Rotorcraft Design for Alternative Fuels

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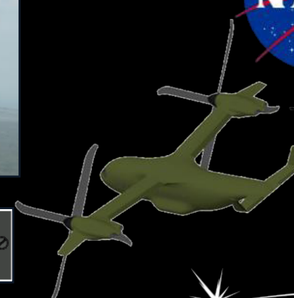
Advanced Concepts

Sikorsky Aircraft Corporation

Stratford, CT

Sikorsky Innovations

Visions of the Future



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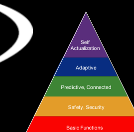

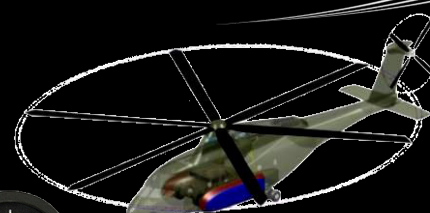

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Visions of the Future: Alternative Propulsion

Project Firefly Technology Demonstrator

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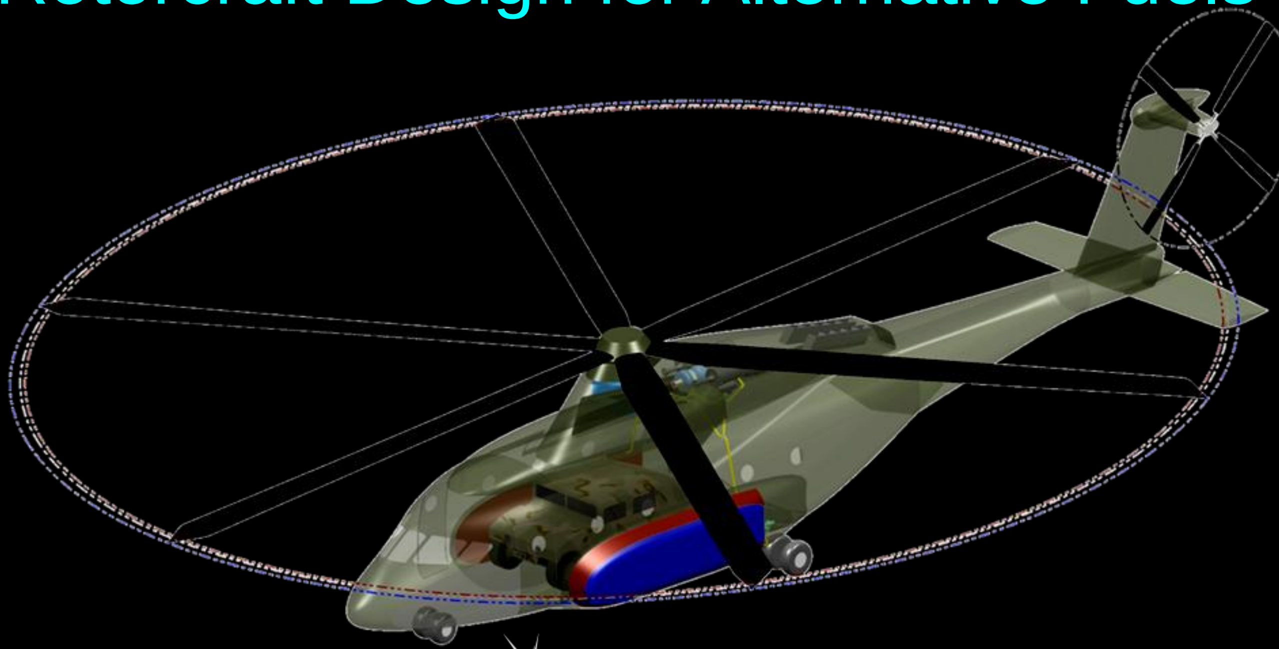
Visions of the Future: Alternative Propulsion

Rotorcraft Design for Alternative Fuels



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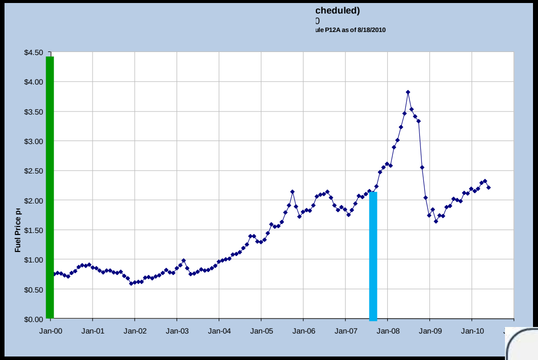
Product Lifetime & Peak Oil



