Jet Fuel Characteristics

Performance Engineer Operations
Flight Operations Engineering
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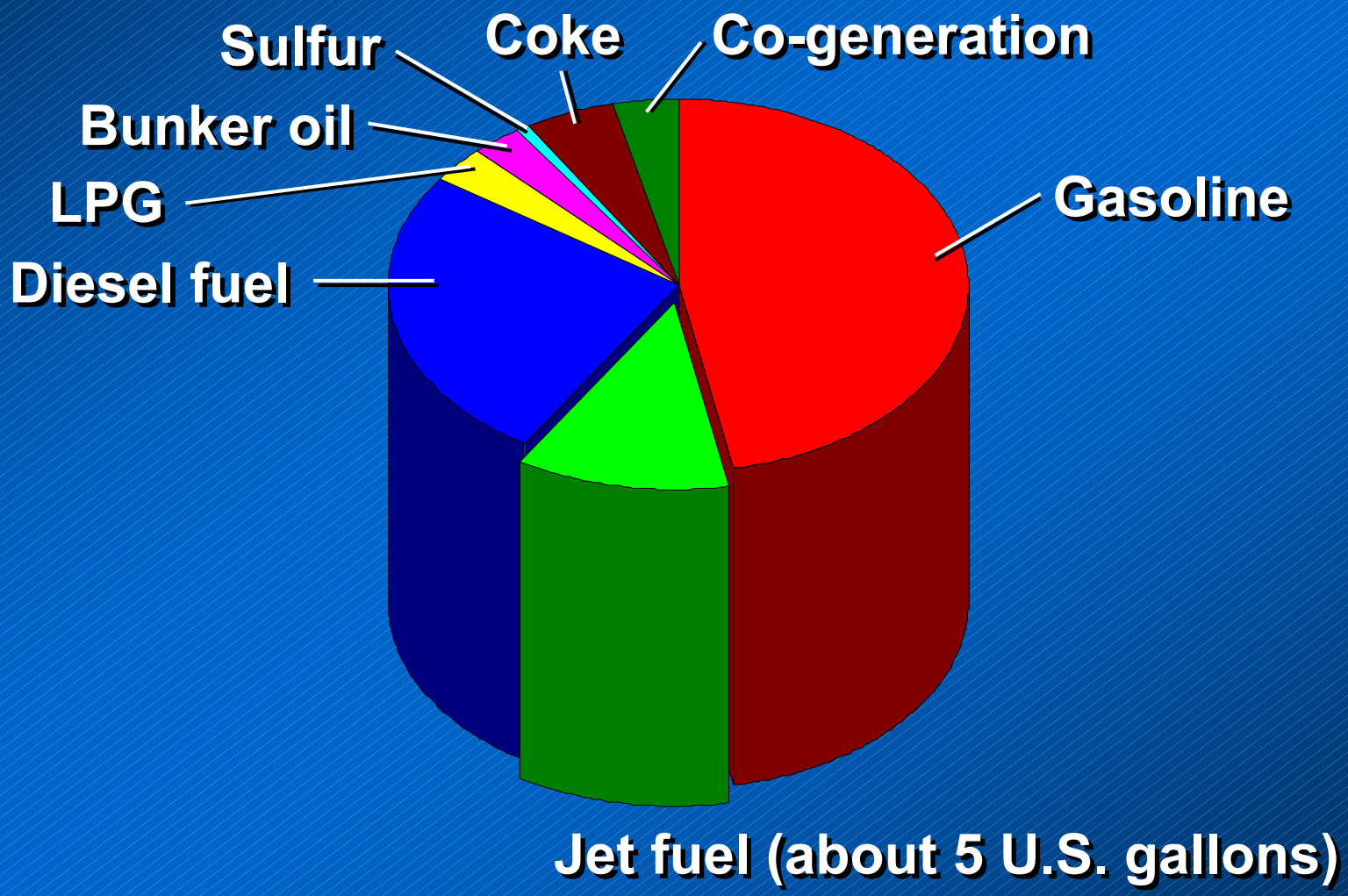
Why this Subject?

- Provide a brief introduction to aviation fuel definitions and characteristics
- Familiarize you with terminology and industry jargon
- Address operational concerns related to fuel
- Inform you of research work and possible future fuels
- Exchange some insight into the Energy of Flight

Topics

- Oil Distillation
- Types of Aviation Fuel
- Specifications
- Composition of Fuel
- Fuel Properties
- Non-Normal Situations
- Alternative Fuels

Distillation of Crude Oil



1 Barrel of Crude = 42 U.S. gallons

Types of Aviation Fuel

- Aviation Gasoline - AvGas
- Turbine Fuels

Aviation Gasoline (AvGas)

- Reciprocating Engines Only
- Rated by Octane - 80/87, 100/130, 115/145 - Red, Blue, Purple
- Commercial Specification - ASTM D 910

Turbine Fuels

'Commercial Grades'

- Jet A "Kerosene Type", freeze point -40°C (U.S. domestic only)
- Jet A-1 "Kerosene Type", freeze point -47°C
- Jet B "Wide Cut", freeze point -50°C

Jet Fuel Characteristics

'Military Grades (U.S.)'

- JP-4 "Wide Cut", similar to Jet B
- JP-5 Higher flash point for carrier operations
- JP-7 Thermally Stable for SR-71 higher temperatures
- JP-8 "Kerosene Type", similar to Jet A-1
- JP-9 Missile fuel (higher energy per unit volume)

Commercial Turbine Fuel
Specifications

- Industry/Government specifications
- American Society for Testing and Materials (ASTM)

ASTM D1655 Jet A, Jet A-1, Jet B

Commercial Turbine Fuel

Specifications

TABLE 2
COMMERCIAL TURBINE FUEL SPECIFICATIONS

Issuing Agency:			ASTM		IATA		Test Method	
Specification:			D 1655		ADD 78-1 (1)			
Revision Date:			1981	1981	Dec 81			
Crude Designation:			Jet A (2)	Jet B				
Fuel Type:			Kerosene	Wide-Cut	Kerosene	Wide-Cut	ASTM	IP
COMPOSITION	Acidity, Total (mg KOH/g)	MAX.	0.1	—	0.1	0.1	D 974 or D 3242	282
	Aromatics (vol. %)	MAX.	20 (3)	25 (3)	20 (3)	20 (3)	D 1319	156
	Olefins (vol %)	MAX.	—	—	—	—	D 1319	
	Sulfur, Mercaptan (wt %)	MAX.	0.003	0.003	0.003	0.003	D 1323	104
	or Doctor Test, N=Negative		N	N	N	N	D 484	30
	Sulfur, Total (wt %)	MAX	0.3	0.3	0.3	0.3	D 1266	107
							D 1552 or D 2622	
VOLATILITY	Distillation							
	Temp. 10% Rec (°C)	MAX.	204.4		204		D 86	123
	20% Rec (°C)	MAX.		143.3		143		
	50% Rec (°C)	MAX.	Rpt	187.8	Rpt	188		
	90% Rec (°C)	MAX.	Rpt	243.3	Rpt	243		
	Final BP (°C)	MAX.	300		300			
	Residue (vol %)	MAX.	1.5	1.5	1.5	1.5		
	Loss (vol %)	MAX.	1.5	1.5	1.5	1.5		
	Flash Point (°C)	MIN	37.8		38		D 56	170/34
	Gravity, °API (60°F)		37-51	45-57	37-51	45-57	D 287	
	Relative Density (15.5°C)		0.7750-0.8398	0.7800-0.8017	0.7750-0.8398	0.7800-0.8017	D 1298	160
	Vapor Pressure, 38°C (kPa)	MAX		21		21	D 323	169
FLUIDITY	Freezing Point (°C)	MAX.	−40 (5)	−50	−47	−50	D 2386	16
	Viscosity @ −20°C (cSt)	MAX.	8	—	8	—	D 445	71
COMBUSTION	Net Heat of Comb. (MJ/kg)	MIN.	42.8	42.8	42.8	42.8	D 3338 or D 4809 (6)	
	Luminometer No.	MIN.	45	45	45	45	D 1740	
	or Smoke Point	MIN.	25	20	25	25	D 1322	
	or Naphthalenes (vol %)	MAX.	3 (4)	3 (4)	3 (4)	3 (4)	D 1840	
CORROSION	Copper Strip (2 hrs @ 100°C)	MAX.	1	1	1	1	D 130	154
STABILITY	JFTOT ΔP (mm Hg)	MAX.	25	25	25	25	D 3241 (7) or D 1660 (8)	323
	JFTOT Tube Color Code	MAX.	<3	<3	<3	<3		
CONTAMINANTS	Existent Gum (mg/100 ml)	MAX.	7	7	7	7	D 381	131
	Particulates (mg/l)	MAX	—	—	—	—	D 2276	216
	Water Reaction Interface	MAX.	1b	1b	1b	1b	D 1094	289
	Water Reaction Separation	MAX.	2	2	2	2	D 1094	289
ADDITIVES	Anti-Icing		Agreement	Agreement	Option	Option		
	Antioxidant		Option	Option	Agreement (7)			
	Corrosion Inhibitor		Agreement	Agreement	Option	Option		
	Metal Deactivator		Option	Option	Agreement	Agreement		
	Antistatic		Agreement	Agreement				
OTHER	Electrical Conductivity (pS/m) (9)		50-450	50-450	50-450	50-300	D 2624 or D 4308	274

