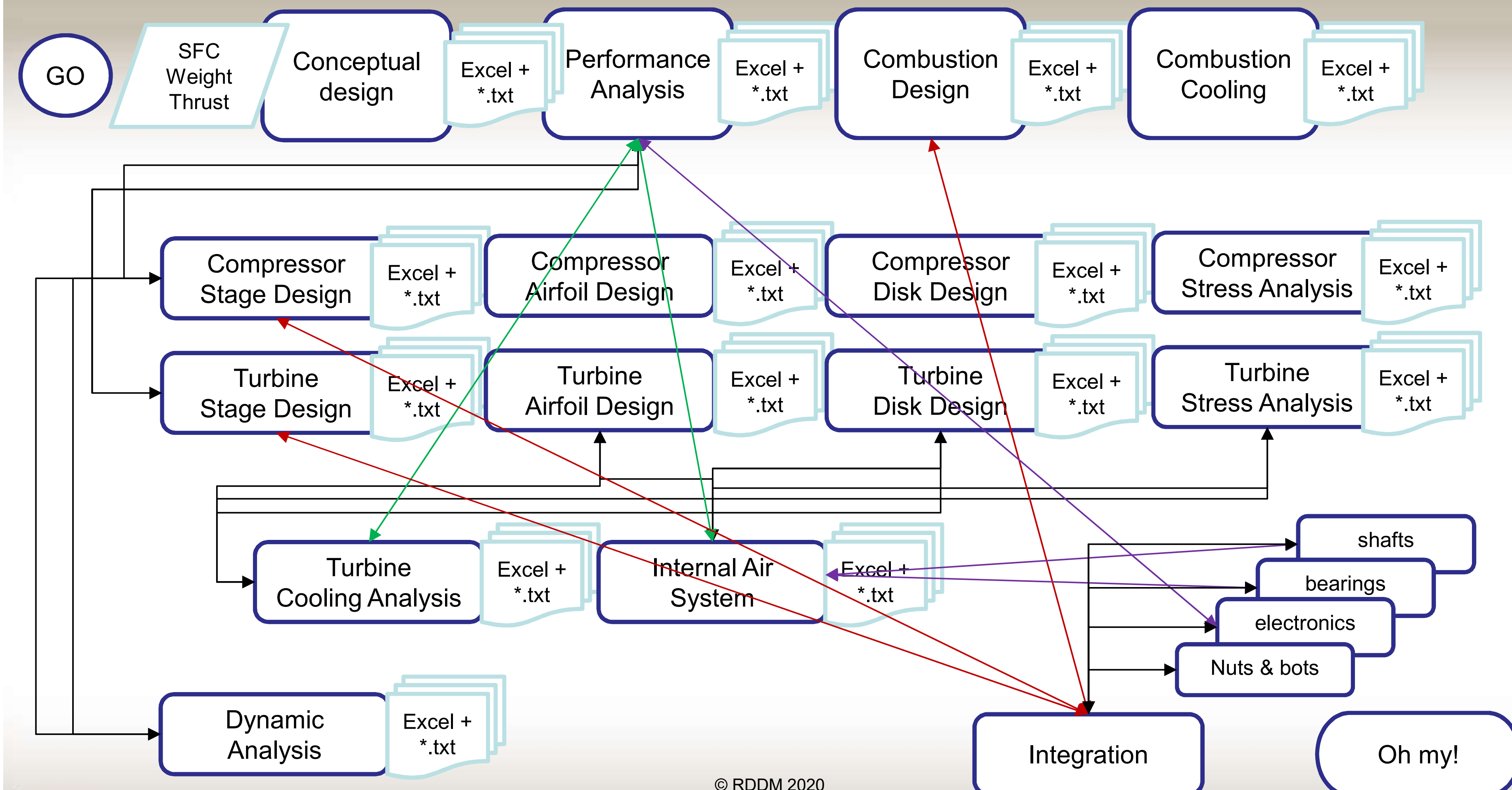
An iterative value stream

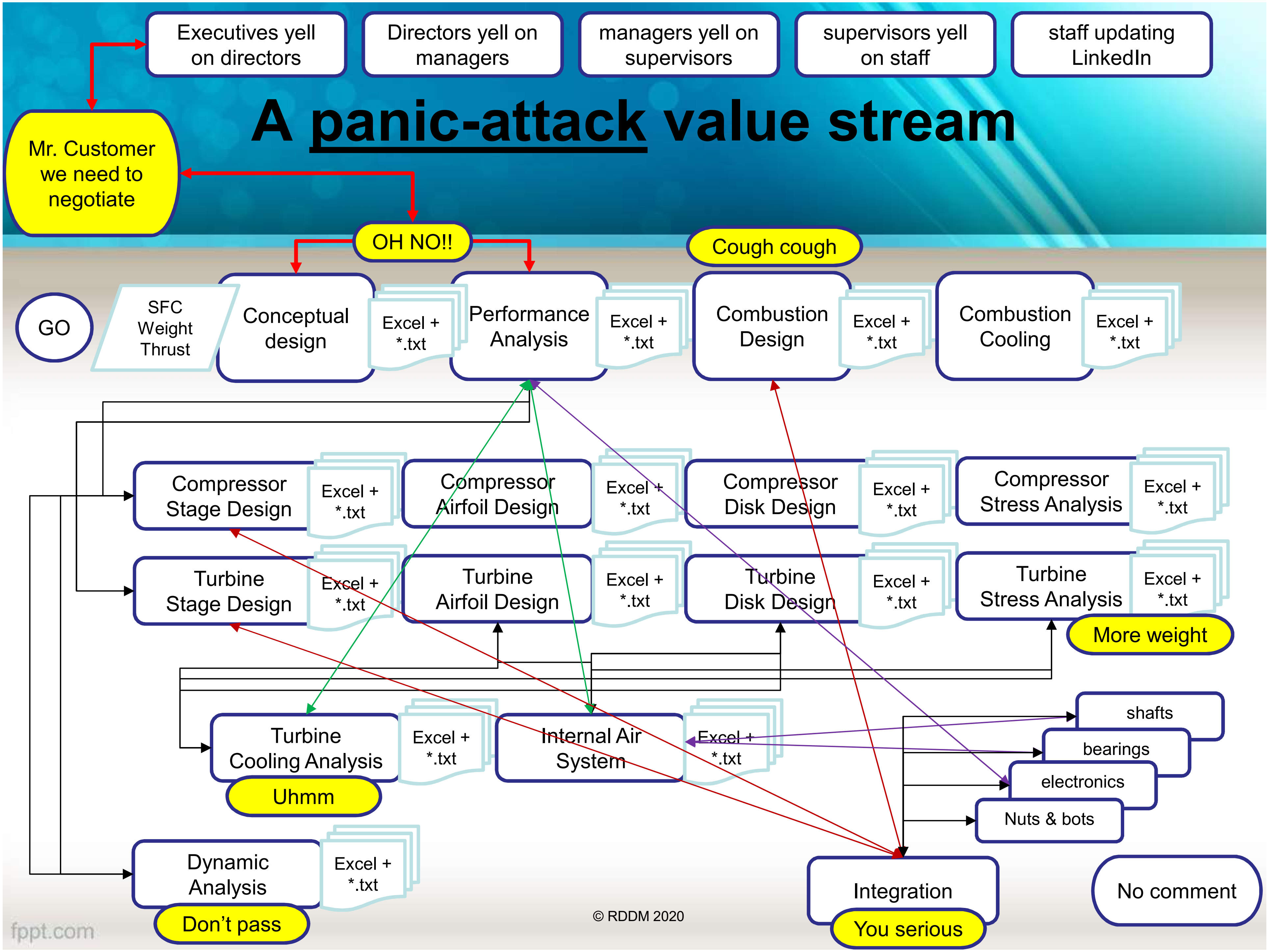


A not so bad value stream



A <u>stressful</u> value stream




A panic-attack value stream
Executives yell on directors
Directors yell on managers
managers yell on supervisors
supervisors yell on staff
staff updating LinkedIn
Mr. Customer we need to negotiate
OH NO!!
Cough cough
GO
SFC Weight Thrust
Conceptual design
Excel + *.txt
Performance Analysis
Excel + *.txt
Combustion Design
Excel + *.txt
Combustion Cooling
Excel + *.txt
Compressor Stage Design
Excel + *.txt
Compressor Airfoil Design
Excel + *.txt
Compressor Disk Design
Excel + *.txt
Compressor Stress Analysis
Excel + *.txt
Turbine Stage Design
Excel + *.txt
Turbine Airfoil Design
Excel + *.txt
Turbine Disk Design
Excel + *.txt
Turbine Stress Analysis
Excel + *.txt
More weight
shafts
bearings
electronics
Nuts & bots
Turbine Cooling Analysis
Excel + *.txt
Uhmm
Internal Air System
Excel + *.txt
Dynamic Analysis
Excel + *.txt
Don't pass
Integration
You serious
No comment
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And remember …

The most dangerous phrase in the language is,

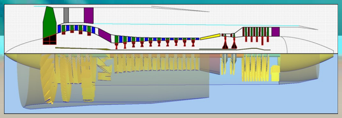
"We've always done it this way."