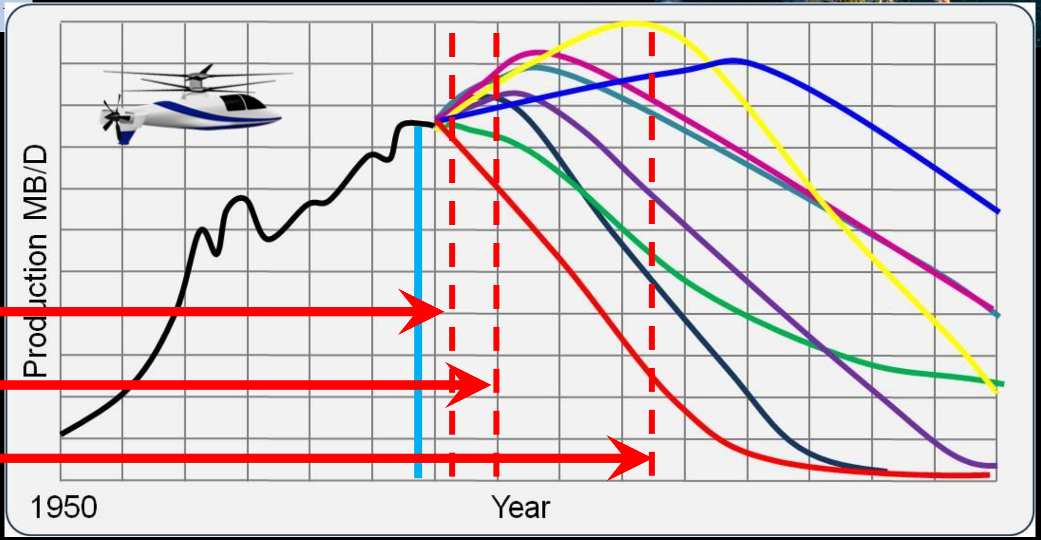
Prepare the Rotorcraft Industry for the Future

Form 41 Fuel Price
Hirsh Report
GHG & Carbon Tax

Concept Launch

Product Service Entry

25 Year Production



Project's Technical Objectives

- Understand Range of Alternative Fuel Options
- Understand Alternative Fuels Supply Chain & Stakeholders
- Understand Propulsion and Fuel System Suppliers & Issues
- Down-select Alternative Fuels for Rotorcraft *Conceptual* Design & Integration Studies
- Evaluate impacts of Alternative Fuels on Rotorcraft Designs (Small, Intermediate, & Large)

Alternative Fuels Database

- Repository for Conventional, Alternate, and Alternative Fuels Data
- Populated by materials specialists at P&W and United Technologies Research Center
- A 'living' document
- Fuels attributes data include:
  - ➢Composition (e.g. %Paraffins, Sulfurs, etc.)
  - ➢Properties (e.g. Density, Viscosity, etc.)
  - ➢Combustion (e.g. Energy Density, etc.)
  - ➢Distribution & Storage (e.g. Color, Toxicity, Water Solubility, etc.)

		Assignemnts	P&W-Biddle/Adamson	P&W-Biddle/Adamson	P&W-Biddle/Adamson
Attribute or Note	1	Units \ Record #	1	2	3
NAME	2		Jet A	Jet A-1	Jet B
Other names	3				CAN / CGSBB 3.23
Category	4		Liquid	Liquid	Liquid
Subcategory	5		Kerosene	Kerosene	Kerosene
Feedstock(s)	6		Petroleum	Petroleum	Petroleum
Process	7		Distillation	Distillation	Distillation
ASTM Spec	8		D-1655	D-1655	D-6615
MIL Spec	9		NA	NA	NA
COMPOSITION	10				
Color	11		Clear to straw yellow	Clear to straw yellow	Clear to straw yellow
Paraffins, %	12	%	80.0%	80.0%	TBD
Olefins, %	13	%	TBD	TBD	TBD
Naphthenes, %	14	%	5.0%	5.0%	5.0%
Aromatics, %	15	%	18.0%	18.0%	8.0%
Sulfur, total, %	16	%	0.055%	0.055%	0.055%
Range	17	%	0.025%	0.025%	0.025%
Acidity	18	mg KOH/g	0.10 max	0.10 max	0.015max
Alcohol	19	%	Negligible	Negligible	Negligible
Amine	20	%	Negligible	Negligible	Negligible
VOLATILITY	21				
TDistillation, 10% Recovery	22	°C	180.0	170.0	64.0
TDistillation, 50% Recovery	23	°C	210.0	200.0	120.0
TDistillation, 90% Recovery	24	°C	252.0	240.0	245.0
TDistillation, Final Boiling Point	25	°C	300.0	262.0	260.0
Flash Point	26	°C	51.2	42.2	TBD
Range	27	°C	5.8	2.5	TBD
Autoignition Point	28	°C	238	238	246
Density at 15C	29	kg / L	0.7895	0.7895	0.7765
Range	30	-/+	0.0297	0.0297	0.0255
Vapor Pressure (Reid)	31	kPa	0.6	0.6	17.5
Range	32	kPa	TBD	TBD	3.5
FLUIDITY	33				
Freeze Point	34	°C	-40 max	-47.0	-50.0
Kinematic Viscosity @ -20ºC	35	cSt	5.5	4.2	1.7
COMBUSTION	36				
Heat of Combustion, gravimetric	37	MJ/kg	42.80	42.80	42.80
Energy Density, volumetric	38	MJ/L	33.79	33.79	33.23
Smoke Point	39	mm	25.00	26.20	25.00
CORROSION	40				
Metal Compatibilities	41		Al, Al alloys, Carbon Molybdenum Steel, 0.5 -3% Ni Steel, 4- 6% Chromium Molybdeum Steel, 300 & 400 Stainless steel,Monel	Al, Al alloys, Carbon Molybdenum Steel, 0.5 -3% Ni Steel, 4- 6% Chromium Molybdeum Steel, 300 & 400 Stainless steel,Monel	Al, Al alloys, Carbon Molybdenum Steel, 0.5 -3% Ni Steel, 4- 6% Chromium Molybdeum Steel, 300 & 400 Stainless steel,Monel
Metal Incompatibilities	42		Bronze, Ni, Cu, Zn, Cd Brass, Fe	Bronze, Ni, Cu, Zn, Cd Brass, Fe	Bronze, Ni, Cu, Zn, Cd Brass, Fe
Composites Compatibilities	43		TBD	TBD	TBD
Compsites Incompatibilities	44		TBD	TBD	TBD
Elastomeric Compatibilities	45		Nylon, Kel-F, Trithene, HDPE, Buna N, HNBR, Kalrez, Chemraz,Flurothene A, Vinylite, Teflon, Fluorel, Viton, Fluororsilicon, Polyacrylate, Epichlorohydrin,	Nylon, Kel-F, Trithene, HDPE, Buna N, HNBR, Kalrez, Chemraz,Flurothene A, Vinylite, Teflon, Fluorel, Viton, Fluororsilicon, Polyacrylate, Epichlorohydrin,	Nylon, Kel-F, Trithene, HDPE, Buna N, HNBR, Kalrez, Chemraz,Flurothene A, Vinylite, Teflon, Fluorel, Viton, Fluororsilicon, Polyacrylate, Epichlorohydrin,
Elastomeric Incompatibilities	46		LDPE, Cholroprene, Butyl, Natural Rubber, EPDM, SBR, Polybutadiene, Silicone	LDPE, Cholroprene, Butyl, Natural Rubber, EPDM, SBR, Polybutadiene, Silicone	LDPE, Cholroprene, Butyl, Natural Rubber, EPDM, SBR, Polybutadiene, Silicone
Lubricant Compatibilities	47		TBD	TBD	TBD
Lubricant Incompatibilities	48		TBD	TBD	TBD

