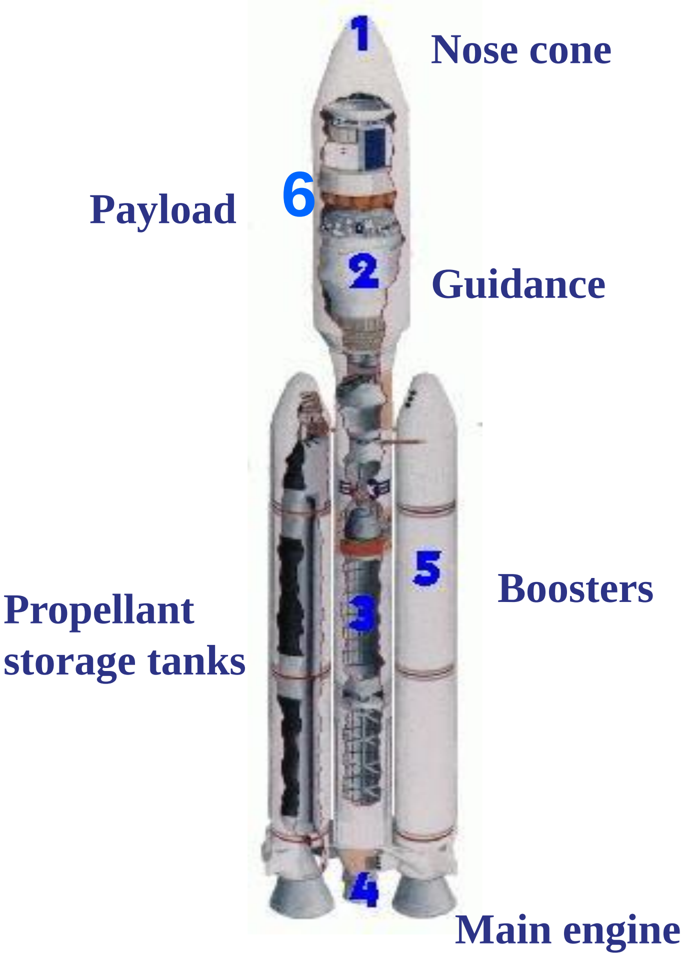
太空發射火箭類別與安全(等級)概述

趙怡欽、許紘瑋、利鴻源、陳建安、詹于霈
國立成功大學航空太空工程學系，台南，台灣
國立成功大學航空太空研究中心，台南，台灣

2022/11/30

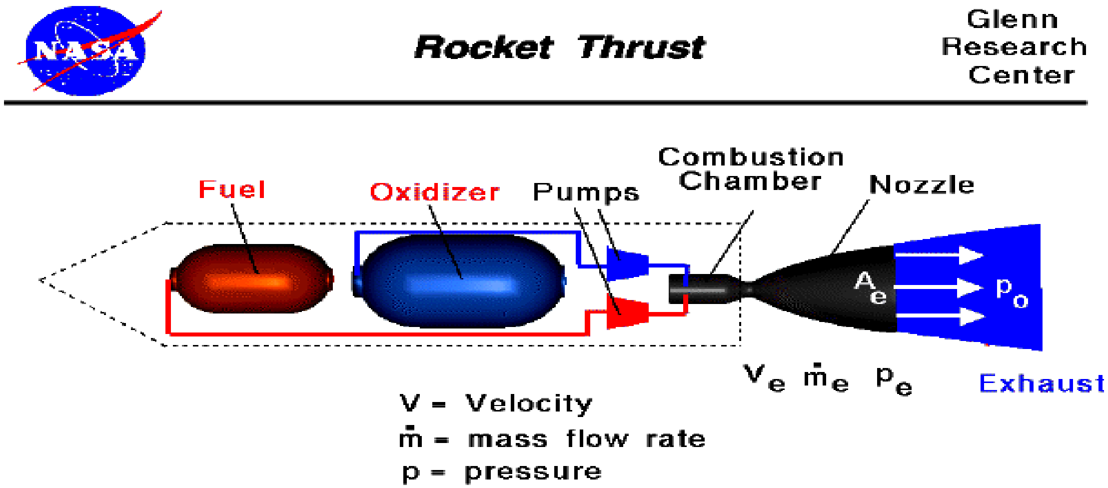
Rocket Propulsion Fundamentals

- **Major Rocket components**:
  - ***1. Nose cone-*** to reduce aerodynamic drag during launching.
  - ***2. Guidance/Control system-*** to control altitude and attitude of the rocket and transfer data and commands.
  - ***3. Storage tanks-*** to store the liquid or solid propellants for use
  - ***4. Main engine-*** to burn propellants in the combustion chamber and generate thrust through the nozzle
  - ***5. Boosters-*** to provide extra thrust during launching
  - ***6. Payload-*** the items carried for the mission



Rocket Propulsion Fundamentals

- **Thrust Equation and Specific Impulse**
  - ***Thrust Equation***



Thrust = $F = \dot{m}_e V_e + (p_e - p_0) A_e$

$$F = \dot{m}_e [V_e + (p_e - p_0) A_e / \dot{m}_e] = \dot{m}_e V_{eq}$$

Where Veq, also called the effective exhaust velocity "c"

Rocket Propulsion Fundamentals

– ***Specific impulse***

Total change in momentum I :

$$I = \int F dt = \int \dot{m}_e V_{eq} dt$$

$$\text{if } V_{eq} = \text{constant}$$

$$I = m_p V_{eq}$$

Define the specific impulse I_{sp}

$$I_{sp} = I / m_p = V_{eq} = F / \dot{m}_e$$

in weight flow

$$I_{sp} = I / m_p g = V_{eq} / g = F / \dot{m}_e g \quad (\text{sec})$$

Note:

1. **Specific impulse is the most important single measure of rocket engine performance**
2. **The unit of specific impulse, (specific thrust), "seconds" (not time, but an abbreviation of the dimension lb-s/lb; lb/(lb/s)).**

Background – Performance Parameters of a LRE

- **Specific impulse, *Isp***

  $$Isp = F/\dot{W}$$

- **The ideal delta-v**

  $$\Delta V = g \times Is \times In(R)$$

  Where the mass ratio, R is defined as

  R = Initial vehicle total gross weight/burnout weight

  E.g. the velocity required to maintain a circular orbit at an altitude of 100 n. mi. is about 25,600 ft/s;

- **The effective exhaust velocity c, characteristic velocity c* and thrust coefficient C_f**

  $$(Isp)_{tc} = c/g, \qquad c = c^* C_f$$

  "cee-star" is used to rate the propellant combustion performance. The thrust coefficient C_f is a **dimensionless** parameter used to measure the gas expansion performance through **the nozzle**.

Rocket Propulsion Fundamentals

- Based upon ideal nozzle performance and ideal 1-D isentropic relation for the nozzle, for ideal thrust equation,

Thrust F= f(throat area, A_t, nozzle inlet pressure, p_1, pressure ratio across the nozzle, p_1/p_2, specific heat ratio, k,),

- Define the thrust coefficient, C_F

$$F=C_F A_t p_1$$

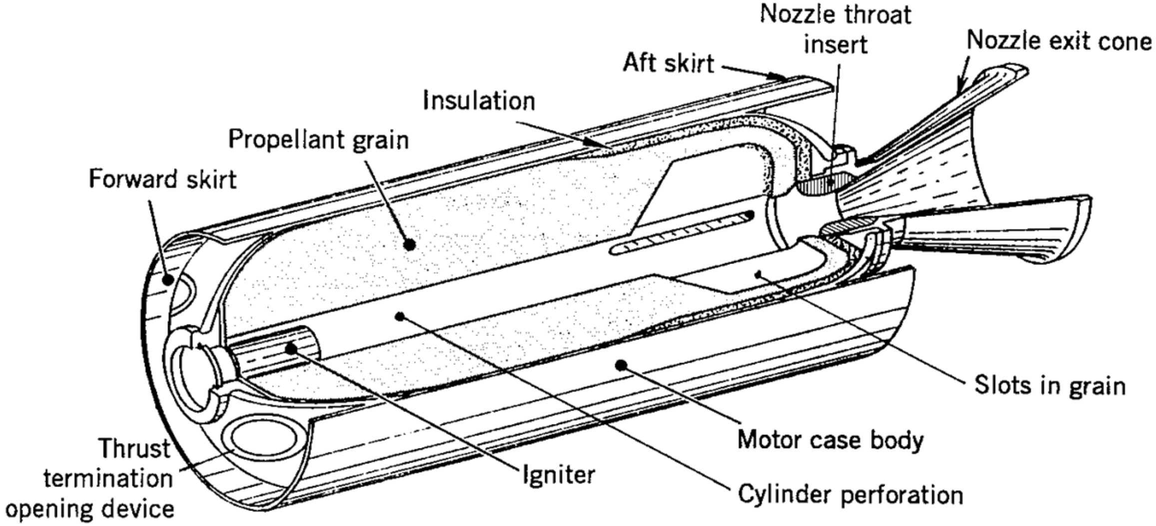
- The *Characteristic exhaust velocity* c^*, is frequently used in the rocket design and performance, and it is defined as

$$c^*= c/C_F = (I_{sp} g/C_F)=(p_1 A_t/m_e)$$

c^* is used primarily with chemical rocket design. It is usually a figure of merit of the propellant combination and combustion chamber design and is independent of the nozzle characteristics. It can be determined theoretically from properties of hot gases and in good agreement with experiment and has been generally used in design calculation.