NOTES: (1) This is not a specification, but Guidance Material.
(2) Jet A-1 is a similar kerosene-type, but Freezing Point is −47°C MAX.
(3) Fuels containing up to 25 vol. % aromatics may be shipped if supplier notifies user.
(4) Min Smoke Point – 20 MIN, but 18 MIN may be shipped if supplier notifies user.
(5) Min Smoke Point – 20 MIN, but 18 MIN may be shipped if supplier notifies user.
(6) At time, place, and temperature of delivery and accept if antistatic additive is used.
(7) Approved corrosion inhibitor to improve fuel lubricity may be added at user's option.
(8) D 2887 is the Referee Method.
(9) Test at 260°C tube temperature. Repeat test at 245°C that meets limits constituted as pass; D 3660 is alternative at 149°C perform 204°C filter temperatures with maximum test limits of 25.3 mm Hg filter ΔP and Code 3 tube rating.

Commercial Turbine Fuel
Specifications (cont.)

- International Air Transport Association (IATA guidance material) IATA ADD76-1 “Kerosene Types” and “Wide Cut”
- Aviation Fuel Quality Requirements for Jointly Operated Systems (AFQRJOS) ‘Check List’, Jet A-1, Jet B (non-U.S.)

"Kerosene Types"

Jet A-1 Specifications

- British - DERD.2494 (AVTUR)
- Canadian - CAN/CGSB 3.23-M86
- French - AIR 3405/C
- Russian - GOST 10227-86 T-1, TS-1 (TS-1 freeze point -50º to -60ºC)
- Romanian - 3754/73, CS-3, STAS 5639

"Wide Cut"

Jet B Specifications

- British - DERD.2486 (AVTUR)
- Canadian - CAN/CGSB 3.22-M86
- French - AIR 3407/B
- Russian - GOST 10227-86, T-2
- German - TL 9130-006 Issue 6

Engine Manufactures
Specifications

- General Electric - Specification No. D50TF2
- Pratt & Whitney - Service Bulletin No. 2016
- Rolls-Royce - Appendix 2 to Engine Operating Manual
- FAA/JAA Approved Airplane Flight Manual

Airplane Flight Manual

ENGINE LIMITATIONS (Continued)

ENGINE FUEL SYSTEM

The approved fuel is designated in the CFM56-3 Series Installation Manual, as revised. Fuel conforming to commercial jet fuel specification ASTM-D-1655, Jet A, Jet A1 and Jet B are authorized for unlimited use in this engine. Fuels conforming to MIL-T-5624G for grades JP-4 and JP-5, and to MIL-T-83133 grade JP-8 are acceptable alternatives. The engine will operate satisfactorily with any of the foregoing fuels or any mixture thereof.

The maximum tank fuel temperature is 49°C (120°F).

Inflight tank fuel temperature must be maintained at least 3°C (5°F) above the freezing point of the fuel being used or -45°C (-49°F) whichever is higher.

Anti-icing fuel additive PFA 55MB at a concentration not to exceed 0.15 percent by volume may be used. No fuel system anti-icing credit is allowed.

ENGINE OIL SYSTEM

Minimum oil pressure is 13 psi. If engine oil pressure is in the yellow band with takeoff thrust set, do not takeoff.

Maximum oil temperature limit for continuous operation is 160°C.

Maximum oil temperature is 165°C. Operation between 160°C and 165°C is limited to 15 minutes.

The approved oil is designated in the CFM56-3 Service Bulletin 79-001, as revised.

See Non-Normal Procedures, Section 3.2, for oil pressure below 13 psi.

ENGINE OPERATION IN RAIN, HAIL OR SLEET*

When flight in moderate or heavy rain, hail or sleet is encountered or anticipated, engine start switches must be set to FLIGHT and a minimum 45% N1 must be maintained except on short final when landing is assured.

* Applicable to airplanes that have not incorporated CFMI Service Bulletins 72-450, "ENGINE - FAN ASSY - INTRODUCTION OF A NEW SPLITTER FAIRING", 72-462, "ENGINE - GENERAL - REINTRODUCTION OF THE 12 VBV DOORS CONFIGURATION", 72-579, "ENGINE - FAN AND BOOSTER - REPLACEMENT OF THE CONICAL SPINNER BY AN ELLIPTICAL SPINNER", and 72-580, "ENGINE - GENERAL - INTRODUCTION OF VBV SYSTEM MODIFICATIONS", on both engines. Incorporation of Boeing Service Bulletin 737-71-1273 is required when the above CFMI service bulletins are not incorporated.

REVERSE THRUST

Use for ground operation only. Intentional selection of reverse thrust in flight is prohibited.

Airplane Flight Manual

PERFORMANCE CONFIGURATION

The airplane configuration as presented under Performance Configuration, Section 4.1, must be observed.

Approved tires that are capable of at least 235 MPH true ground speed must be installed in order to utilize the maximum structural and performance-limited takeoff weights. The main gear tires must be H49 x 19-22 with at least a 56,600-pound rated load (32 ply or greater rating). Basic nose gear tires are 49 x 17 tires with at least a 50,400-pound rated load (32 ply or greater rating).

OPERATIONAL LIMITS

Runway slope -- ±2%

Maximum Takeoff and Landing Tailwind Component -- 15 knots*

Maximum Operating Altitude -- 45,100 feet pressure altitude

Maximum Takeoff and Landing Altitude -- 10,000 feet pressure altitude

Takeoff, Landing, and Enroute Operational Limits -- use Environmental Envelope chart, Section 4.1

* The capability of the airplane has been satisfactorily demonstrated for takeoff and manual landing with tailwinds up to 15 knots. This finding does not constitute operational approval to conduct takeoffs and landings with tailwind components in excess of 10 knots.

FUEL DENSITY LIMITATIONS

The available range of fuel densities for the 747-400 is 6.0 pounds per gallon to 7.1 pounds per gallon. For densities less than 6.43 pounds per gallon, the gross weight is limited as shown on page 9 of this section.

Airplane Flight Manual

757 BOEING

AIRPLANE FLIGHT MANUAL

CERTIFICATE LIMITATIONS

E N G I N E S Rolls-Royce RB211-535E4

ENGINE THRUST

EPR values for Takeoff and Maximum Continuous Thrust are presented on the appropriate Thrust Setting charts in Section 4.2.