Fuel Categories

<u>Conventional</u>

- Jet A
- Jet A-1
- JP-4
- JP-5
- JP-7
- JP-8
- JP-8+100
- JP-10
- Avgas 80
- Avgas 91
- Avgas 100
- Avgas 100LL

<u>Alternate</u>

Synthetic Blends

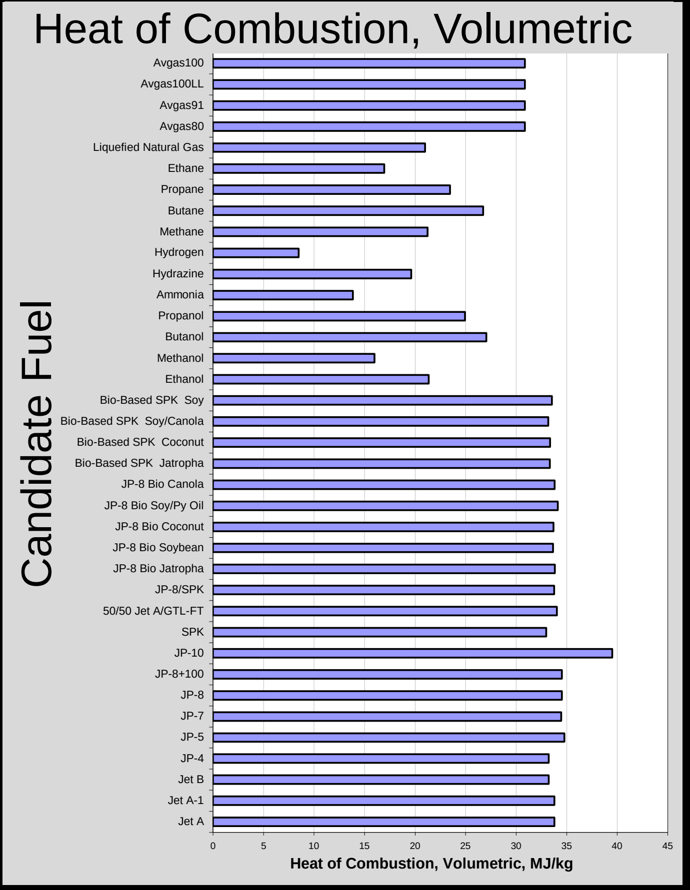
- 50/50 Jet A / F-T
- 50/50 JP-8 / F-T
- 50/50 JP-8 / SPK
- Etc.

*100% Synthetics**

- F-T SPK
- Bio JP-8
- Bio SPK
- Etc.