Launch Vehicle Selection

- **Solid vs. Liquid Propellant**
  - ***Solid Propellant rocket***
    - Major components of solid rocket: propellant grain, igniter, combustion cylinder, nozzle.

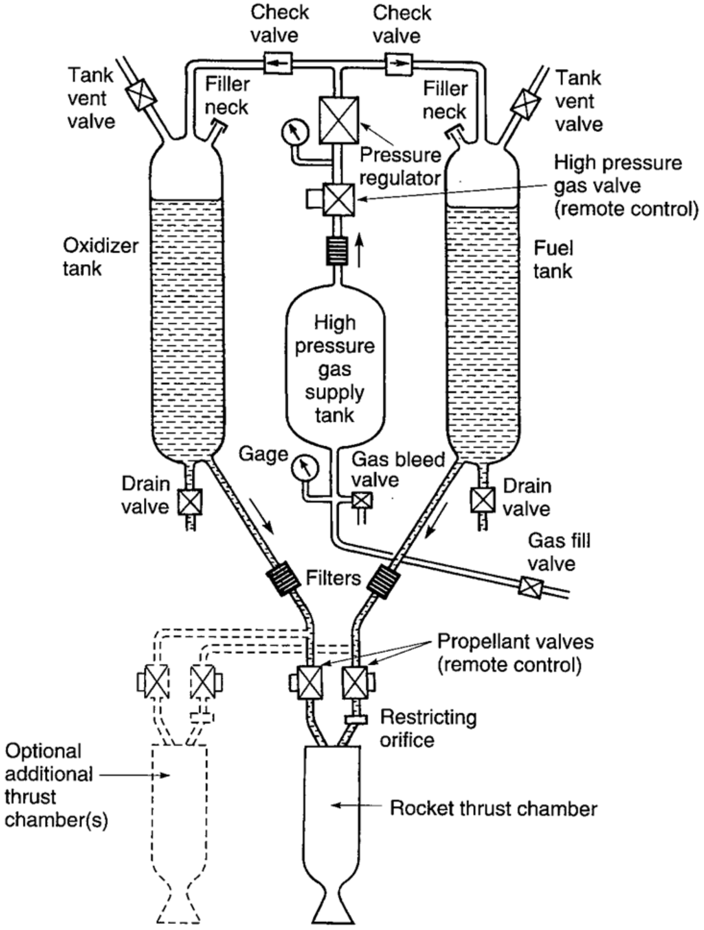


Launch Vehicle Selection

- Advantages and disadvantages – solid propellants
  - Advantages:
    - High reliability, no moving parts
    - High mass fraction
    - Simple and easy to operate
    - No leakage problem
    - Long storage period
    - Reduced size and drag
  - Disadvantages:
    - Low propellant energy and short burning period
    - Not adjustable for thrust level, burning period and restart
    - May degrade due to long period of storage
    - Need insulation coating for combustor and nozzle
    - Produce toxic exhaust

Launch Vehicle Selection

- *Liquid propellant rockets*
  - Major components:
    - Combustion Chamber
    - Igniter,
    - Nozzle,
    - Propellant storage tanks and feed system (including: valves, throttle and flow controling devices etc.)



Launch Vehicle Selection

- Advantages and disadvantages – liquid propellants
  - Advantages:
    - High specific impulse
    - Better thrust control, including throttling, restart capability and thrust termination
    - Reusable parts
    - Non-toxic exhaust
    - Multiple burns configuration
    - Reduced launch accident and failure
  - Disadvantages:
    - Complicated system and low mass fraction
    - Propellant leakage
    - Cryogenic propellant – not storable
    - Sloshing during flight – affects flight stability

Launch Vehicle Selection

– ***Selection considerations***

- Solid rockets are useful
  - for high thrust, compact package in a single burn requirements – First stage propulsion.
  - also for reliable, ease of integration, and simplified ground operational requirements – for apogee and perigee "kick motor" for Earth-orbiting spacecrafts.
- Liquid rockets are useful
  - For accurate throttling requirements – such as planetary landers and ascent propulsion systems.
- Selection of solid, liquid or combination is a design issue with no single "correct" resolution.
- Design cares should be exercised for possible mechanical failures due to advanced design, such as thrust variations and thrust vector control for solid rockets and deep throttling for liquid rockets.

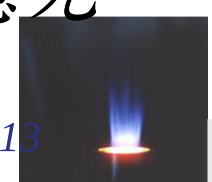
再用型載具發展

- *1969年人類登陸月球後，因耗資龐大的農神五型火箭僅可用於一次推送太空船任務，構思設計可重複使用的發射載具。*
- *1972年美國正式開始進行太空梭計畫，1981年由『哥倫比亞號』進行第一次飛行。*
- *太空梭計畫的目的是發展可重複使用100次以上的太空船（軌道船100次，主引擎55次，固體火箭25次），每次使用僅需二～四週的修復作業，即可再執行任務。*

Prof. Y.-C. Chao

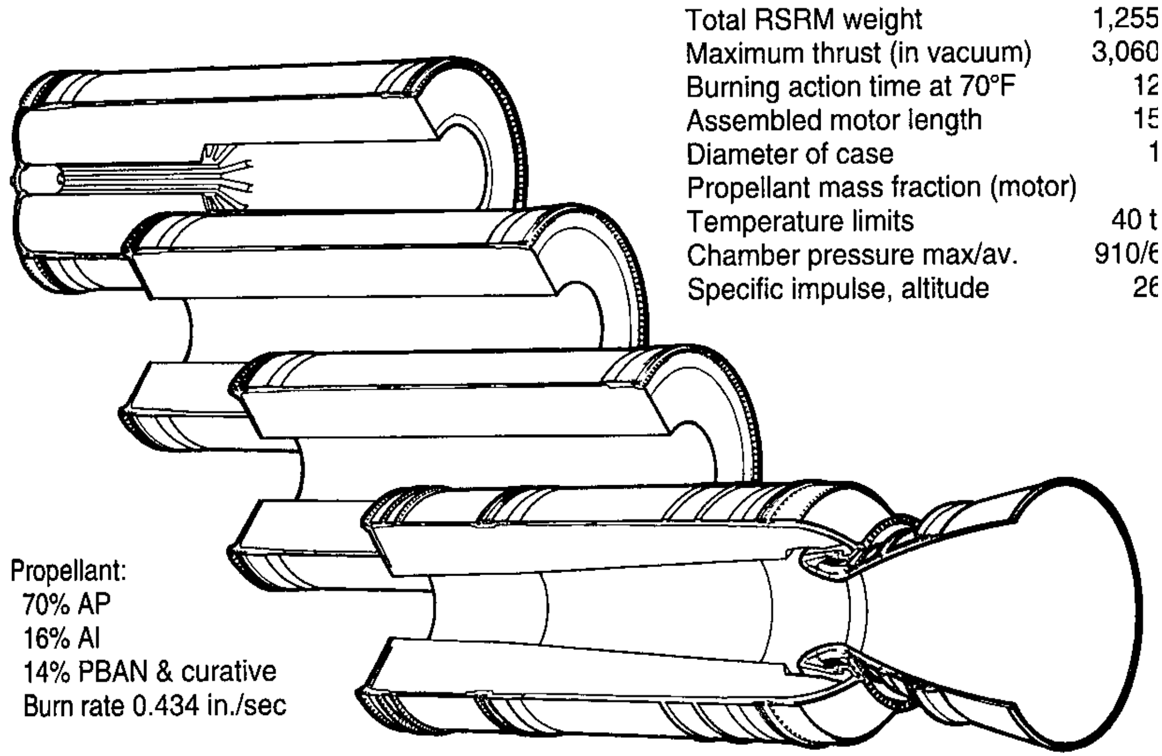
再用型載具發展 -1

- *太空梭*的設計是結合*發射載具*、*太空船及滑翔機*為一體，*垂直起飛水平降落*：
  - 軌道船：一個具有三角翼的載人飛機
  - 加力器：兩具固體火箭助推器
  - 外部燃料箱：儲存主引擎的液體推進劑（液態氧及液態氫）。
- *太空梭的建造：*
  - 企業號（1976）、哥倫比亞號（1981）、挑戰者號（1982）、發現號（1983）、亞特蘭提斯號（1985）及努力號（1991）。
- *太空梭屬於第一代的再用型載具。估計每次發射須動員3000人，經費約美金5億元*