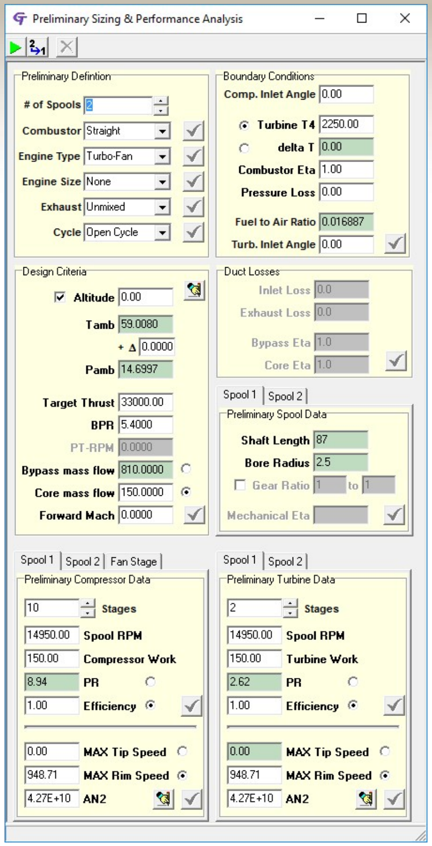
- Rear Admiral Grace Murray Hopper

The design process

WHAT EACH DISCIPLINE DOES

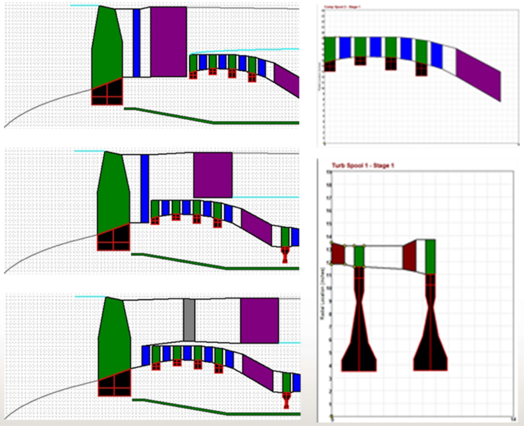
Conceptual Design & Performance



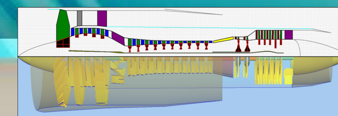


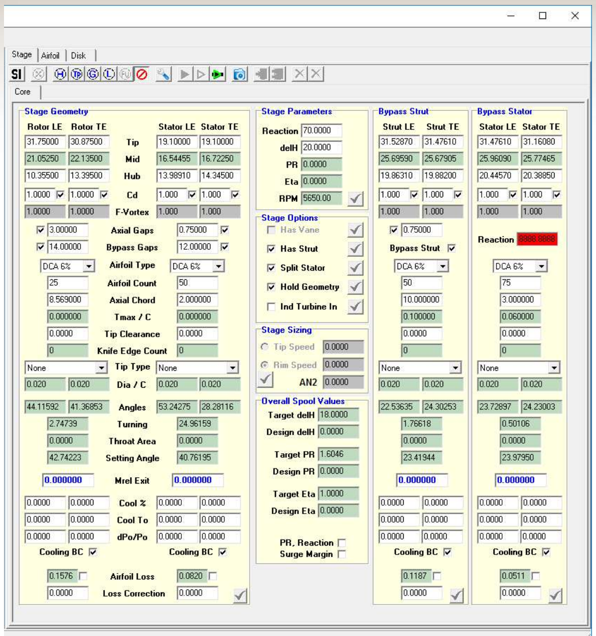
The engineer:

- Creates different gas turbine configurations
- Suggests stage counts based on past experience or optimization
- Develops a simplified design-point performance condition
- Executes a simplified performance analysis
- Executes complex steady- and transient- performance analysis