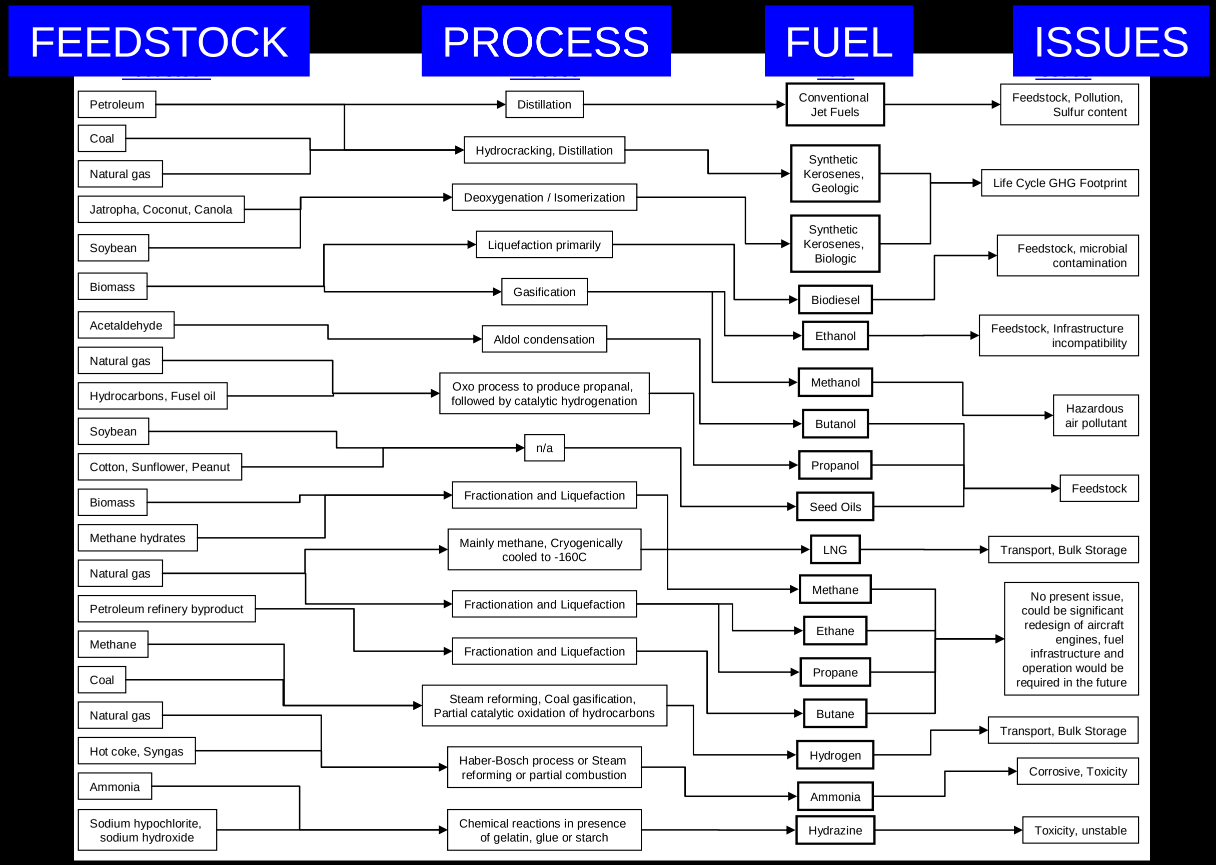
<u>Alternative</u>

- Ethanol
- Methanol
- Butanol
- Propanol
- Ammonia
- Hydrazine
- Hydrogen
- Methane
- Ethane
- Propane
- LNG
- Diesel
- Biodiesel
- Etc.



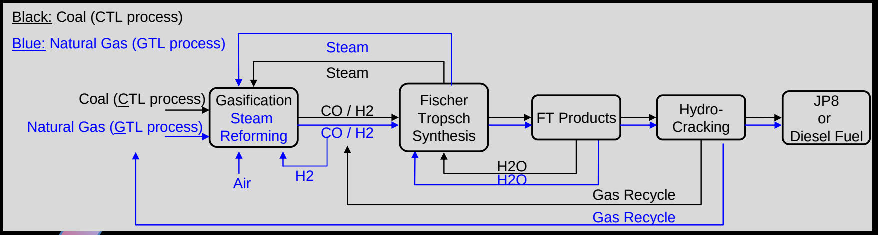
* Not fully compatible with current BoM

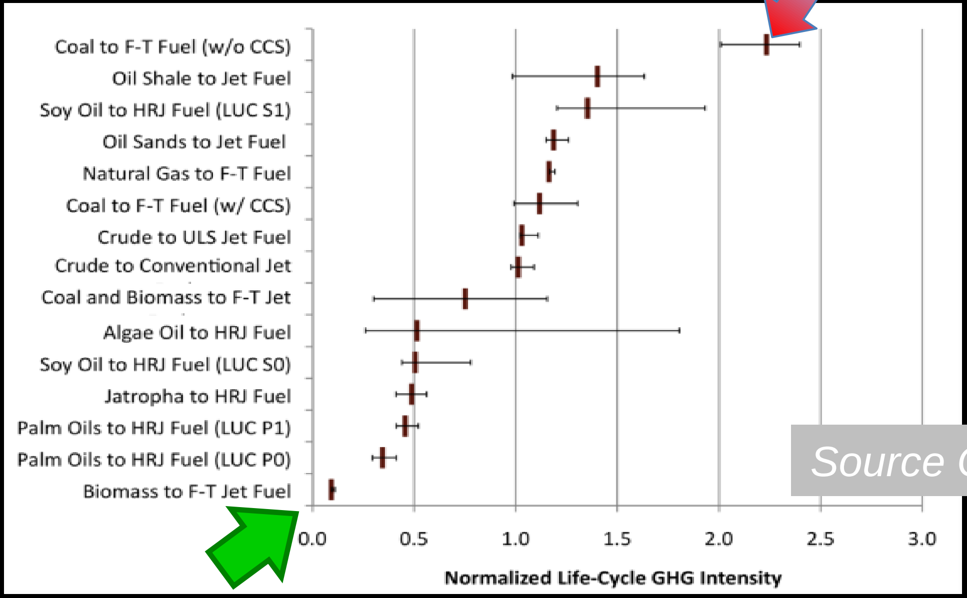
Survey & Study Supply Chain & Stakeholders