ENGINE RPM

The maximum operational limits are:

N1 - Low Pressure Compressor Rotor 108.8% (5 Min)
108.4% (Continuous)
N2 - Intermediate Pressure Compressor Rotor 100.3% (5 Min)
98.0% (Continuous)
N3 - High Pressure Compressor Rotor 99.0% (5 Min)
95.8% (Continuous)
Maximum Overspeed (20 Seconds) N1 - 110.0%; N2 - 101.3%; N3 - 100.2%

ENGINE EGT

Operating Condition	Temperature Limits	Time Limit
Takeoff	850 deg C	5 Minutes
Maximum Continuous	795 deg C	Continuous
Starting, Ground and Flight	570 deg C	Momentary, 2 SEC.
Overtemperature	870 deg C	20 Seconds

ENGINE LIMIT DISPLAY MARKINGS

Maximum and minimum limits.....Red
Precautionary range.....Amber

The engine limit display markings on EICAS may be used to determine compliance with the maximum and minimum limits and precautionary ranges. If EICAS markings show more conservative limits than those specified above, the limit markings shown on EICAS must be observed.

ENGINE FUEL SYSTEM

The fuel designation is per Rolls-Royce O.I. F-211(535E4)-B, Appendix 2.

The maximum tank fuel temperature is 49 deg C (120 deg F), except JP-4 or JET B which is 29 deg C (85 deg F).

Tank fuel temperature must be maintained at least 3 deg C above the freezing point of the fuel being used or -40 deg. (F or C), whichever is higher.

Airplane Flight Manual

BOEING 767

AIRPLANE FLIGHT MANUAL

CERTIFICATE LIMITATIONS

E N G I N E S (Continued)

ENGINE FUEL SYSTEM

The fuel designation is Pratt & Whitney Service Bulletin 2016, as revised. Fuel conforming to commercial jet fuel specification ASTM-D-1655, Jet A, Jet A1 and Jet B are authorized for unlimited use in this engine. Fuels conforming to MIL-T-5624 grades JP-4, JP-5, and JP-8 are acceptable alternatives. The engine will operate satisfactorily with any of the foregoing fuels or any mixture thereof.

The maximum tank fuel temperature is 49 deg C (120 deg F) except JP-4 or Jet B which is 43 deg C (110 deg F).

Inflight tank fuel temperature must be maintained at least 3 degrees C above the freezing point of the fuel being used.

Anti-icing fuel additive PFA 55MB at a concentration not to exceed 0.15 percent by volume may be used. No fuel system anti-icing credit is allowed.

ENGINE IGNITION

On for takeoff and landing.

ENGINE OIL SYSTEM

Minimum oil pressure is 35 psi.

Maximum oil temperature is 163°C. Operation between 135°C and 163°C is limited to 20 minutes.

The oil designation is Pratt & Whitney Service Bulletin 238, as revised.

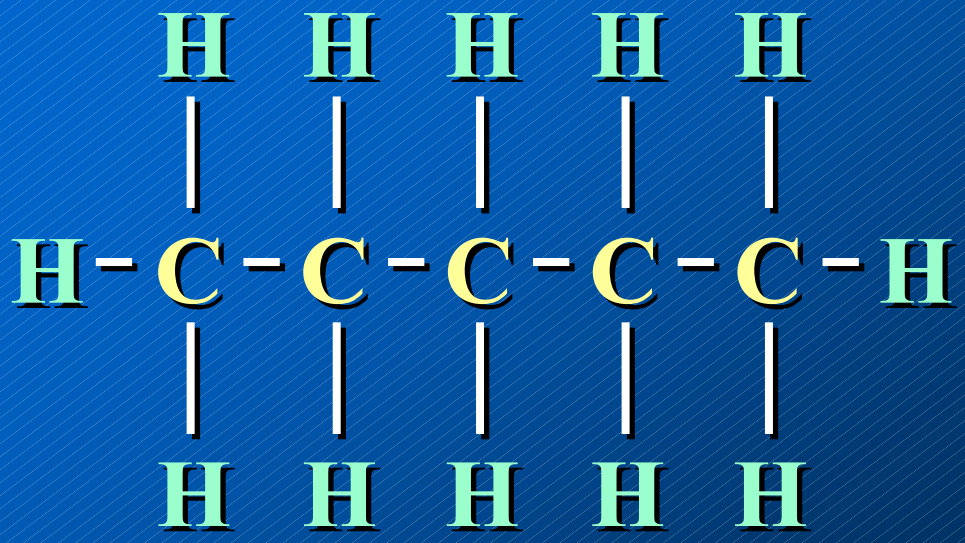
REVERSE THRUST

Use for ground operation only. Intentional selection of reverse thrust in flight is prohibited. Backing the airplane with use of reverse thrust is not permitted.

Turbine Fuel Composition

Four groups of Hydrocarbons in Jet Fuel:

- **Paraffins, Isoparaffins, Cycloparaffins**
- **Aromatics**
- **Naphthalenes**
- **Olefins**



Other Fuel Constituents

- Sulfur - corrosion and emissions
- Gums - filter clogging and sticky valves
- Water - corrosion and filter clogging
- Naphthenic Acid - corrosion

Fuel Additives

- Approved Additives only
- Antioxidents
- Metal Deactivators
- Fuel System Icing Inhibitors
- Corrosion Inhibitors
- Static Dissipators

Turbine Fuel Properties

- Density (Specific Gravity SG)
- Lower Heating Value (LHV)
- Viscosity
- Lubricity
- Low Temperature
- Volatility
- Electrical
- Bulk modulus
- Thermal Oxidation Stability
- Material Compatibility
- Toxicity

Density, Specific Gravity

- Density = Mass/Volume
- Specific Gravity (SG) also known as Relative Density
- Typical Jet A, Jet A-1: SG = 0.815
- Typical Jet B: SG = 0.764
- Varies with temperature
- °API = (141.5/SG) - 131.5
- SG measured with hydrometer per ASTM D1298
- Airplane Densitometers

Lower Heating Value (LHV)

- LHV = Net Heat of Combustion (BTU/lb)
- Jet A: 18,484 - 18,645 (ave. 18564)
- Density relationship to LHV
- Performance analysis based on 18,580 BTU/lb
- Boeing Airplane Performance Monitoring program (APM) input

APM Program Documentation

5.7.4 Fuel Lower Heating Value Correction to Fuel Flow

Method as taken from the Boeing document D6-33468, entitled "The Determination of Cruise Fuel Mileage by Flight Testing Model 747 Production Airplanes, Revision D," approved for issue February 1979.

Purpose: To correct fuel lower heating value to a nominal value of 18,580 BTU/Lb. The user may alter the relationship between specific gravity and fuel lower heat value. The relationship exists as the equation of a line given as y = mx + b, where x is the specific gravity, m is the slope and b is the y-intercept. The slope and y-intercept may be input in the User-Input file as LHVM and LHVB respectively. If no slope or y-intercept are input the default values of -5220 and 22777 are used. If the actual value of LHV is known, it may be placed in the CONFIG section of the database, see Appedix 2 for details.