- Repatriates the detailed design values to the design-point and off-design performance condition for iterative convergence



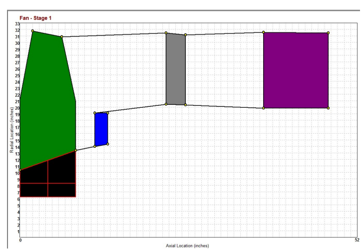
The compressor and turbine aerodynamicist

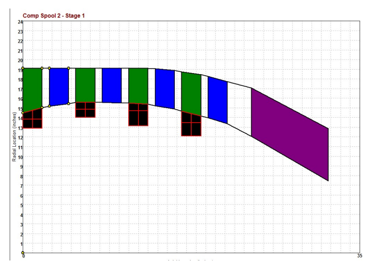


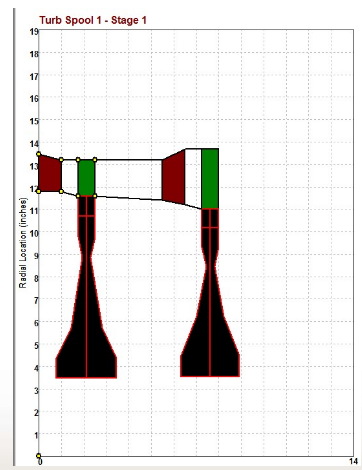


The engineer:

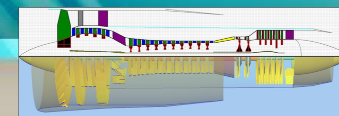
- Executes the 1D design-point and off-design mean-line
- Designs and analyzes:
  - Fan stage(s)
  - Axial and Centrifugal Compressor stage(s)
  - Axial Turbine stage(s)
    - Cooled or Uncooled