Processes & Life Cycle Analyses

e.g. CTL FISCHER-TROPSCH PROCESS





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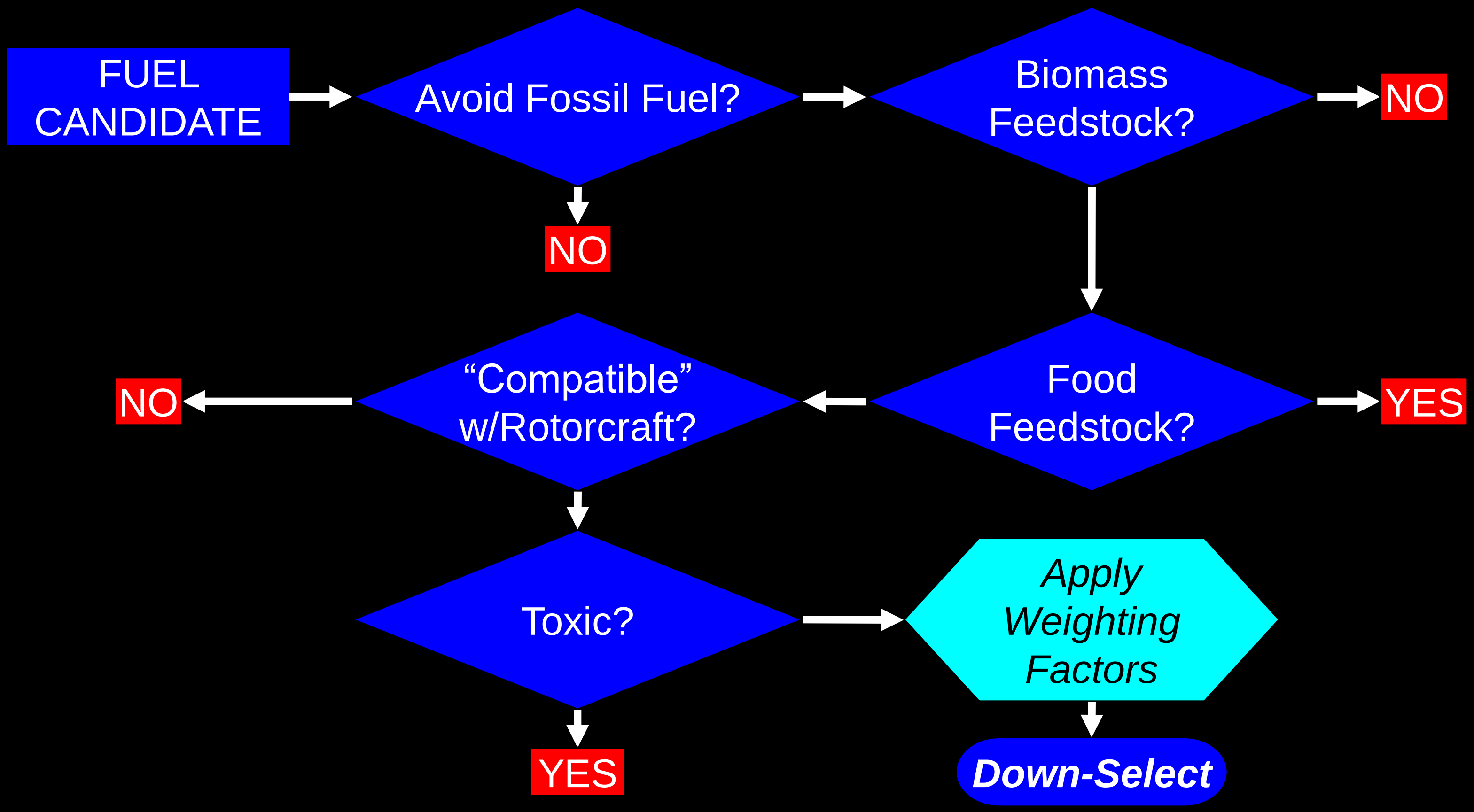
Down-selection Process



Down-select to 2 Fuels: Biodiesel & Butanol

Fuels	Feedstock	Avoid Fossil Fuel?	Biomass-Based?	Food Feedstock?	Compatibility w/ Conventional Rotorcraft	Toxicity	Heat of Combustion Gravimetric (MJ/kg)	Liquid vs. Gas	Compatibility	Toxicity	Enregy Content Normalized to JP-8	Score	Rank
Biojet	Biomass	Yes	Yes	No	Yes	Moderate	43.50	1.00	1.00	0.85	1.00	0.85	
Biodiesel B100 S500	Biomass	Yes	Yes	No	Maybe	Moderate	44.41	1.00	0.75	0.85	1.02	0.65	
Bio-Based SPK	Biomass	Yes	Yes	No	Maybe	Moderate	44.40	1.00	0.75	0.85	1.02	0.65	
Biodiesel EN14214	Biomass	Yes	Yes	No	Maybe	Moderate	35.00	1.00	0.75	1.00	0.80	0.60	1
Biodiesel B100 S15	Biomass	Yes	Yes	No	Maybe	Moderate	40.00	1.00	0.75	0.85	0.92	0.59	
Butanol	Biomass	Yes	Yes	No	Maybe	Moderate	33.26	1.00	0.75	0.85	0.76	0.49	2
Ethanol	Biomass	Yes	Yes	No	Maybe	Low	26.87	1.00	0.75	1.00	0.62	0.46	3
Propanol	Biomass	Yes	Yes	No	Maybe	Moderate	30.80	1.00	0.75	0.85	0.71	0.45	4
Methane	Biomass	Yes	Yes	No	No	Low	50.03	0.75	0.50	1.00	1.15	0.43	5
Methane	Methane Hydrates	Yes	No	No	No	Low	50.03	0.75	0.50	1.00	1.15	0.43	
Methanol	Biomass	Yes	Yes	No	Maybe	Low	20.01	1.00	0.75	1.00	0.46	0.35	6
Ammonia	Oth	[illegible]	[illegible]	[illegible]	[illegible]	High	22.47	1.00	0.75	0.50	0.52	0.19	
Ammonia	Bior	[illegible]	[illegible]	[illegible]	[illegible]	High	22.47	1.00	0.75	0.50	0.52	0.19	
Hydrogen	Wat	[illegible]	[illegible]	[illegible]	[illegible]	Low	120.00	0.25	0.25	1.00	2.76	0.17	7
Hydrazine	?	[illegible]	[illegible]	[illegible]	[illegible]	High	19.40	1.00	0.50	0.50	0.45	0.11	