Inputs
Scalars

T_{Fuel} = Fuel Temperature [Deg C]
$\rho Fuel$ = Fuel Density [Lb/Gal]
LHV_{ref}= Reference LHV (18580 BTU/Lb)
M = LHV Equation Slope (default -5220)
B = LHV equation y-intercept (default 22777)

From LHV = M(x) + B Where x = Specific Gravity

Algorithm

Step 1. $S.G. = \frac{[(0.0063)(T_{Fuel} - 15.56)] + \rho Fuel}{8.32\ 82}$

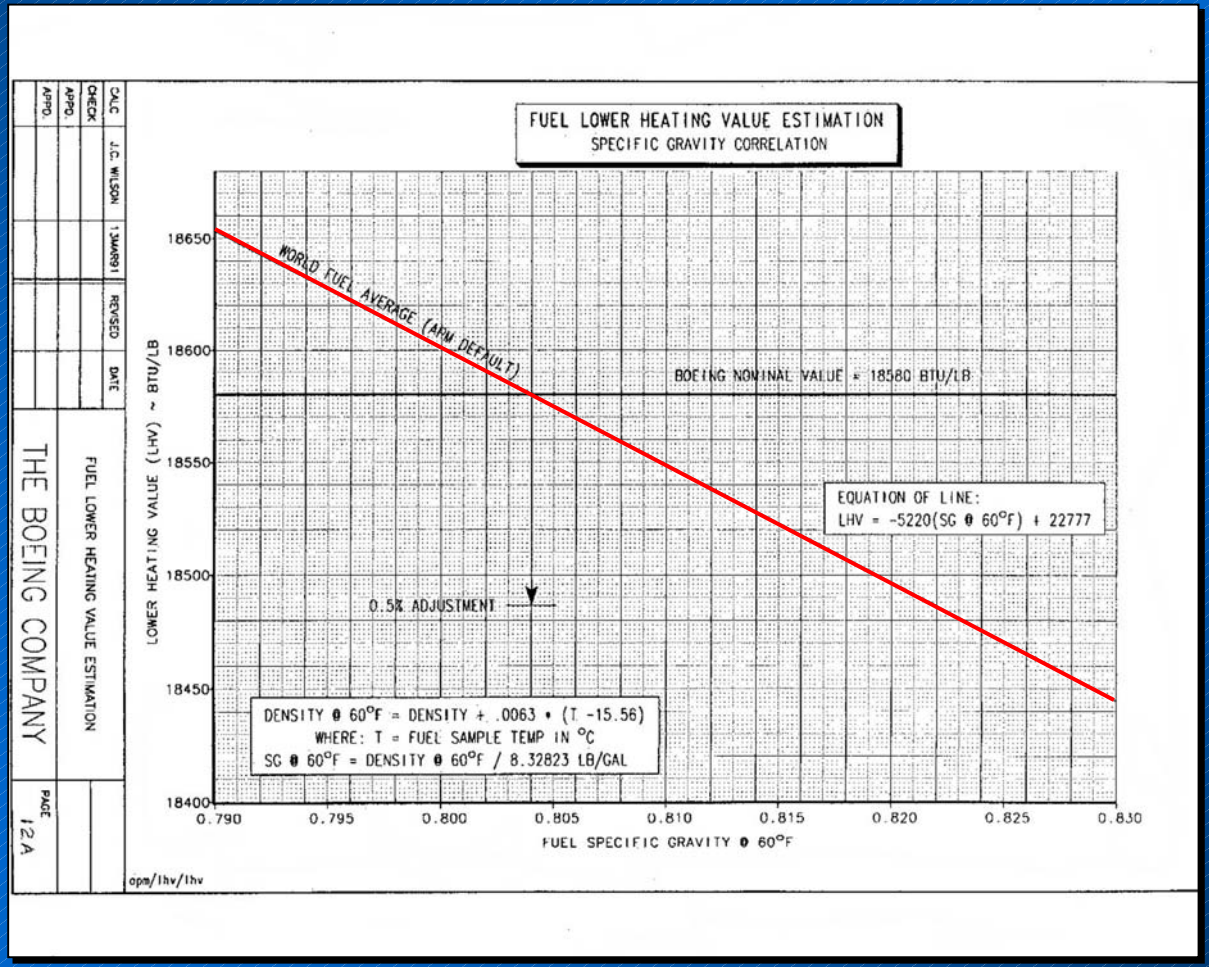
Step 2. LHV = -5220(S.G.) + 22777

or

LHV = M (S.G.) + B

Step 3. $Wf_{Corr} = Wf_{Calc}\ (LHV_{ref} / LHV)$

Fuel Lower Heating Value Estimation



Viscosity

- Fuel line pressure drop and pumping capabilities
- Low temperatures increase viscosity
- Measuring units are Centistokes (mm^2/sec)

Fuel Lubricity

- Controls, valves, bearing, pumps
- Low viscosity prevents hydrodynamic film
- Absorbs into surface - Boundary layer lubricants
- Refining removes lubricants (thermally stable fuels, SR-71)
- Corrosion inhibitors augment Lubricity

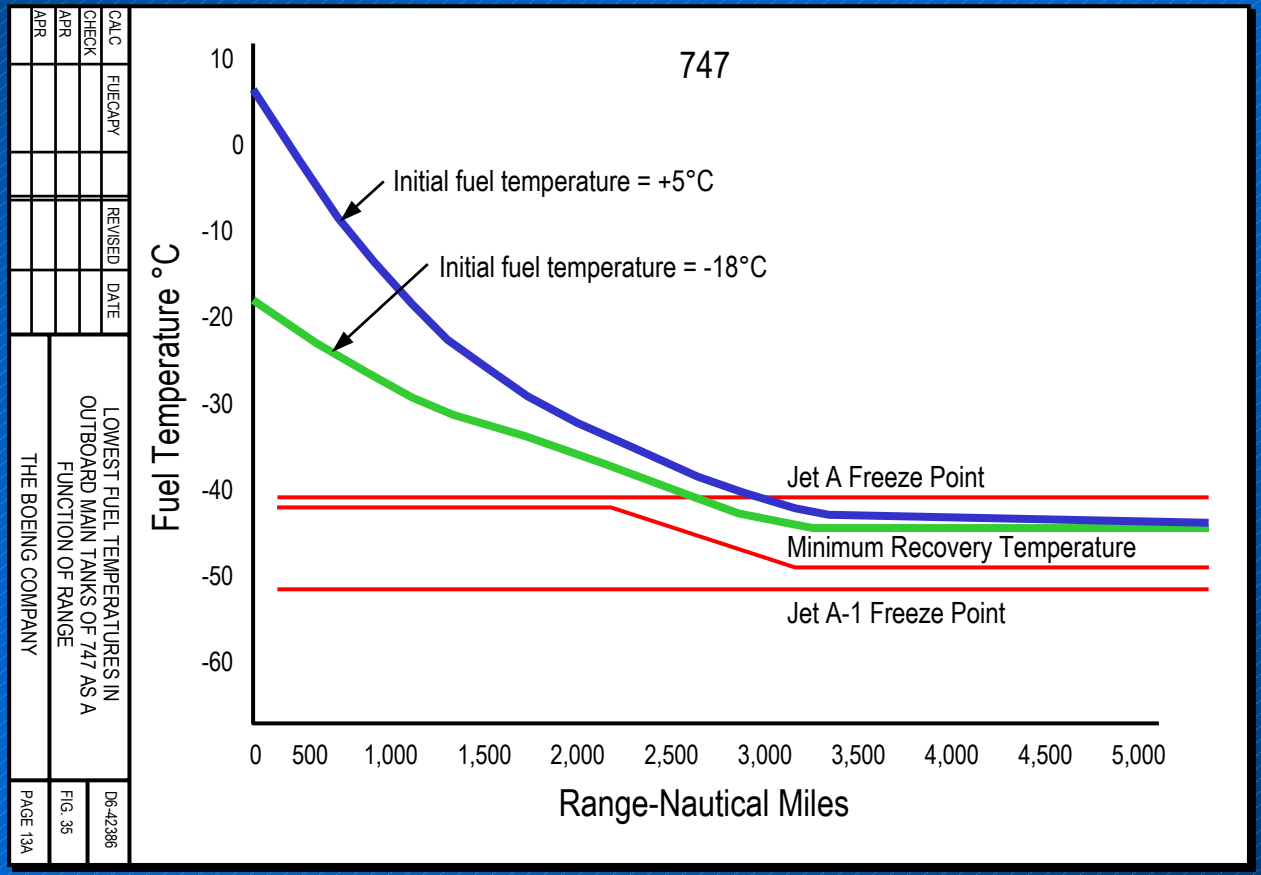
Low Temperature Properties

- Freeze Point (wax crystals disappear)
- Pour Point (1.5 inch cylinder test) (4ºC to 20ºC below Freeze Point)
- Cloud Point (haze forms)
- Fuel will not flow when indicated temperature is below pour point
- Fuel starts to solidify when recovery temperature is below pour point
- Operational Considerations