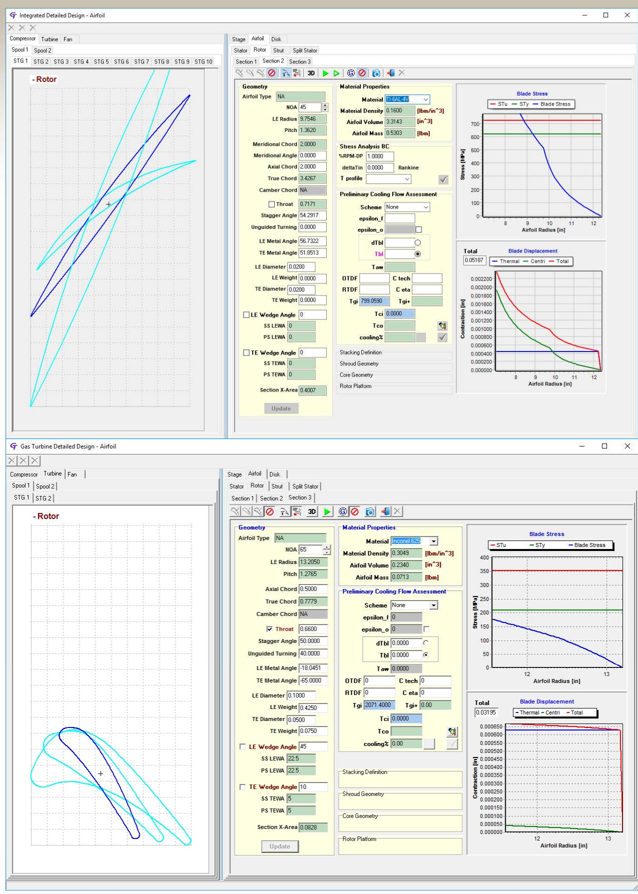






Aerodynamics, cooling, and stress



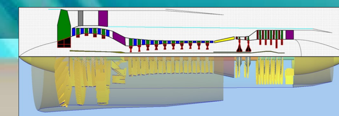


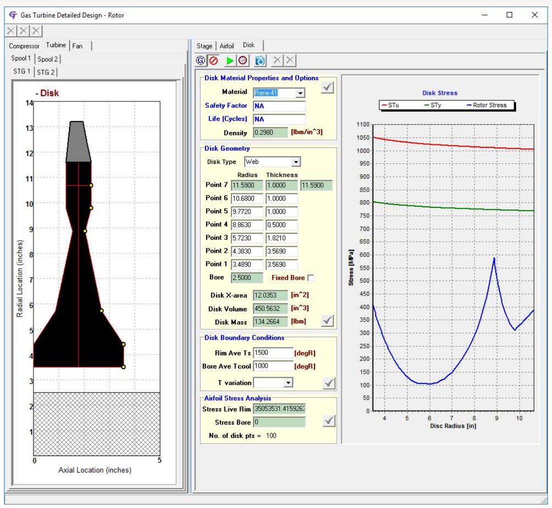
The engineer designs the airfoils for:
- Fan stage(s)
- Compressor (axial and/or centrifugal) stages
- Axial Turbine stages

The engineer also:
- Executes simplified and complex stress analysis
- Executes preliminary and detailed cooling flow design and analysis

Airfoils include
- Stator, Rotor, Strut, and Bypass Stator

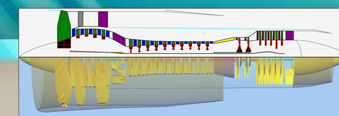
Disk design and stress

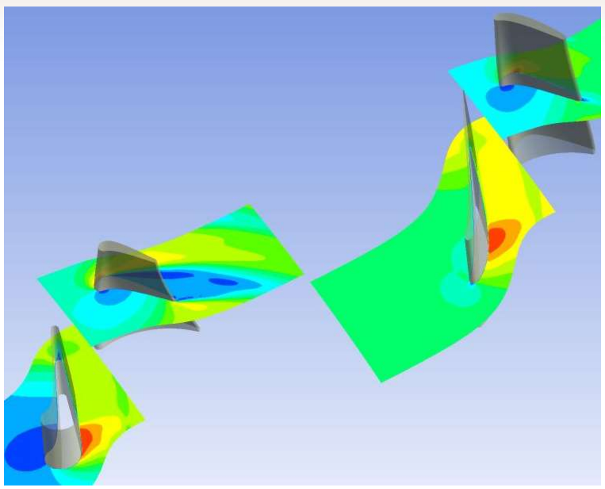




The engineer:
- Creates different axisymmetric disk profiles
- Executes simplified and complex stress analysis
- Executes blade fixing analysis