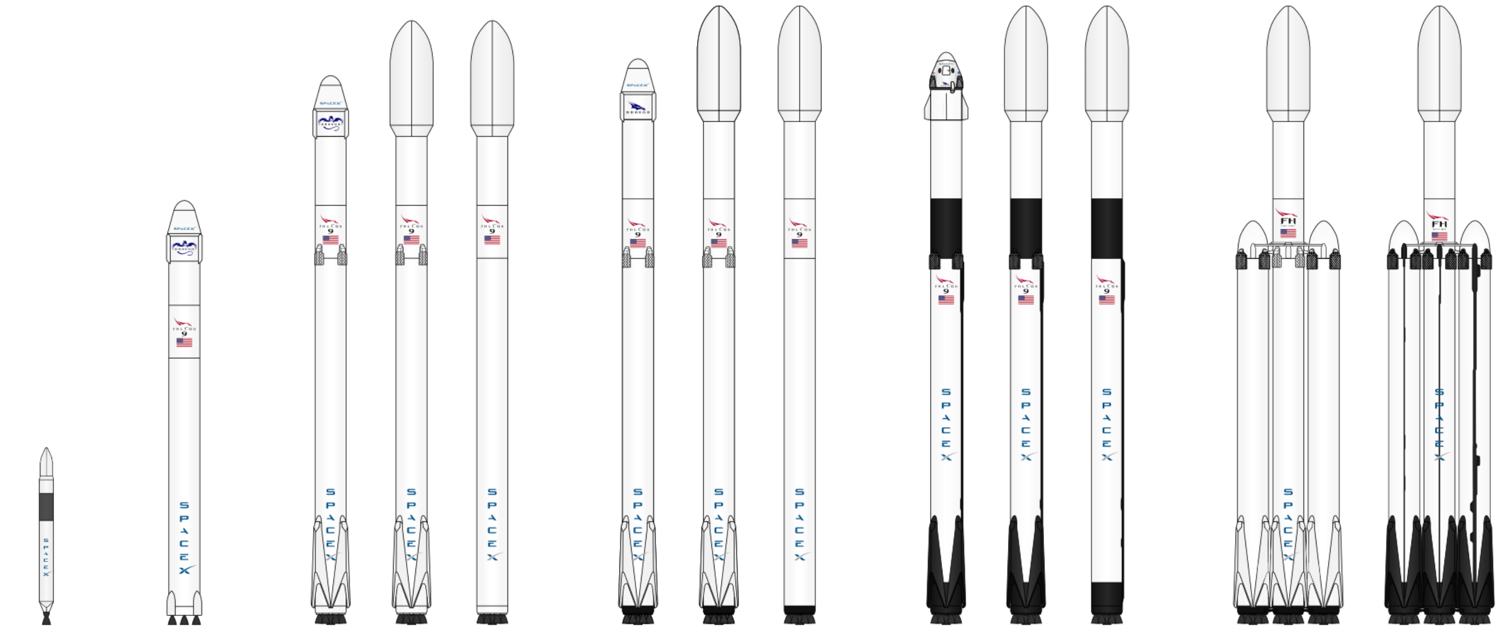
太空梭加力器

- 藥柱分為四段，使用前在發射現場組裝結合。
- 藥柱燃畢後，點燃前、後端的各四個小型分離火箭，與外部燃料槽分離。
- 海上回收時，先堵住噴嘴利於漂浮，並保護燃燒室內部，拖回港口拆解清洗。



- 總重：570公噸，藥重：502公噸。藥重比：0.88

Space X 獵鷹號可回收火箭系列

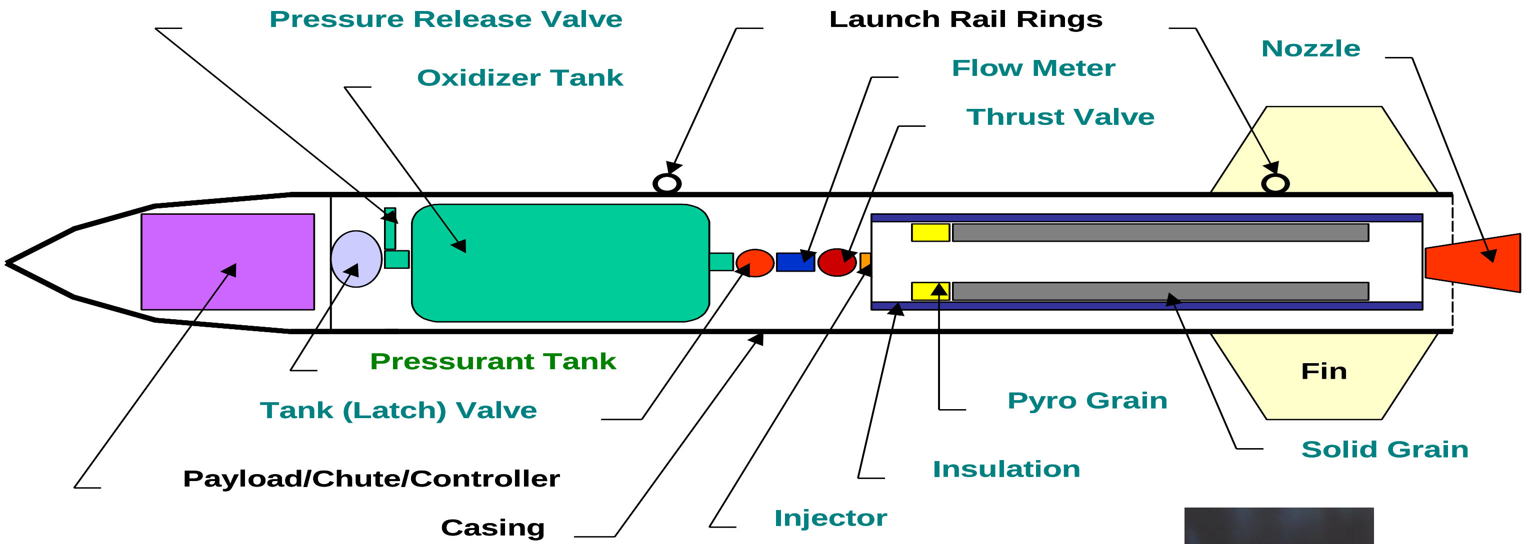


從左至右分別為獵鷹1號火箭、獵鷹9號火箭1.0版、獵鷹9號火箭1.1版的三個版本、獵鷹9號運載火箭全推力版的三個版本、獵鷹9號Block 5的三個版本以及獵鷹重型火箭的兩個版本

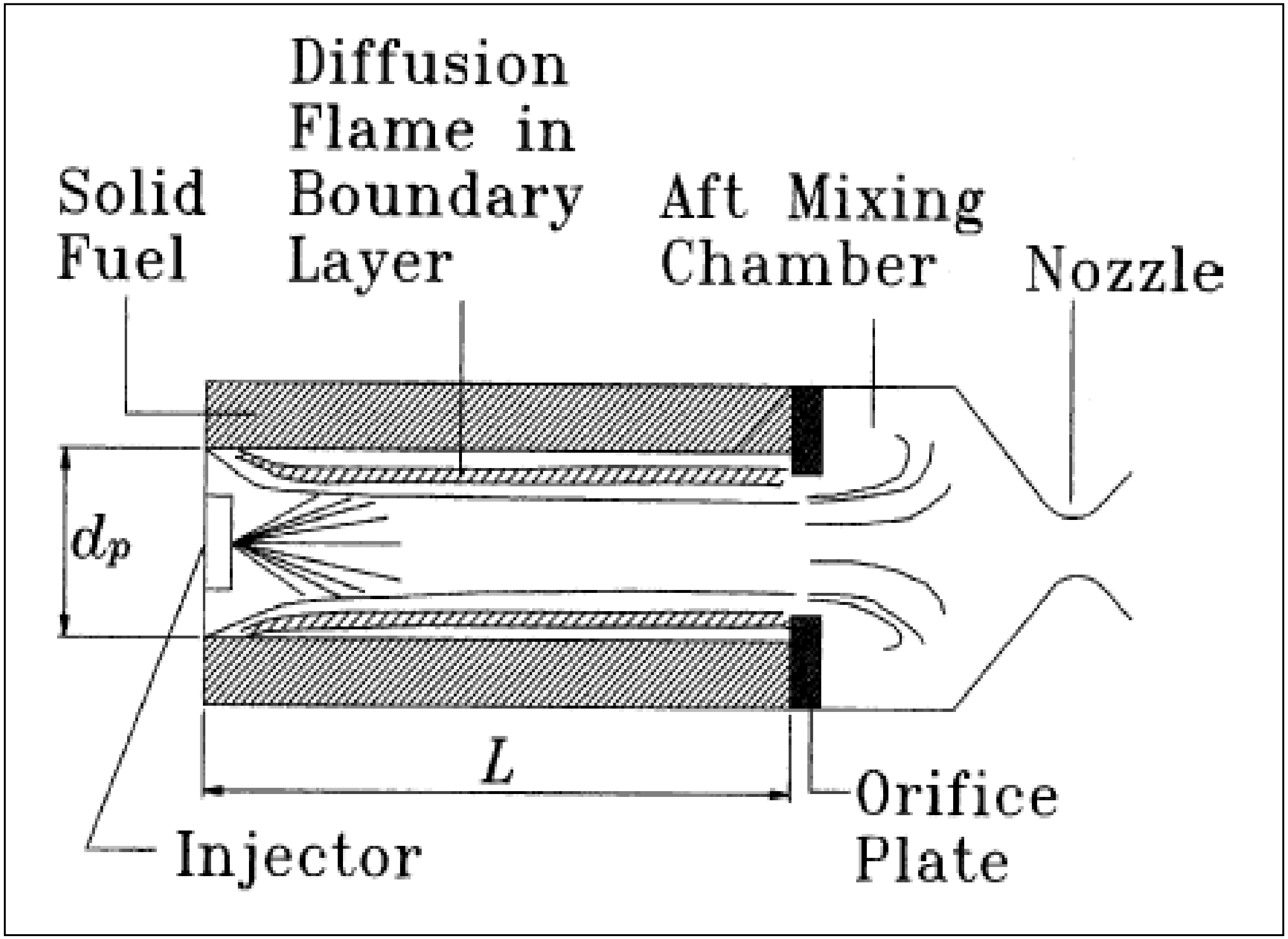
Introduction of Hybrid Rocket

❑ The characteristic of the hybrid propellant system

- It can be assumed the solid propellant carrying liquid oxidizer.
- It possesses high safety and controllability characteristics.
- The fuel and the oxidizer are stored separately, so the thrust can be controlled by the flow rate of the oxidizer. Even the rocket can be shutdown and restart.