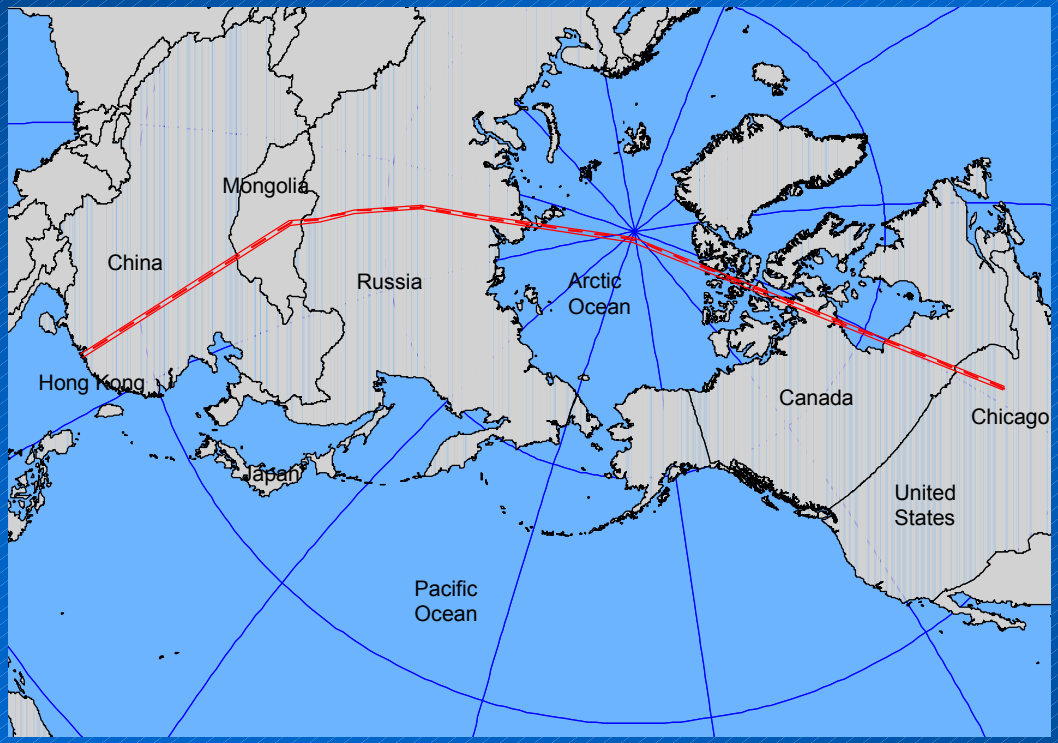
Operational Considerations

- Pilots must maintain fuel temperature at least 3ºC above fuel freeze point
- Low temperature operations is a concern for fuel transfer, boost pump inlets and in fuel lines
- The rate at which the fuel temperature declines is a function of air temperature, airplane geometry, fuel management schedule and time
- Fuel temperature will approach the recovery temperature
- Recovery Temperature is slightly lower than TAT
- TAT and Recovery Temperature are a function of ambient air temperature and Mach

Lowest Fuel Temperatures



Increasing use of Polar Routes



777 Demonstration Flight:
15 hours 22 minutes total flight time
At 10 hours into the flight, OAT = -64ºC, TAT = -35ºC, Recovery Temp = -38ºC. The lowest fuel temperature was -32ºC at 11 hours into the flight.

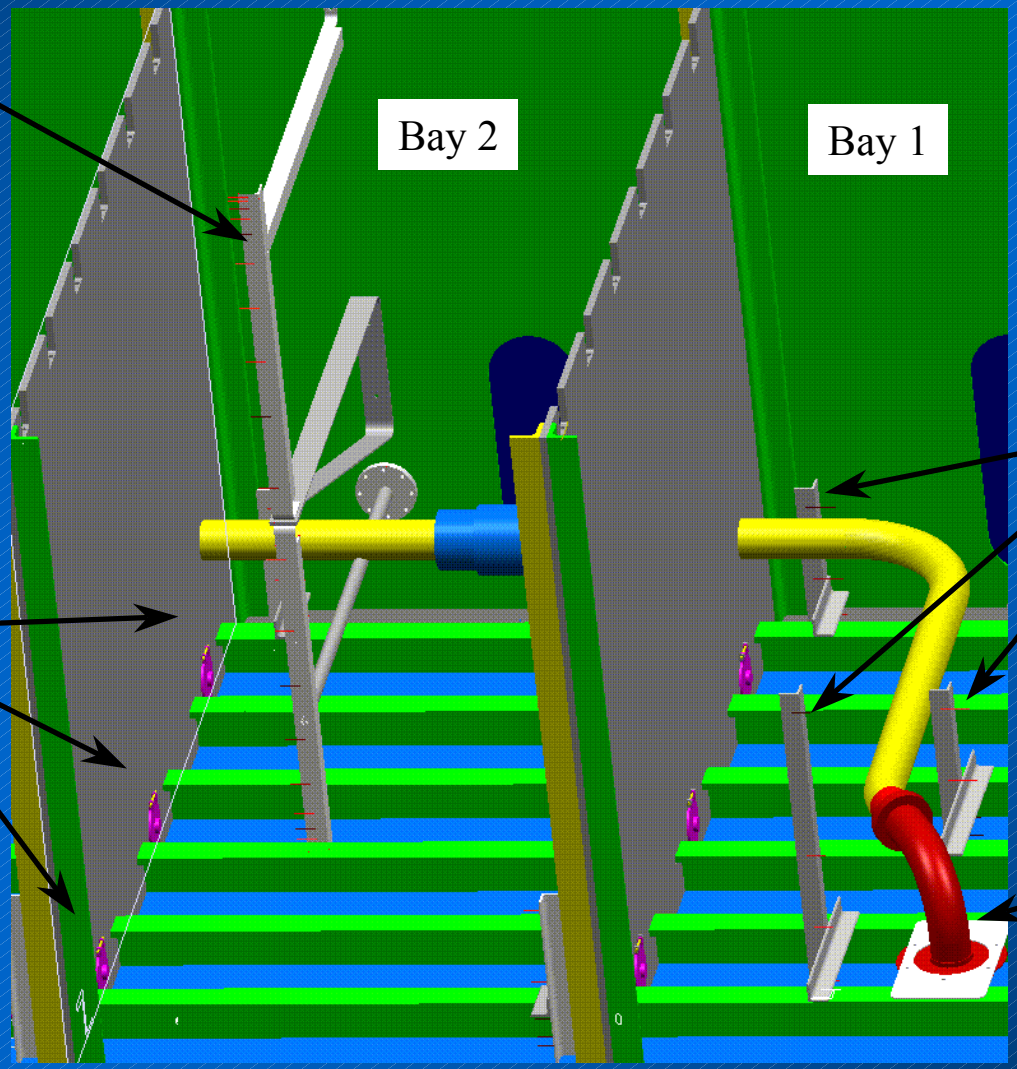
Actual Fuel vs. Specification

- Specification: Jet A -40ºC, Jet A-1 -47ºC, Jet B -50ºC
- Freeze Point of actual fuel varies from day-to-day and airport-to-airport
- Actual delivered fuel <u>might</u> have freeze point as much as 40% better than specification
- Pilot must observe specification value unless test results are known