xD analysis



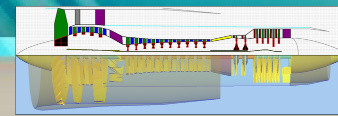


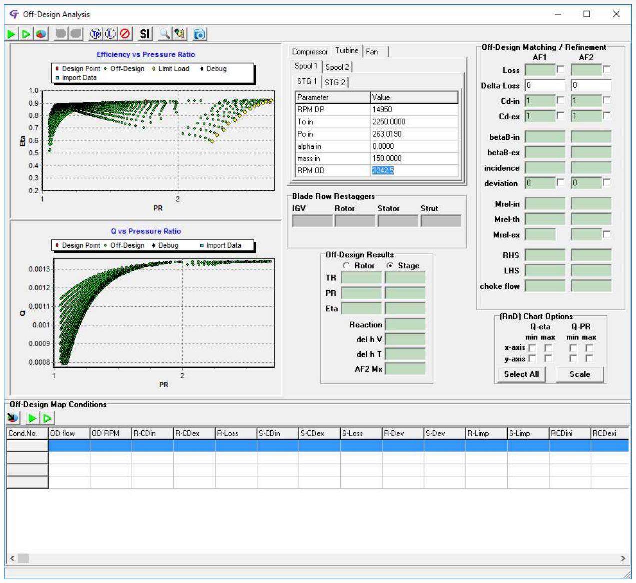
The engineer:

- Executes 2D through-flow analysis
- Executes 3D CFD
  - Steady state and transient analysis
  - (or) Time invariant and time variant
- Fine tunes the aerodynamics
- Updates mean-line and through-flow performance values based on 3D analysis

GE likes to use the term “3D aero design”

Off design behaviour

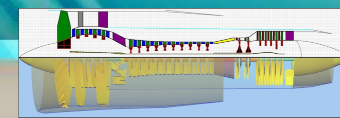


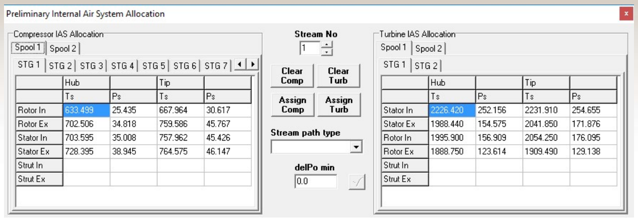


The engineer:

- Executes off-design analysis to feed Performance group
    - Compressor off-design
    - Turbine off-design
    - IAS
    - Stress
- May execute 1D, 2D, and/or 3D off-design analysis

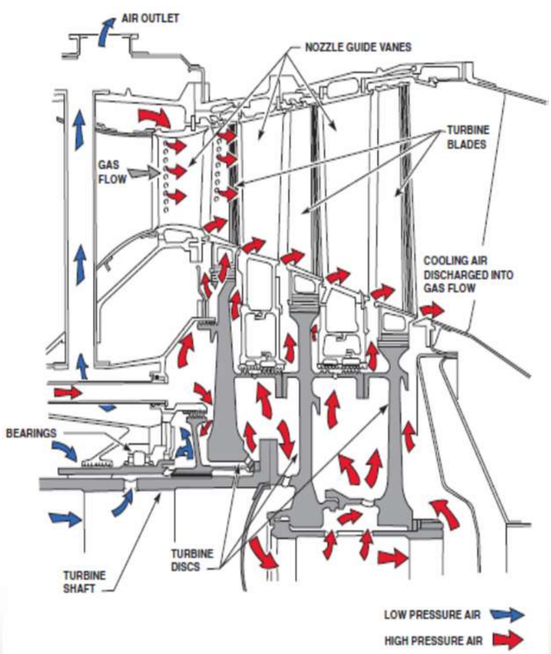
Air system





	Hub		Tip	
	Ts	Ps	Ts	Ps
Rotor In	633.499	25.435	667.964	30.617
Rotor Ex	702.506	34.818	759.586	45.767
Stator In	703.595	35.008	757.962	45.426
Stator Ex	728.395	38.945	764.575	46.147
Strut In				
Strut Ex				