Fundamentals



Schematics of hybrid rocket configuration

Specific Advantages of Hybrid Rockets

1. *Improved Safety, High Reliability and Minimal Environmental Impact*
2. *Simplified Throttling and Shutdown*
3. *Propellant Versatility*
4. *Greater Operability and Reduced Servicing Requirements*
5. *Relatively Low System Cost*
6. *High Propulsion Performance*

Specific Disadvantages of Hybrid Rockets

1. Combustion efficiencies of hybrid rockets (typically 93–98%)
2. The density impulse of hybrid rockets is usually lower than that of solid propellant rockets
3. The regression rates of commonly used solid fuels in classical hybrids are relatively low in comparison with solid propellants
4. Some fuel "slivers" could remain in the combustion chamber the effective solid-fuel mass fraction is slightly reduced in the hybrid motor.
5. Oxidizer-to-fuel mass ratio can vary during hybrid motor operation, resulting in slight variations in specific impulse.
6. The predictive analytical models and numerical codes have not yet reached a highly matured stage

國際探空火箭發展路徑與經驗

◆固態火箭發動機

→輕便與軍事應用支持，技術相對成熟。

→無法重複點火

→危險性高，需專門人員及存放場地。

◆液態火箭發動機

→可控推力，燃燒效率高。

→系統複雜

→需投入大量人力及時間研發相關技術

◆混合火箭發動機

→系統較簡單

→可重複點火

→燃料、氧化劑分開存放，危險性較低適合學術研究。

→傳統燃燒效率不佳，導致比衝(Isp)較低，較適合上層火箭。

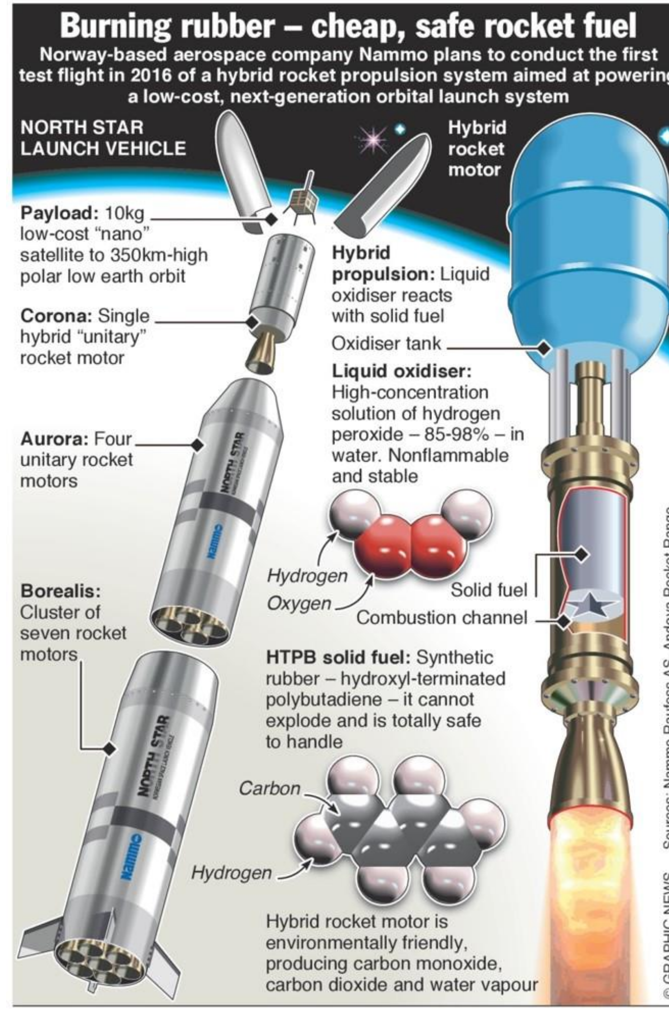


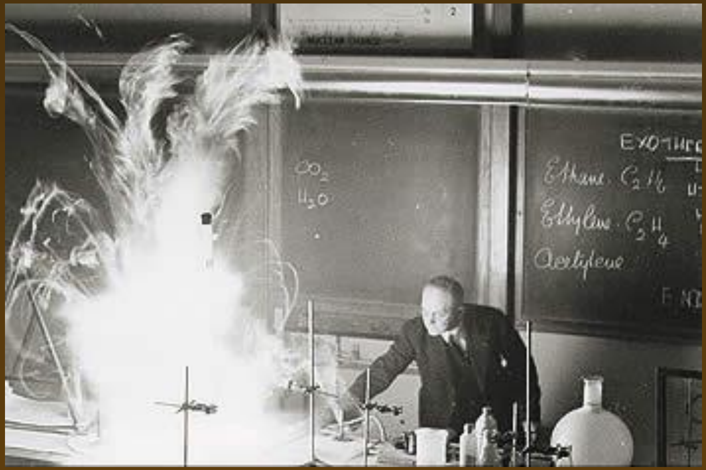
Table 1 Performance of hybrid propellants, $Pc = 500$ psia and $Pe = 14.7$ psia

Fuel	Oxidizer	Optimum O/F	Sea level I_{sp}, s	c^*, ft/s
HTPB	LOX	1.9	280	5972
PMM($C_5H_8O_2$)	LOX	1.5	259	5449
HTPB	N_2O	7.1	247	5264
HTPB	N_2O_4	3.5	258	5456
HTPB	RFNA	4.3	247	5219
HTPB	FLOX(OF_2)	3.3	314	6701
Li/LiH/HTPB	FLOX(OF_2)	2.8	326	6950
PE	LOX	2.5	279	5877
PE	N_2O	8.0	247	5248
Paraffin	LOX	2.5	281	5920
Paraffin	N_2O	8.0	248	5268
Paraffin	N_2O_4	4.0	259	5469
HTPB/Al(40%)	LOX	1.1	274	5766
HTPB/Al(40%)	N_2O	3.5	252	5370
HTPB/Al(40%)	N_2O_4	1.7	261	5509
HTPB/Al(60%)	FLOX(OF_2)	2.5	312	6582
Cellulose ($C_6H_{10}O_5$)	GOX	1.0	247	5159
Carbon	Air	11.3	184	4017
Carbon	LOX	1.9	249	5245
Carbon	N_2O	6.3	236	4992
		Cryogenic hybrids		
Pentane(s)	LOX	2.7	279	5870
CH_4(s)	LOX	3.0	291	6140
CH_4(s)/Be(36%)	LOX	1.3	306	6292
NH_3(s)/Be(26%)	LOX	0.47	307	6452
		Reverse hybrids		
JP-4	AN	17.0	216	4651
JP-4	AP	9.1	235	5007
JP-4	NP	3.6	259	5476

Fig. 3 High energy upper stage hybrid-fuel: Li/LiH/PBAN oxidizer: F_2/O_2.