Down-select Results:

1. *Biodiesel*
2. *Butanol*
3. *Ethanol*

Proceed to engines & rotorcraft design

Biodiesel & Butanol Attributes

NAME	UNITS	JP-8	Biodiesel	Butanol
Other names		NATO F-34 / F-35	B100 S15	Butyl alcohol, butyl hydroxide, butanolen, propylcarbinol
Category		Liquid	Liquid	Liquid
Subcategory		Kerosene	Middle Distillate	Alcohol
Feedstock(s)		Petroleum	Biomass	Acetaldehyde (or biomass)
Process		Distillation	Liquefaction primarily	Aldol condensation (or fermentation of biomass)
ASTM Spec		NA	D6751-09	D304-05
MIL Spec		MIL-DTL-83133	NA	NA
COMPOSITION				
Color		Clear to straw yellow	Clear to straw yellow	colorless
Paraffins, %	%	TBD	0%	0%
Olefins, %	%	5.0%	0%	0%
Naphthenes, %	%	5.0%	0%	0%
Aromatics, %	%	17.0%	0%	0%
Sulfur, total, %	%	0.085%	0.0015% max	0.00%
Range	%	0.035%		0.00%
Acidity	mg KOH/g	0.0150	0.50 max	0.00%
Alcohol	%	Negligible	0%	100%
Amine	%	Negligible	0%	0.00%
VOLATILITY				
TDistillation, 10% Recovery	°C	180.0	report	117.7
TDistillation, 50% Recovery	°C	210.0	report	117.7
TDistillation, 90% Recovery	°C	252.0	360.0 max	117.7
TDistillation, Final Boiling Point	°C	268.0	360.0 max	117.7
Flash Point	°C	48.9	130.0 min	28.9
Range	°C	5.9	100 - 170 C	
Autoignition Point	°C	238	NA	343.3
Density at 15C	kg / L	0.8070	0.8750	0.8139
Range	-/+	0.0325		
Vapor Pressure (Reid)	kPa	0.6	<0.275	2.2
Range	kPa	TBD		
FLUIDITY				
Freeze Point	°C	-47.0	-3 to 19 (cloud point)	-89.3
Kinematic Viscosity @ -20ºC	cSt	5.5	1.9-6.0 (@ 40C)	13.516
COMBUSTION				
Heat of Combustion, gravimetric	MJ/kg	42.80	39-41 (use 39 as avg.)	33.26
Energy Density, volumetric	MJ/L	34.54	33.90	27.07
Smoke Point	mm	25.00	TBD	TBD
CORROSION				