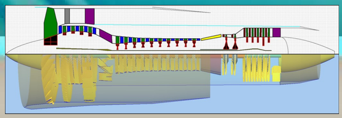
	Hub		Tip	
	Ts	Ps	Ts	Ps
Stator In	2226.420	252.156	2231.910	254.655
Stator Ex	1988.440	154.575	2041.850	171.876
Rotor In	1995.900	156.909	2054.250	176.095
Rotor Ex	1888.750	123.614	1909.490	129.138
Strut In				
Strut Ex				

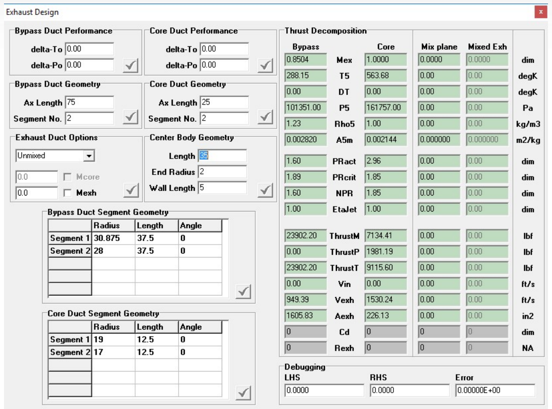


The engineer:

- Executes the preliminary and detailed air-system allocation between compressor and turbine stages
  - Bearings
  - Fixings
  - Seals
  - Hydraulic fluid systems (lubrication and cooling)
  - Fuel systems
  - Hot gas path ingestion
  - Sand particle removal

Duct design

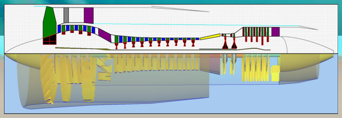


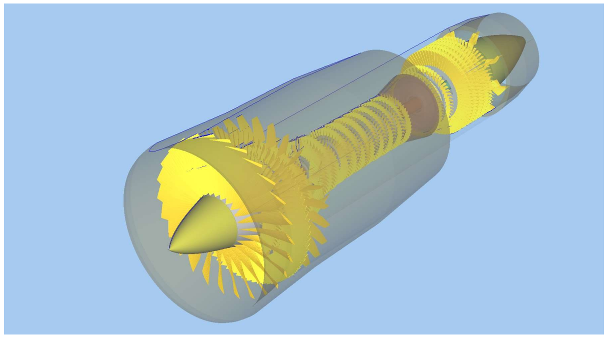


The engineer:

- Creates different exhaust geometries
  - Unforced unmixed
  - Unforced mixed
- Nacelle design
  - Axisymmetric
  - Non-axisymmetric

Overall Design





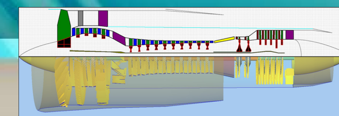
The engineer:

- Gathers all 2D and 3D designs from the disciplines
- Creates full 2D and 3D representations of the overall design
- Checks for clashes
- Weight calculations
- Integrated hot-to-cold conversion

Gas turbine design

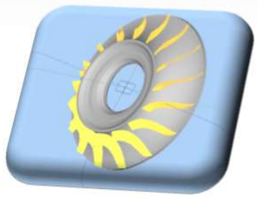
IT DOESN’T END THERE

Other activities



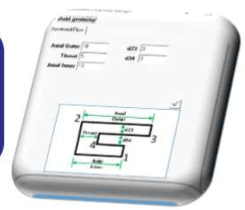
Complex integrated Performance analysis

Centrifugal compressor design



Shaft dynamics

Combustion design



Cost analysis

Testing

Lifing Analysis

Sales

Digital twin (production data analysis)

After Service

Procurement

Production

Manufacturing

R & D

Etc …

Any questions?