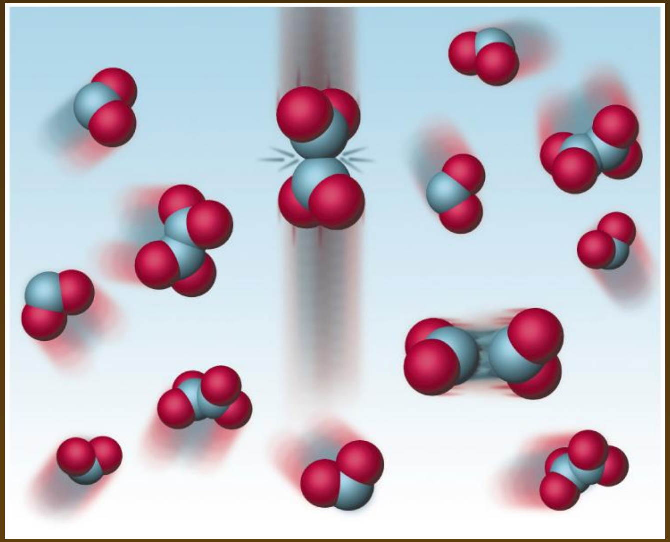
Criteria for oxidizer selection

- Performance
  - Isp
- Economic factors
  - availability, cost, logistics
- Hazards
  - Corrosion
    - Nitrogen tetroxide, hydrogen peroxide, fluorine
  - Explosion hazard
    - Often in the presence of impurities: hydrogen peroxide, liquid oxygen
  - Fire hazard
    - Vigorous reaction with many compounds: nitric acid, fluorine, etc
  - Health hazards
    - Toxicity, carcinogenity



ignition of cotton wool soaked in liquid oxygen

Desirable oxidizer properties



dynamic equilibrium between N2O4 and NO2

- Low freezing point
- High density
- Stability and storability
- Heat transfer properties
  - For regenerative cooling:
    - high specific heat,
    - high thermal conductivity
    - high boiling/decomposition temperature
- Pumping properties
  - Low vapor pressure and low viscosity are desirable
- Small temperature effects
  - E.g. density as function of temperature
- Ignition, combustion and flame properties

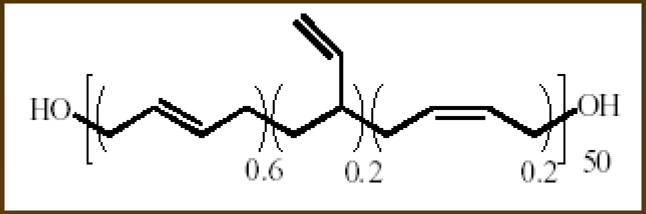
Criteria for fuel selection

- Performance
  - Isp
- Economic factors
  - availability, cost, logistics
- Processing
  - Thermoplastic, curable polymers
  - Viscosity, reactivity
- Hazards
  - Explosion hazard
    - In case of a gas generator hybrid
  - Fire hazard
  - Health hazards
    - Toxicity, carcinogenity (mostly of the curative)

double-planetary mixer for fuel mixing

Desirable fuel properties

- High density
- Stability and storability
- High regression rate
  - Also sensitivity to Gox, P, etc.
- Good mechanical properties
- Hypergolic ignition (if desired)



Hydroxyl terminated polybutadiene

Hybrid rocket motor firing

Oxidizer overview (AIAA-92-3592)

Properties of Common Hybrid Oxidizers

Oxidizer	Normal Boiling Point (°F)	Normal Operating Temperature (°F)	Density at Operating Point (lbm/ft3)	Heat of Formation[a] (cal/mole)
LO_2	-297	-297	71.0	-2,896
N_2O_4	70	70	90.5	-4,676
IRFNA[b]	148	70	102	-43,400
WFNA[c]	181	70	93.6	-41,404
85% H_2O_2	302	70	86.1	-50,642
N_2O	-128	70	49.0	19,608
LF_2	-307	-307	93.6	-3,056
FLOX	-307	-307	77.1	-3,024
LNF_3	-201	-201	96.7	-31,700

a. At Normal Operating Conditions

b. Contains 55% HNO3, 44%N2O4, 0.5% H2O, 0.7% HF

c. Contains 96.8 HNO3, 0.5% NO2, 2% H2O

CESARONI
TECHNOLOGY
INCORPORATED

Oxidizer handling and storage (AIAA-92-3592)

Oxidizer	Thermal Stability	Handling Hazard	Storability	Materials Compatibility
LO_2	Good	Good	Cryogenic	Al., stainless steel, nickel alloys, copper, Teflon, Kel-F
N_2O_4	Decomp above 70°F	Very toxic, hazardous skin contact	Good, should be kept anhydrous	Al., stainless steel, nickel alloy, Teflon
IRFNA	Good	Very toxic, hazardous skin contact	Corrosive	Al., stainless steel, Teflon, Kel-F, polyethylene
HNO_3	Good	Toxic, hazardous skin contact	Corrosive	Al., stainless steel, Teflon, Kel-F, polyethylene
85% H_2O_2	Decomp above 285°F	Hazardous skin contact	Deteriorates @ 1% /yr	Al., stainless steel, Teflon, Kel-F, polyethylene
N_2O	Decomp above 400°F	Good	Good	Al., stainless steel, Teflon, Kel-F, polyethylene
LF_2	Good	Toxic, reactive with many metals	Cryogenic	Aluminum, stainless steel, nickel alloys, brass
FLOX	Good	Toxic, less reactive	Cryogenic	Aluminum, stainless steel, nickel alloys, brass
LNF_3	Good	Toxic	Cryogenic	Aluminum, stainless steel, nickel alloys, brass

CESARONI
TECHNOLOGY
INCORPORATED

Propellant cost (AIAA-92-3592)

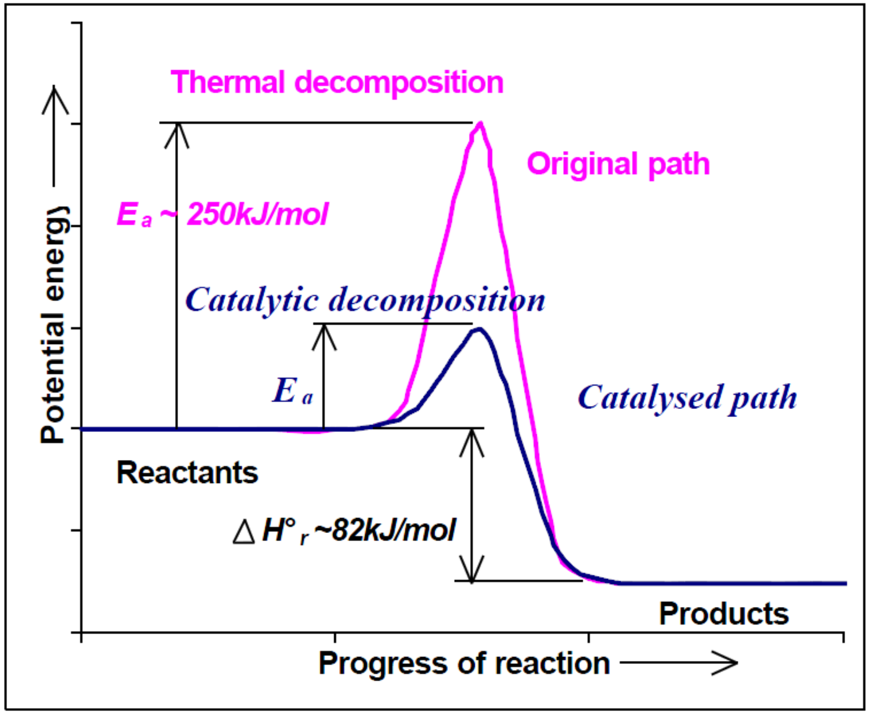
Fuel	Oxidizer	Average Propellant Cost ($/lb)[a]	Facility Costs	Oxidizer Storage and Feed System	Operations
HTPB	LO_2	0.47	Low	Low	Low
	N_2O_4	3.08	Low	Medium	Medium
	N_2O	0.74	Low	Low	Low
HTPB/20% Al	LO_2	0.55	High	Low	Low
	N_2O_4	2.84	High	Medium	Medium
	N_2O	0.76	High	Low	Low
HTPB/40%Li/ 15%LiH	FLOx	3.26	Medium	High	High

a. Based on the O/F ratios of Table 4

氧化亞氮分解反應特性

- 分解反應式：

  $N_2O_{(g)} \rightarrow N_{2(g)} + \frac{1}{2}O_{2(g)}$ + Heat
- 產物：36.3%O_2 + 63.7%N_2
- 絕熱火焰溫度：1640 °C
- 熱分解起始溫度：520 °C
- 自維持熱分解：1000 °C
- 需藉由觸媒降低分解所需活化能



氧化亞氮分解用觸媒研製

44th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit
21 - 23 July 2008, Hartford, CT

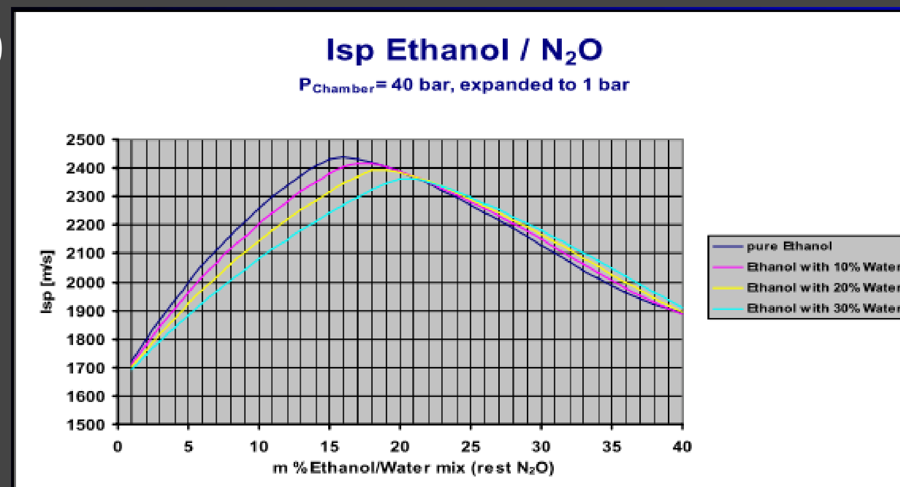
AIAA 2008-4830

Handling Considerations of Nitrous Oxide in Hybrid Rocket Motor Testing

Zachary Thicksten[1], Frank Macklin[2], and John Campbell[3]
SpaceDev Inc., Poway, CA, 92064, USA

Is nitrous oxide safe?