LHV BTU/lb

JP-8 18,300

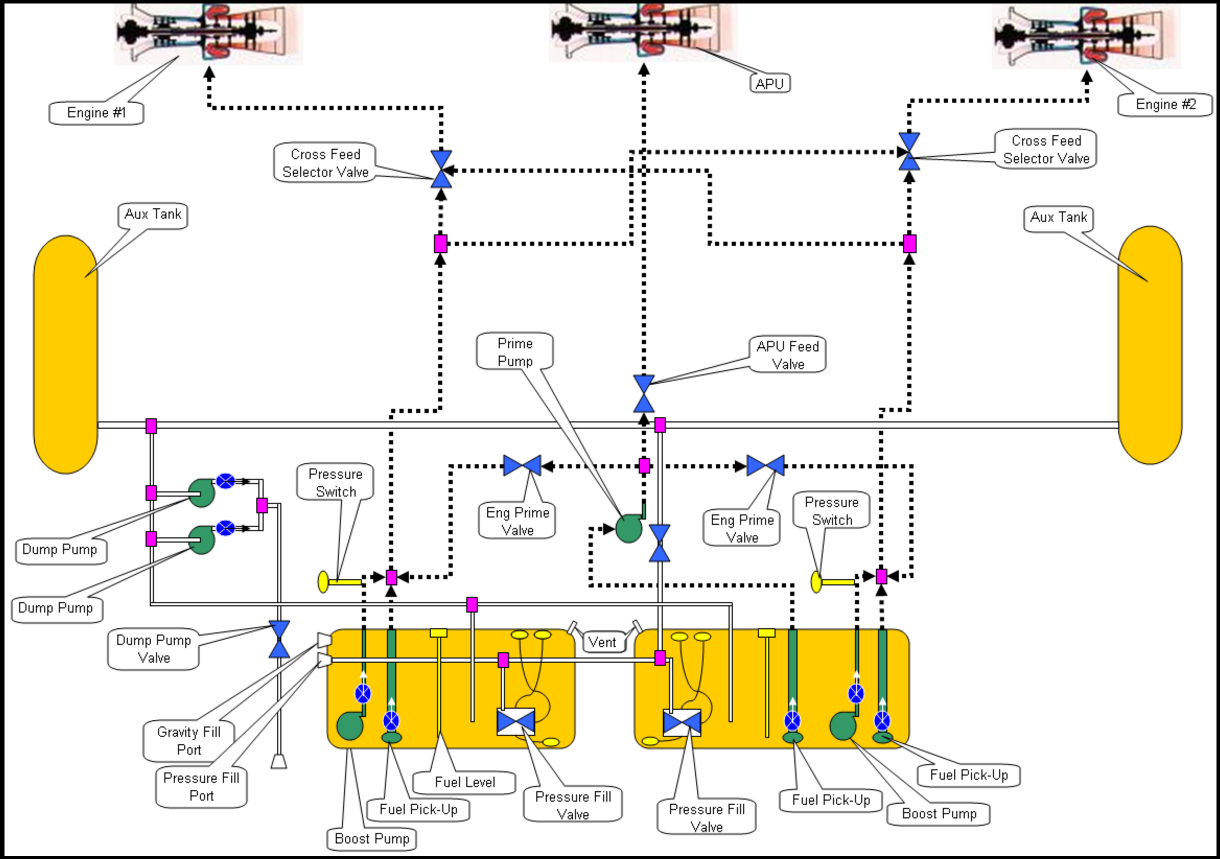
Biodiesel 16,770

(-8%)

Butanol 14,300

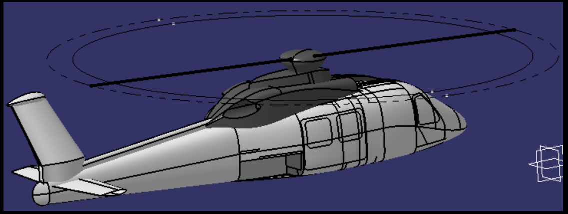
(-22%)

Survey & Study Propulsion & Fuel Systems

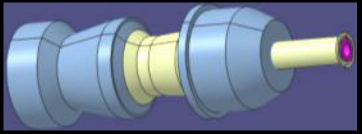


Rotorcraft Sizing: Conventional Baseline (JP-8)

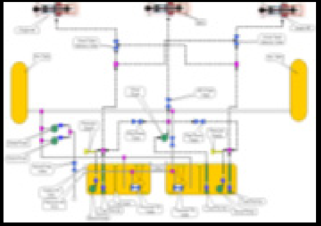
- **Sizing: Small, Intermediate, & Large Utility Rotorcraft**
  - Small: Payload 1200 lb; Radius 125 nm, V_{MCP} 150 KTAS
  - Intermediate: Payload 3600 lb; Radius 250 nm, V_{MCP} 170 KTAS
  - Large: Payload 25,000 lb (External); Radius 125 nm, V_{MCP} 170 KTAS
  - All at 95ºF @ 6,000 ft



- **Parametric Rotorcraft CATIA models**
  - Small, Intermediate, & Large
  - Scalable dimensions

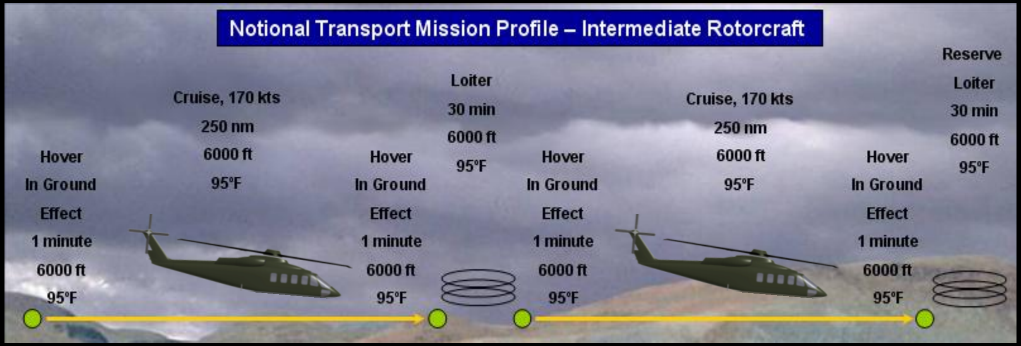


- **Parametric Engine CATIA models**
  - 1000 , 3000, & 6000 SHP engines
  - Scalable dimensions
  - Proprietary OEM information protected



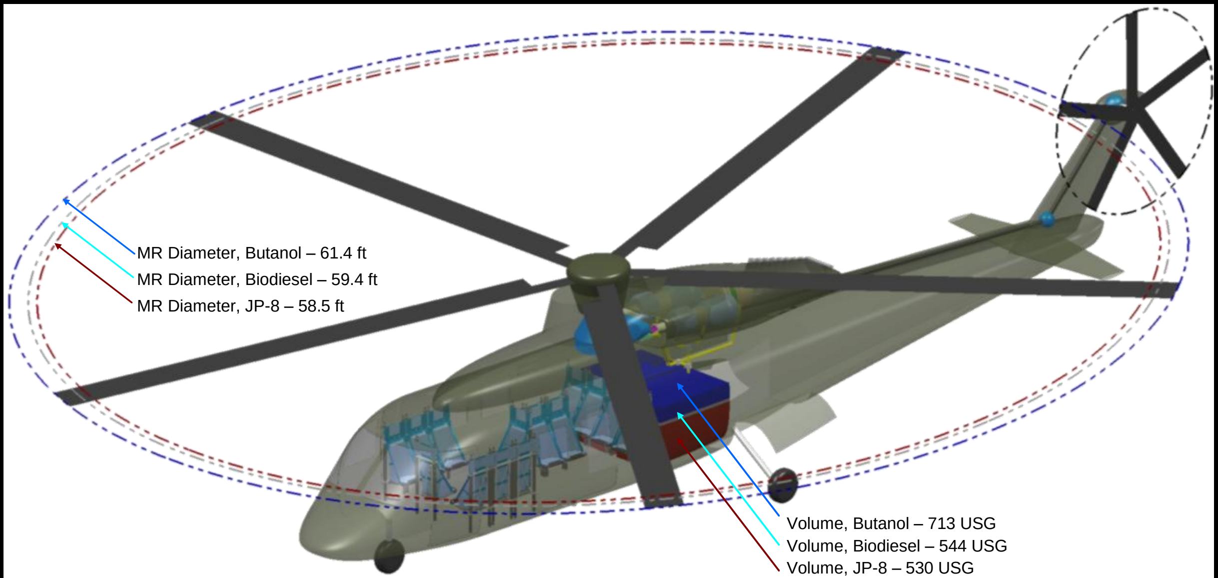
- **Fuel system schematics**
  - Capture size effects
  - Materials compatibility