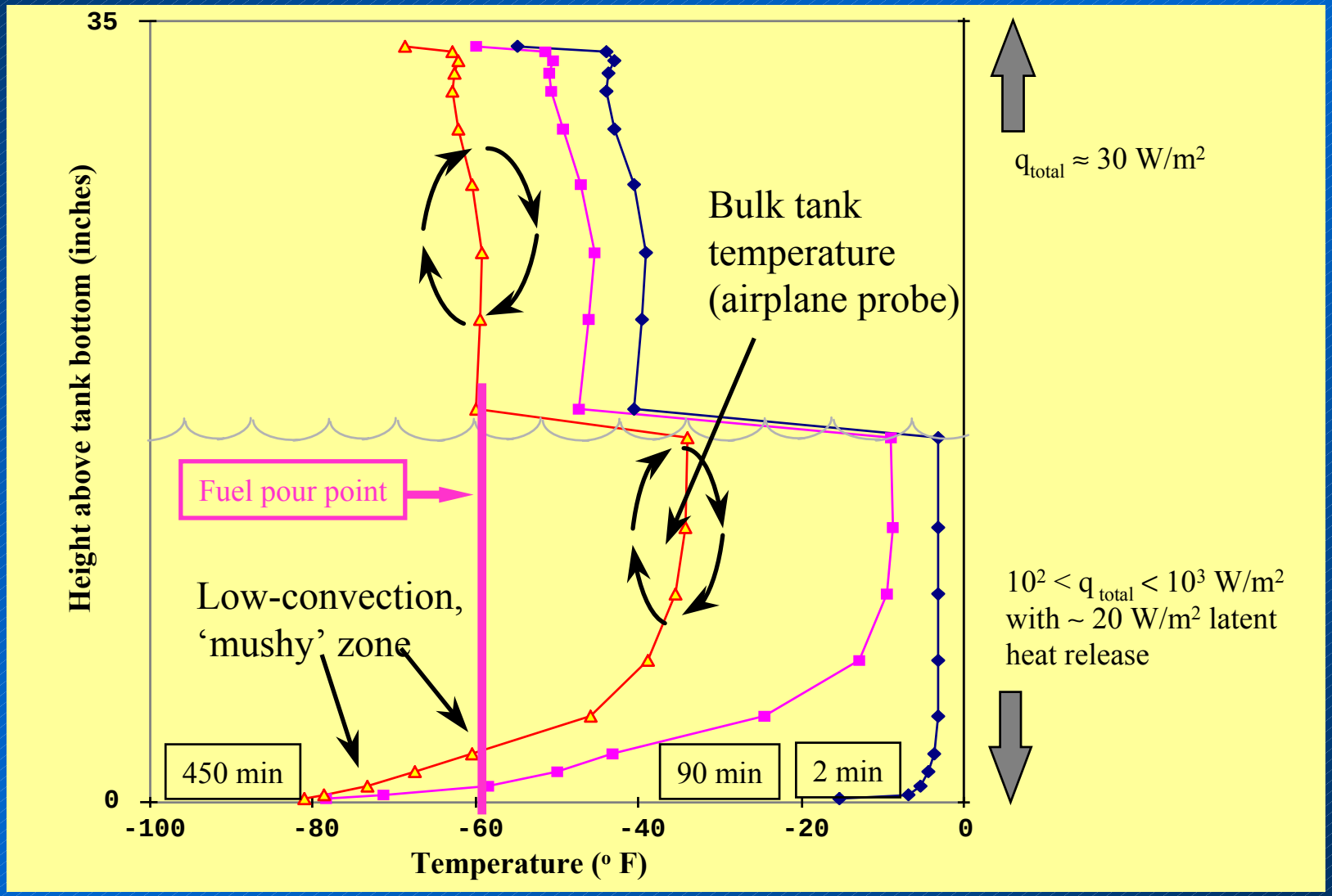
Operational Response to Cold Fuel

- Increase Mach (.01 Mach is 0.5ºC)
- Divert around cold air mass
- Descend to lower (warmer) altitude (extreme cases may require 25,000 ft at .85 Mach)
- Dispatch with known fuel freeze point

Cold Fuel Flow Research



Cold Fuel Flow Research



Cold Fuel Summary

- Fuel Tank tests at cold temperatures
- Computer Models of tank cooling - Fuel Temperature Prediction Program (FTPP)
- IATA is reviewing ASTM/GOST testing procedures
- Fuel additives being considered
- Fuel Freeze points are being monitored in U.S.
- IATA team to audit fuel quality around the world
- Future system to monitor fuel freeze points at airports on-line, real time. (Phase Technology)

Volatility

- Tendency to change from liquid to vapor
- Reid vapor pressure
- Relative to Jet A-1 at 60°F:
  - Jet B vapor pressure is 1,750% higher
  - AvGas vapor pressure is 4,600% higher

Electrical

- Dielectric constant (fuel quantity)
- Electrical Conductivity

Flammability and Ignition
Characteristics

- Flammability vs. Altitude
- Flash Point

Bulk Modulus

- Fuel is used as hydraulic fluid in servo valves
- Jet A-1: 193 kpsi
- Airplane hydraulic fluid (Skydrol): 210 kpsi

Thermal Oxidation Stability

- Gums and Deposits
- Fuel additives to reduce thermal degradation
  (thermally stable fuels only, SR-71)
- Commercial grades controlled by specification

Material Compatibility

Metals

- Satisfactory
  - Aluminum and alloys
  - Carbon steels
  - Stainless steels
- Unsatisfactory
  - Bronze
  - Nickel
  - Copper
  - Zinc
  - Cadmium

Packing and gaskets

- Satisfactory
  - Nylon
  - Polyethylene
- Unsatisfactory
  - Fluorothene
  - Vinylite
  - Teflon