- Good availability (Car-Tuning, Gas-vendors)
- Self pressurizing (Vapor pressure at 20 °C is ~50.1 bar)
- Nontoxic, low reactivity rel. safe handling (General safe ???)
- Additional energy from decomposition (as a monopropellant: ISP of 170 s)
- Specific impulse doesn't change much with O/F



- Unnecessary high pressures. Only storable in high pressure bottles or under sub cooled conditions. Draining and reuse normally not applicable: Wasted propellant
- Low density (Liquid phase: 750 kg/m 3 at 20 °C), lousy density-ISP
- Expensive (>20x as much as LOX)
- Strong dependency of pressure from temperature (At a hot day is can even be supercritical)
- N2O is a strong greenhouse gas
- Mass flow difficult to measure (2-phase flow)
- Rel. high mass fraction in the residual gas phase (after depleting the liquid) which is often of low usefulness
- N2O is a monopropellant (as H2O2 or Hydrazine. Risk of runaway reaction)
- Saturated fluid (small pressure- and temperature changes → boiling → cavitation → imploding bubbles)

Incidents

Explosion at Scaled Composites (Constructor of the Spaceship 1 & 2)

- 3 persons killed
- Cold flow test of the injector of a hybrid motor (no grain was installed, no combustion test!)
- Heavy burns of the casualties (→ decomposed N_2O, so injuries not only from stored pressure energy in the vessel)
- Trigger still unknown (Oct. 07). Guess: water hammering caused by cavitation combined with organic contamination (So-called "Dieseling")

Incidents 2

Explosion N_2O of a tank truck in Eindhoven NL [1]

- Tank truck with 7.5 metric tons of sub cooled N_2O (rel. low pressure)
- Result of the investigation: A not pre cooled centrifugal pump was running hot and started decomposition of the nitrous oxide. N_2O at > 5.7 bar and a present ignition source can start a runaway reaction [2]. Flashback into the tank.

Incidents 3

Explosion of a N_2O hybrid motor (Flashback) [3]

- To low Δp over the injector ➔ Combustion instabilities ➔ pushing back combustion gases into the nitrous tank.
- Following decomposition of the nitrous oxide
- Movie (Thanks to Troy Prideaux)

Incidents 4

Explosion N_2O/alcohol engine (Flashback) [4]

- Design flaw of the Injector caused a contamination of the N_2O channels with alcohol. „Water hammering“ in the N_2O ignited the mixture and destroyed injector and valves.

Movie (Tanks to Henrik Schulz from DARK)

Potential risks

- N_2O is normally used under saturated condition: 2-phase flow with high potential of water hammering ➔ adiabatic compression of cavitation bubbles ➔ "Dieseling" specially when contaminated with fuel and at combustible surfaces like seals, filling hoses, carbon fiber tanks etc.)

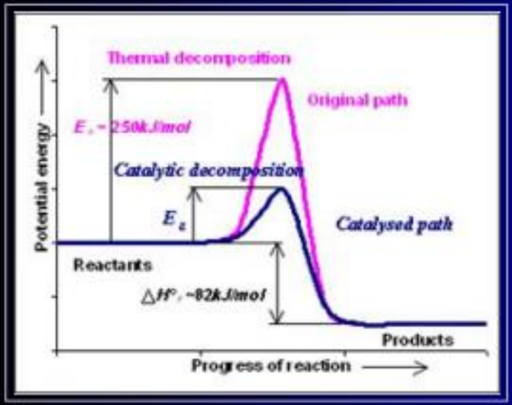
Imploding vapor bubble with jet (up to 100000 bar at the ground of the jet and temperatures of several thousand K !)

$\frac{p_G}{p_N}$ [-]	$P_{i\,max}\left[\frac{N}{mm^2}\right]$	$T_{i\,max}$ [K]
0,1	1,3	610
0,05	7,2	990
0,01	405	3140
0,005	2290	5160

Potential risks 2

N_2O is a monopropellant (as H_2O_2 or Hydrazine)!

- Under certain conditions more energy is produced by the decomposition than necessary to reach the decomposition temperature → run away reaction!
  $N_2O(g) \longrightarrow N_2(g) + \frac{1}{2}O_2(g) + 82$ kJ/mol
- Particularly the vapor phase can lead to a deflagration or even a detonation at pressures > 5.7 bar if a contamination of fuel is present
- Catalysts can lower the critical temperature to 250 °C (E.g. copper and its oxides)



Potential risks 2

- Very good solubility in oil, grease and other hydrocarbons like plastics etc. (That's why it works so well for whipped cream). Also solid plastics like HTPB or fiber reinforced plastics can be saturated when exposed to nitrous oxide for a long period and can then transform to a high explosive.
- According to several sources, electro static discharge during injection into a combustion chamber can occur. Combined with the point above this can lead to an unexpected disassembling of the engine.
- Freezing of valves and venting orifices.
- Unknown Voodoo [5]:

d. Anomalies

One disturbing observation during the gaseous test program was the rather frequent (about 10 percent of the tests) occurrence of unexplained events in two categories, spontaneous ignitions and spontaneous temperature rises. In the first category, sudden temperature and pressure spikes were sometimes observed while N_2O was being vented from the pipe. These anomalies generally occurred at low-pressure conditions where steady-state decomposition cannot be sustained. The other category consisted of unusual increases in pipe wal' temperatures (by 20 to 50°F) during filling operations without any sudden pressure rise or other indication of a decomposition reaction. Both of these anomalies remain unexplained.

Suggestions

- Δp over injector > 10 bar. A screaming hybrid is a sign for combustion instabilities and therefore for a too low Δp.
- Only use the liquid phase
- For hybrids: Do not expose the grain to nitrous oxide for a long period (no saturation of the grain). Venting and dumping not through the combustion chamber
- Electr. ground tanks etc.
- NO combustibles materials for seals, hoses (also filling hose) and tanks (e.g. Fiber reinforced ones without metallic liner). Metals (INOX, Alu), PTFE, PCTFE or some Silicones are ok. Viton, FKM, FPM are chemical compatible but are swelling significantly when exposed to N_2O. Avoid copper alloys. Only use compatible lubricants like CRYTOX. Ask your supplier for chemical and physical compatibility with N_2O!
- Use some kind of deflagration trap (E.g. a big sintered metallic filter) in the feeding lines, burst disks at the tank. Hydro testing the tanks > 100-150 bar.
- Density of N_2O change significantly with temperature. Do not fill the tank completely: 13-15% ullage for a possible temperature increase from 15°C to 25°C [6],[7]

Suggestions

- Remote operated filling and draining. Electrical ground the tanks and filling lines
- Attention after unsuccessful ignition. With N_2O saturated grain or other fuel can be explosive.
- To avoid bubbles and therefore cavitation: Use sub cooled N_2O and pressurize it with N_2 or Helium.
- Use LOX ;-) 
- Let me know if you have other suggestions or you think I am paranoid: bruno.berger@spl.ch

The Handling and Properties of Nitrous Oxide

1. *Health Effects from Inhalation of Nitrous Oxide*
2. *Reactivity*
   a. *It is generally stable in both liquid and gaseous forms at lower temperatures and pressures.*
   b. *Nitrous oxide lines and tanks must be cleaned to insure that no fuels or catalysts are present*
   c. *Nitrous oxide can form explosive mixtures with many common hydrocarbons used as oils and lubricants as well as other fuels.*
   d. *At temperatures exceeding 1200°F (650°C) nitrous oxide can begin to rapidly exothermically decompose at pressures as low as 1 atmosphere without any contamination. =< Thermal runaway!!*
   e. *At pressures above 200psi, and ambient temperatures, it is possible to start a self sustaining reaction in a tank or large diameter pipe with an ignition source.*
   f. *Nitrous Oxide is safest when stored in its pure liquid form at low temperatures and pressures.*
3. *Common Ignition Source*

Design of Nitrous Oxide Systems for Hybrid Rocket Systems

A. *Material Compatibility*
   1. *304 or 316 stainless steel is preferred.*
   2. *Materials such as copper, nickel, platinum, and other common catalysts are avoided because of possible catalytic effects at higher temperatures and pressures.*
   3. *The materials that are compatible with liquid oxygen can be used in nitrous oxide service. However, Checking all materials, such as o-rings, valve seats, etc for nitrous oxide compatibility prior to installation in nitrous oxide service is suggested.*