Intermediate Rotorcraft Sizing



Sizing Variations	JP-8	Biodiesel	%Change	Butanol	%Change
Design Gross Weight (lb)	20,400	21,100	**+3.4%**	22,500	**+10.3%**
Empty Weight (lb)	11,900	12,100	**+1.7%**	12,700	**+6.7%**
Fuel Weight (lb)	3,575	3,975	**+11.2%**	4,850	**+35.7%**
Fuel Capacity (USG)	530	544	**+2.6%**	713	**+34.5%**
Rotor Diameter (ft)	58.5	59.4	**1.6%**	61.4	**5.0%**
Max Power (SHP)	2,700	2,800	**3.7%**	2,950	**9.3%**

Intermediate Rotorcraft Internal View

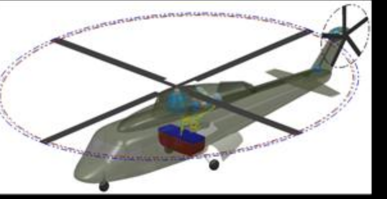


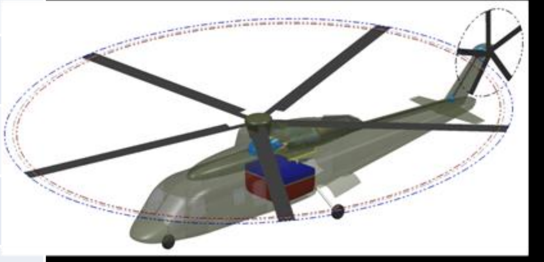
Intermediate Rotorcraft Sizing Variations	JP-8	Biodiesel	Butanol
Design Gross Weight (lbs)	20,400	21,100	22,500
Empty Weight (lbs)	11,900	12,100	12,700
Mission Fuel Weight (lbs)	3,600	4,000	4,800
Fuel Capacity, Internal (USG)	530	544	713
Main Rotor RPM	227	223	216
Uninstalled MRP @ SLS (per engine), SHP	2,700	2,800	2,950

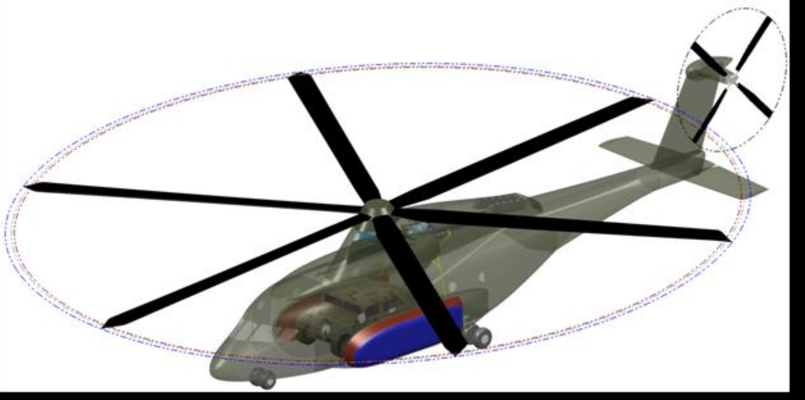
Intermediate Rotorcraft Design Constants	
Cabin Seats	16
Mission Radius (nm)	250
Speed @ MCP, 6K/95F (kts)	170
Number of Engines	2
Engine Power Class, SHP	3,000

Average Impact on Rotorcraft Sizing

Rotorcraft Design Parameter	Average Design Parameter Change	
	Biodiesel vs. JP-8	Butanol vs. JP-8
Design Gross Weight	**+2%**	**+7%**
Empty Weight	**+1%**	**+5%**
Max Power	**+3%**	**+7%**
Fuel Volume	**+2%**	**+32%**
Rotor Diameter	**+1%**	[illegible]







Alternative Fuels Might Simplify Logistics

Project Recommendations

1. Explore additives and blends to biodiesel and butanol to mitigate impact to future gas turbine engines and their operation.
2. Define a superset of materials for the complete fuel and propulsion system to accommodate all of the following: alternate fuels, 100% synthetic biojet, biodiesel, and biobutanol.
3. Define a robust propulsion system architecture (nozzles, combustor, turbines, etc.) that accommodates alternate fuels, 100% synthetic kerosenes, biodiesel, and biobutanol.
4. Begin developing certification procedures for selected *alternative* biofuels.
5. Explore possible synergies between future ground transportation and rotorcraft fuel infrastructure, civilian and military (wartime and peacetime).
6. Perform trade studies to understand the costs & benefits of alternative fuel.

Contributors

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