Toxicity

- Not highly toxic
- Handle with Care

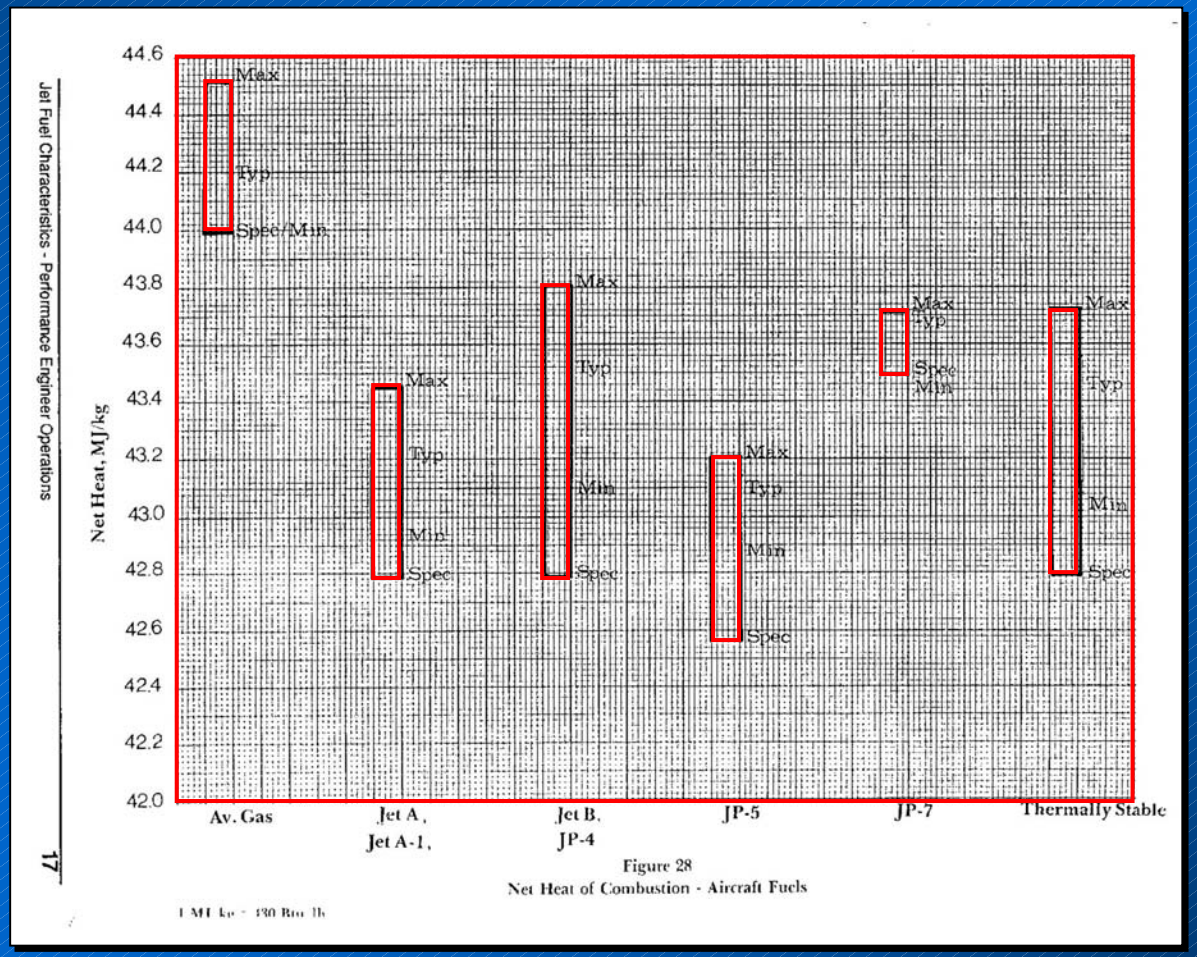
Non-Normal Situations

Mixing of Fuels

- Jet A and Jet B - Ok, increased volatility
- Mixing Jet A and Jet A-1 raises freeze point significantly towards that of Jet A
- AvGas - Vapor pressure, boil off, cavitation, fueling dangers, hot section deposits, lubrication
- Diesel/heating oils - Cold flow, viscosity, freeze point

Airplane Fuels

Net Heat of Combustion



Net Heat, MJ/kg

44.6
44.4
44.2
44.0
43.8
43.6
43.4
42.8
43.0
42.6
42.4
42.2
42.0

Av. Gas | Jet A, Jet A-1 | Jet B, JP-4 | JP-5 | JP-7 | Thermally Stable

Airplane Fuels
Vapor Pressure

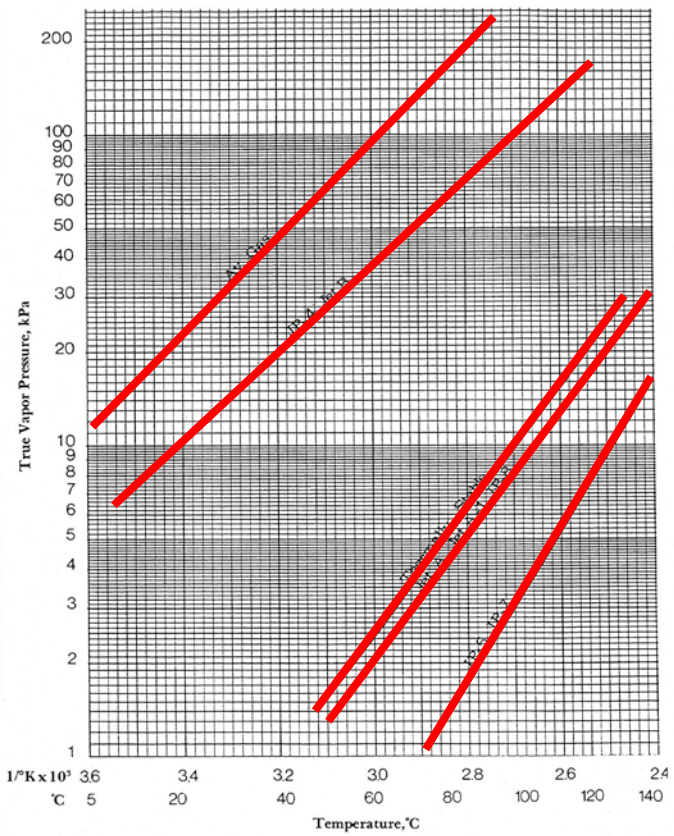


Figure 20
Vapor Pressure - Aircraft Fuels

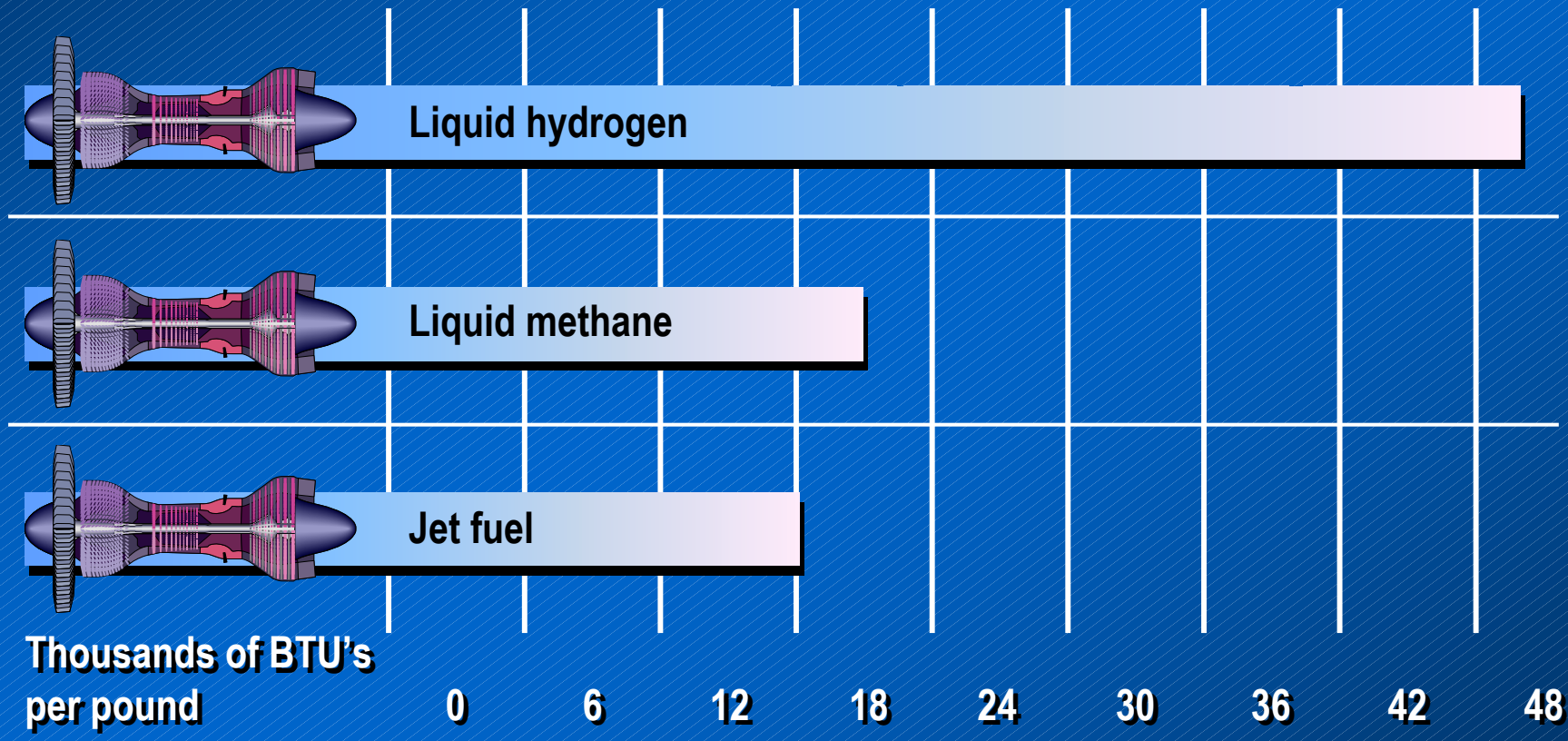
1 kPa = .145 psi

Future Fuels

- Hydrogen
- Methane
- Synthetic Fuels (about 4 times more expensive)

When The Tank Runs Dry...