B. *Electrical Conductivity of Nitrous*

C. *Rust Contamination Issues*

D. *Pumping of Nitrous Oxide*

E. *Pressurization of Nitrous Oxide Tanks*

   1. *The maximum pressurization ramp rate of 20psi per second is limited.*

F. *Warming of Nitrous oxide*

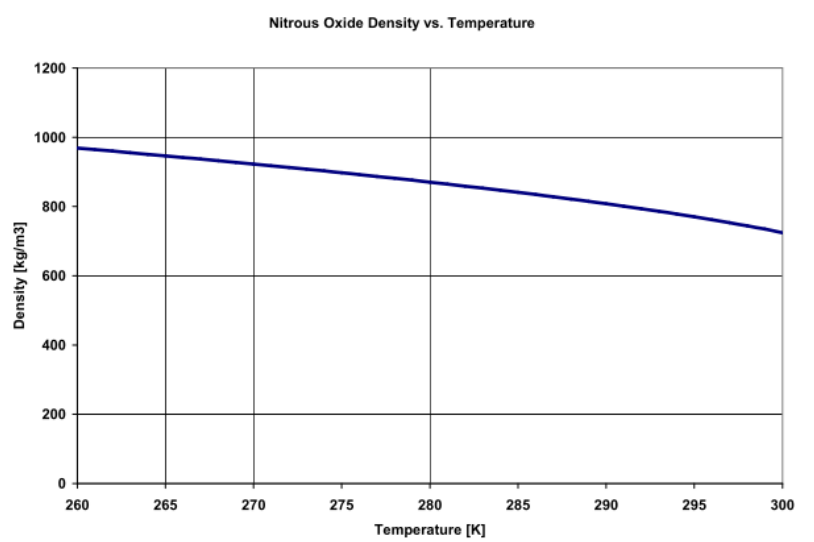


Figure IV-2: Density of Nitrous Oxide as a Function of Temperature at Saturation Conditions[8,9]

Preparation of Components for Nitrous Oxide Service

A. *Cleaning and Handling of Parts*
   1. *Pre-cleaning*
   2. *Deep cleaning*
   3. *De-ionized water rinse*
   4. *Dry with nitrogen*
B. *Inspection of Cleaned Parts*
   1. *Visual*
   2. *Wipe*
   3. *UV Lamp*
C. *Installation or Storage of Cleaned Parts*

過氧化氫（hydrogen peroxide）特性

- 過氧化氫具有高氧化性
- 可經觸媒分解成水加氧氣並放處出大量的熱

$$H_2O_2 \rightarrow H_2O + \frac{1}{2}O_2 \ldots\ldots\ldots\ldots\ldots - \Delta H = 2884KJ/kmole$$

H_2O_2 content %	Adiabatic decomposition temp. °C	% Evaporation of water
50	100	65.5
70	233	100
80	487	100
85	613	100
90	740	100
95	867	100
100	996	100

2.2. Toxicological properties

Effect on the skin

Concentrations of 5 % W/W and above can cause irritation or burns, with the severity increasing with concentration.

Effect on the eyes

Splashes of dilute H_2O_2 in the eyes cause pain. With solutions of 6 % W/W and above severe and permanent damage may occur.

Effect of ingestion

The ingestion of H_2O_2 can cause burning of the mouth, throat, oesophagus and stomach, and internal distension from evolved oxygen. In some instances, ingestion of commercial strengths can be fatal.

Effect of inhalation

Inhalation of H_2O_2 vapours or mists is irritating to the respiratory tract. The occupational exposure limit (TLV) is 1.0 ppm (1.4mg H_2O_2 /m^3 air) for a normal 8 hour/day and 40 hour/week working period.

Decomposition properties

Effect of pH

In alkaline solution, the rate of decomposition increases rapidly as the pH is increased.

Hydrogen peroxide and alkali must never be inadvertently mixed.

Effect of light

Light can cause photochemical decomposition of hydrogen peroxide. The absorption of radiation by hydrogen peroxide solutions occurs over a wide continuous spectrum. Hydrogen peroxide solutions should not therefore be exposed for long periods to light, especially direct unfiltered sunlight.

Effect of heat

Apart from self-heating as a result of decomposition, consideration must be given to the effect of temperature rises caused by outside sources of heat. For purely physico-chemical reasons, the rate of the decomposition reaction in solution (homogeneous) will increase 2 to 3 times for every 10°C increase in temperature, and the rate of the surface decomposition (heterogeneous) will increase 1 to 2 times per 10°C. The effect of increased contamination from dissolution of the surface can of course make the situation worse.

Decomposition properties

Heterogeneous decomposition

Fast decomposition may also occur if the hydrogen peroxide is brought into contact with insoluble solids. This is known as heterogeneous decomposition. Hydrogen peroxide will decompose to some extent on any surface even at ambient temperature, although the rate varies enormously with the nature and state of the surface. Thus, the rate of decomposition on silver is 10^7 times faster than that, for example, on polyethylene, which is one of the common handling materials. Some of the solids which catalyse the decompostion of hydrogen peroxide are the hydroxides and oxides of the heavy metals, as well as the noble metals themselves. The following is a list of the most active catalysts :

Ruthenium oxide	RuO_4	Platinum	Pt
Manganese oxides	Mn_2O_3, MnO_2	Osmium	Os
Iron oxides	FeO, Fe_2O_3	Iridium	Ir
Cobalt oxide	CoO	Palladium	Pd
Nickel oxides	NiO, Ni_2O_3	Rhodium	Rh
Lead oxide and hydroxide	PbO, $Pb(OH)_2$	Silver	Ag
Mercuric oxide	HgO	Gold	Au

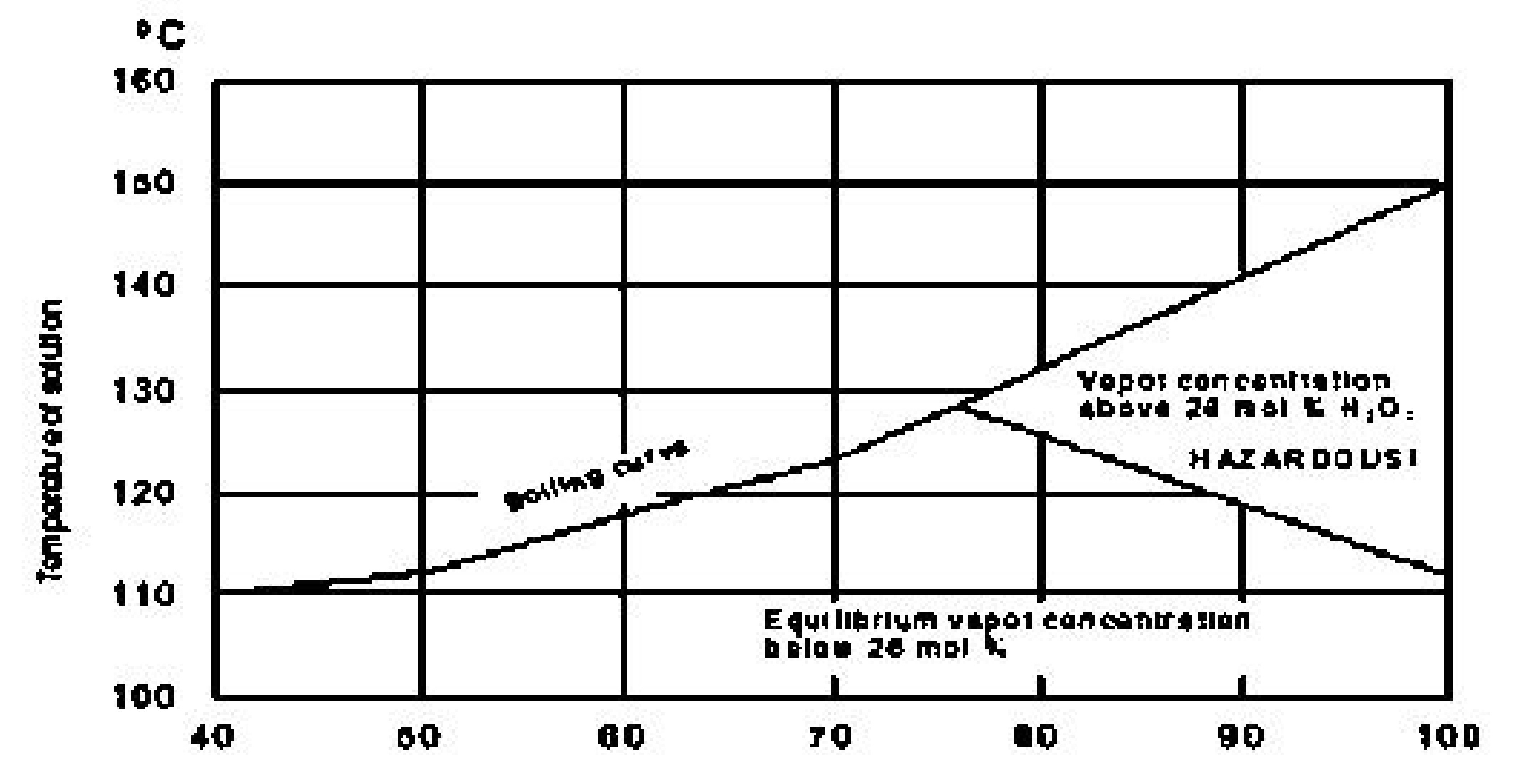
高濃度過氧化氫安全事項

- 操作人員需穿著塑膠防護衣、眼罩，並需在通風良好處避免吸入過氧化氫蒸汽。
- 小型儲存可使用**玻璃**、**PE**、**鋁**、**不銹鋼**、**鐵氟龍**容器；大型儲存大多使用**鋁合金**，並加入穩定劑以減緩過氧化氫分解，且容器需**加裝洩壓閥**。
- 容器及管路需乾淨，可使用**低濃度過氧化氫**或**稀硝酸**清洗。