Alternative Fuels



A pound of hydrogen has almost three times the energy of a pound of conventional fuel.

Questions?

Survey of Aviation Turbine Fuels

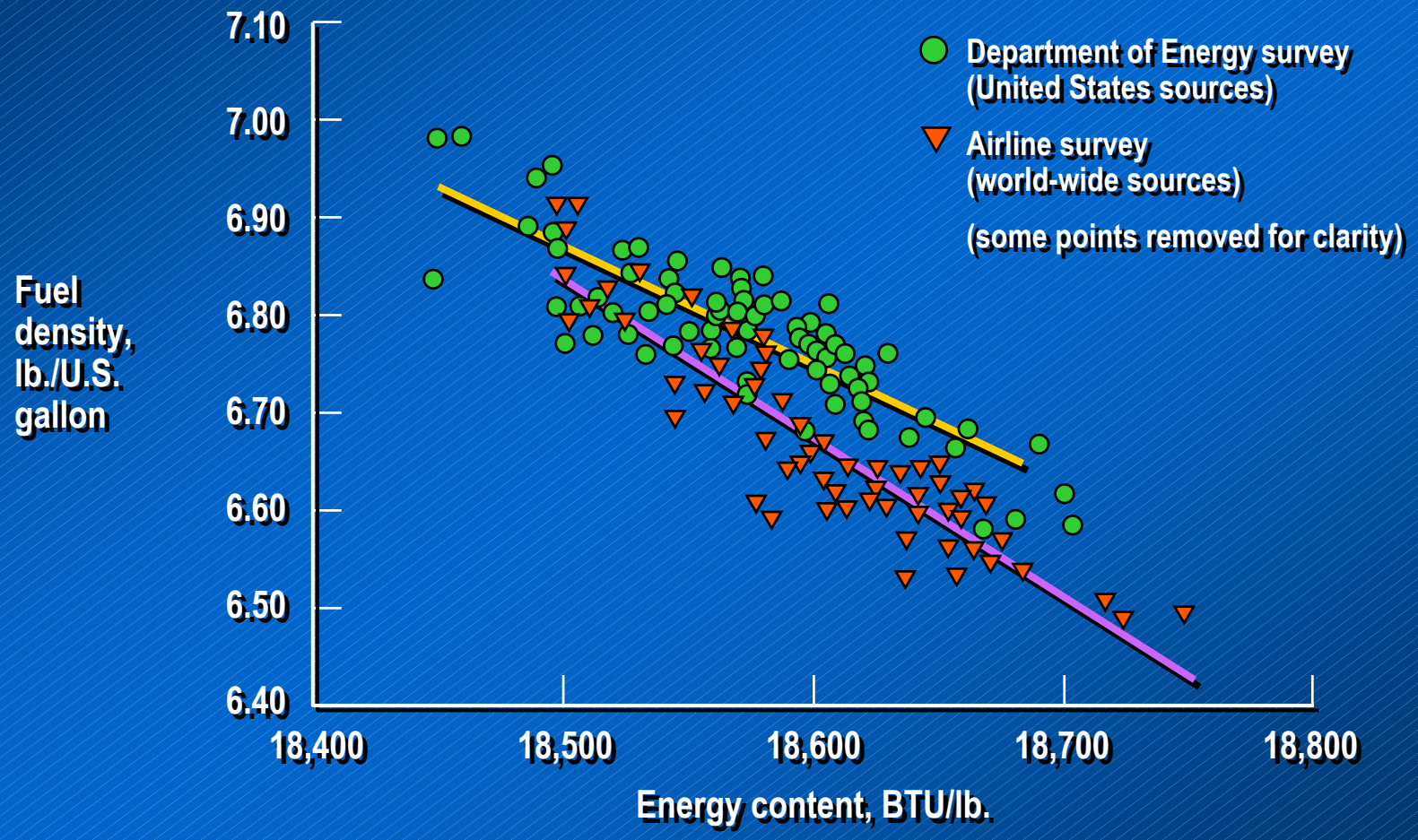


Figure 1

Fuel Energy Content Versus Fuel Density

Boeing Fuel Conservation Newsletter, Issue No. 9, January-March 1983

We recently received a question on the relationship between fuel energy content and fuel density. The question came from an airline reviewing its fuel tankering policy. Like most other operators this particular airline's fuel takering policy assumes constant fuel density, and the airline felt that unless a change in fuel density was accompanied by an equivalent change in fuel energy content, the tankering analysis would not be valid.

Before addressing the fuel tankering problem, we think it may be of interest to discuss how fuel density and energy content may effect airplane performance and flight operations.

Fuel density does not have much direct bearing on flight operations because all performance data are based on a fuel weight-pounds, kilos, tons, pounds per hour, nautical miles per pound, etc. This includes fuel load, trip fuel, reserves. Operations Manual performance, computer flight plans, and so on. Fuel volume is not used because it would be necessary to account for density. Fuel density may appear in load sheet calculations for some models, and has an obvious impact on full tank or volume limited operations. The one place where fuel density is important is in working out the fuel bill. Dispatch, or the captain, requests the required fuel uplift by weight; the amount of fuel pumped on board is measured by volume; and the total cost of the load of fuel is based on a price per unit volume, dollars per gallon for example. This is part of the fuel tankering problem. By assuming constant fuel density in the tankering calculations it has also been assumed that if the fuel price is the same at departure and destination airports, then a given amount of money will buy the same weight of fuel at each location.

The other part of the tankering problem is that constant fuel energy content is assumed, which implies that a given weight of fuel will always propel the airplane for the same number of miles. The fuel energy content, or fuel lower heating value (LHV), is usually expressed in units of British Thermal Unit per pound of fuel (BTU/lb.) The fuel consumption is inversely proportional to the LHV, for example, a 1% decrease in LHV would reduce the fuel mileage by 1%, and increase fuel flow by 1%.

During performance flight testing, a fuel sample is taken from each tank before flight and the average LHV is determined by laboratory tests. The performance data are then adjusted to a reference LHV. The Boeing Operations Manual and Performance Engineers' Manual are based on the same reference LHV.

Our current policy is to use a reference value of 18,580 BTU/lb., which is the average for fuel surveys made by the U.S. Department of Energy (DOE) for various U.S. fuel sources.

Figure 1 shows a plot of the DOE results for 1980-1981 plus data provided to Boeing by a major international airline for worldwide fuel survey. The figure shows the relationship between fuel density and energy content. In general, lighter fuels have a higher energy content but for a given volume the lighter fuel does not produce the same energy. For example, fuel with density 6.9 lb./gallon has an energy content of about 18,480 BTU/lb., thus one gallon of fuel produces 127,370 BTU's.

Lighter fuel, with 6.65 lb../gallon density, has an energy content of 18,680 BTU/lb., so one gallon of this fuel only produces 124,200 BTU's.

In spite of the possible variations in fuel density and energy content, as illustrated in Figure 1, we do not consider the overall effect on routine flight operations to be significant. The effects on trip fuel are small and are no greater that other unknown or unaccounted factors, such as instrumentation accuracy, weights, winds, CG, etc. We do, however, recommend that if a "problem" airplane is being checked with calibrated instruments, accurate fuel loads, etc., then then it is probably worth while to take fuel samples and to determine the LHV of the fuel.

With regard to the original fuel tankering question, the airline does have a point. To make a totally valid tanker analysis a

Fuel Energy Content Versus Fuel Density (continued)

correction for density and LHV should be made. The LHV correction is difficult since The LHV for the particular fuel load can only be determined after the flight by laboratory analysis. It may be possible, however, to combine density and energy effects into a single correction, based on Figure 1 variation, which could be referenced to density only. However, this may be unnecessarily complicated, particularly since the fuel density of the destination airport is probably unknown. Our general recommendation on tankering fuel is that this should not be done unless the price advantage is really significant. This would allow for unknowns such as wear and tear on airframe, wheels, tires, engines, etc.., and for fuel density and energy content variations.