過氧化氫之純化-----蒸餾法

- 原理：
  - 過氧化氫沸點大於水，加熱過氧化氫溶液則可將雙氧水中之水份蒸發，提高過氧化氫濃度。
- 優點：
  - 效率高
  - 操作容易
- 缺點：
  - 過氧化氫受熱分解
  - 蒸汽爆炸

雙氧水濃度、沸點及爆炸區域對應圖

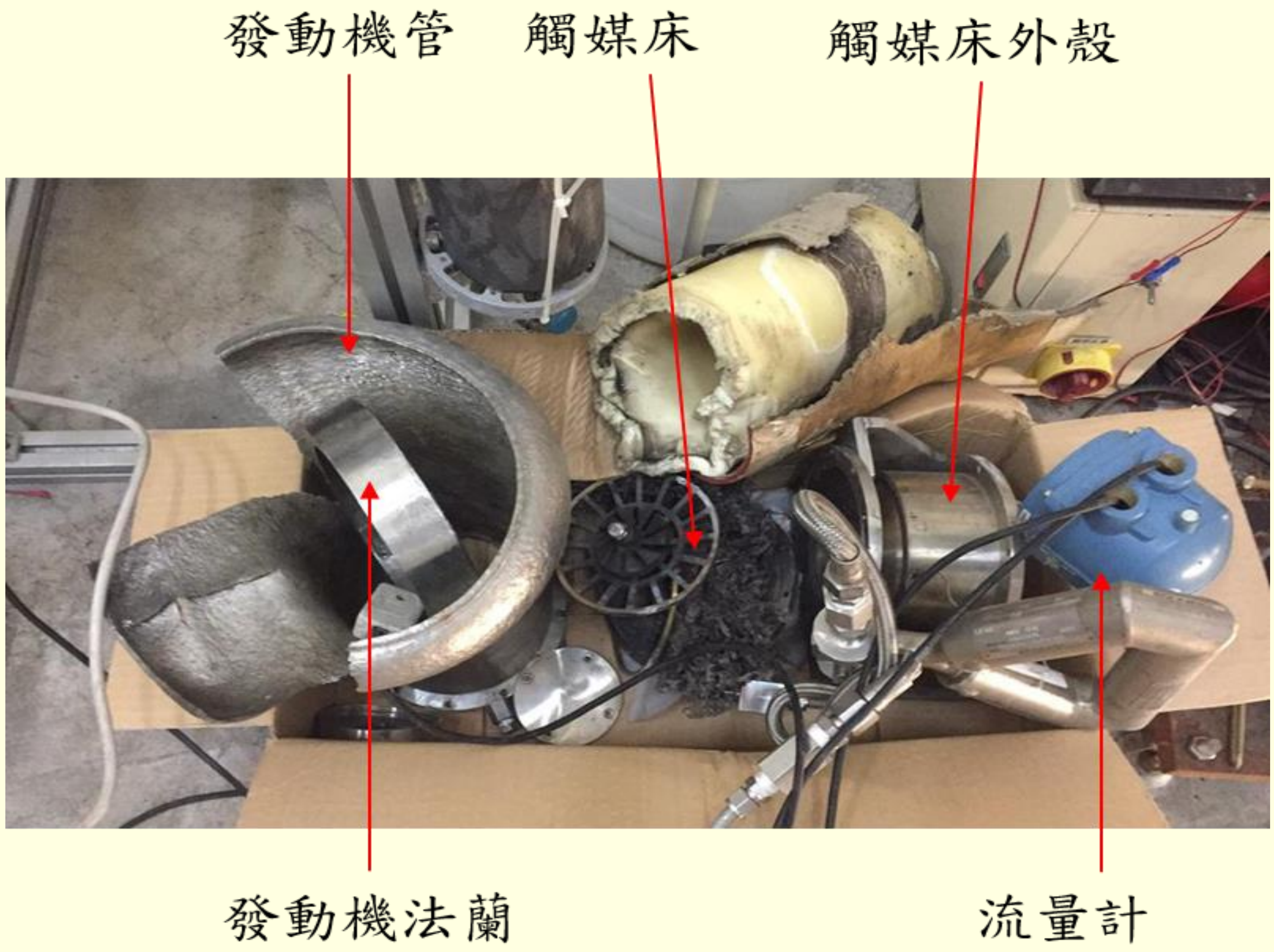


雙氧水純化設備

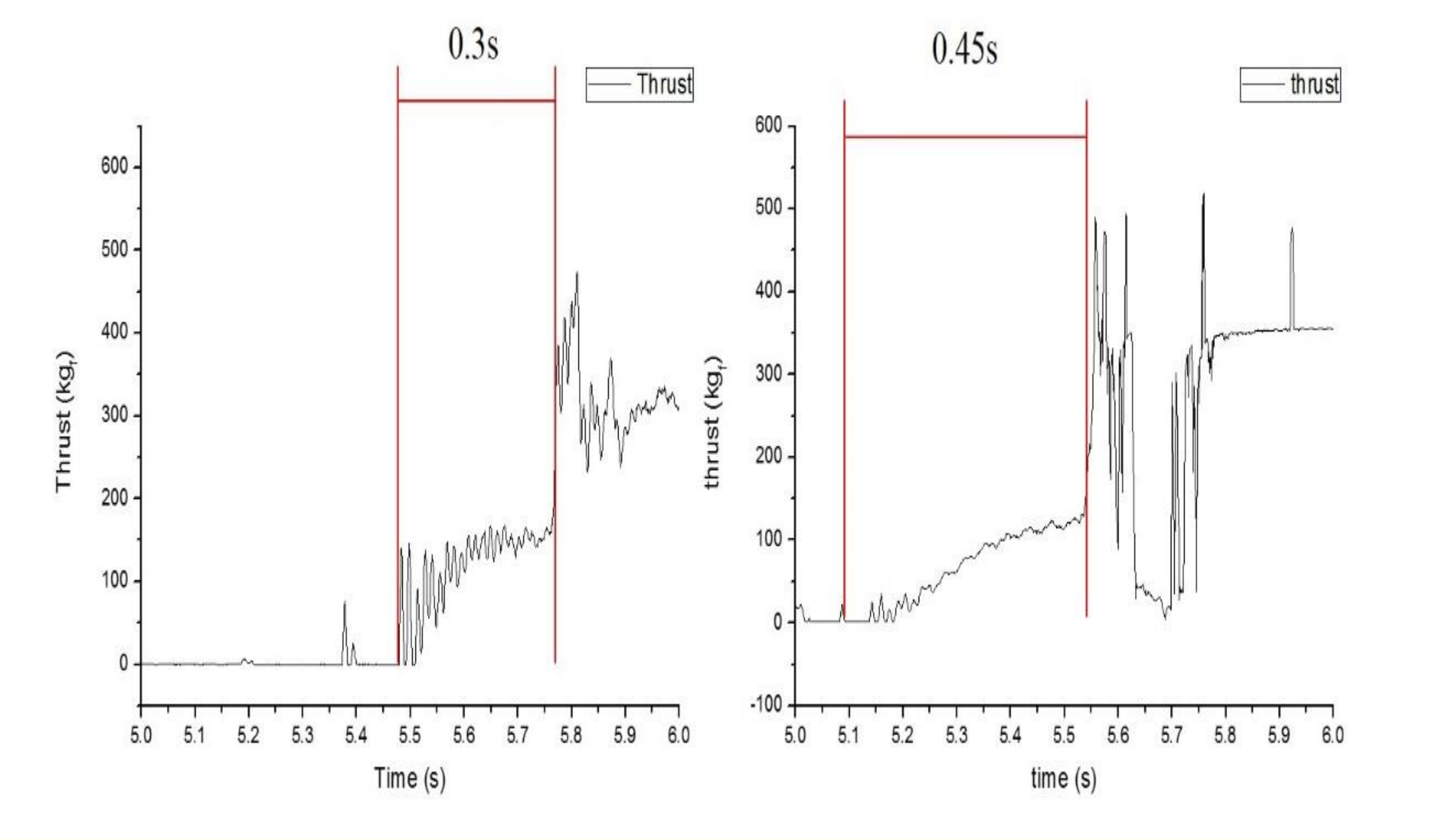
- 旋轉濃縮機
- 恆溫水槽
- 真空泵
- 壓力控制器

Incidents-High Test Peroxide

Incidents-High Test Peroxide



Incidents-High Test Peroxide



簡報結束

Thanks for your attention!!