Suborbital Flights and Spaceports

A feasibility study for a military spaceport

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AAA – Sez. Roma Due “Luigi Broglio”

Agenda

- Origin of the task
- Objective of the task
- Methodology
- Results
- Conclusions
- Way-ahead

Origin of the task

- Sub-orbital flight is becoming a reality
- Effects on several fields: from regulation to air defense
- Italian Air Staff – General Office for Space: a strategy to handle this change
- Military Spaceports to support future sub-orbital systems test flights
- Need for a feasibility study

Objective of the task

- Sub-obj. 1: Analysis of a possible sub-orbital flight profile from/to one of the proposed airbases (Decimomannu AFB, Grazzanise AFB)
- Sub-obj. 2: Risk analysis with respect to the «third party» (on ground)

Methodology (1/4)

- Sub-obj. 1:
  - Identification of a reference flight system (Virgin Galactic)
  - Development of a flight model in a simulated environment
  - Identification of relevant flight phases and relating flight parameters
  - Performance of a typical flight profile and relevant flight parameters recording (v, f_z, H, AoA)

Methodology (2/4)

- Sub-obj. 2:
  - Assumption: only loss and explosion as catastophic events (no FMECA available)
  - A safety target was established: 1E-6 casualty per FH
  - Development of an explosion model using Mod&Sim
  - First part of the analysis: global risk analysis → definition of a population density upper limit
  - Second part of the analysis: specific mission risk analysis → verification of the feasibility of a specific mission

Methodology (3/4)

- Sub-obj. 2 – First Part:
  - For each i-th flight leg:

$$P_{catastr-mission} = \sum_i P_i \times A_i \times DP_i \times T_{\%i} \rightarrow \text{DP}$$

where

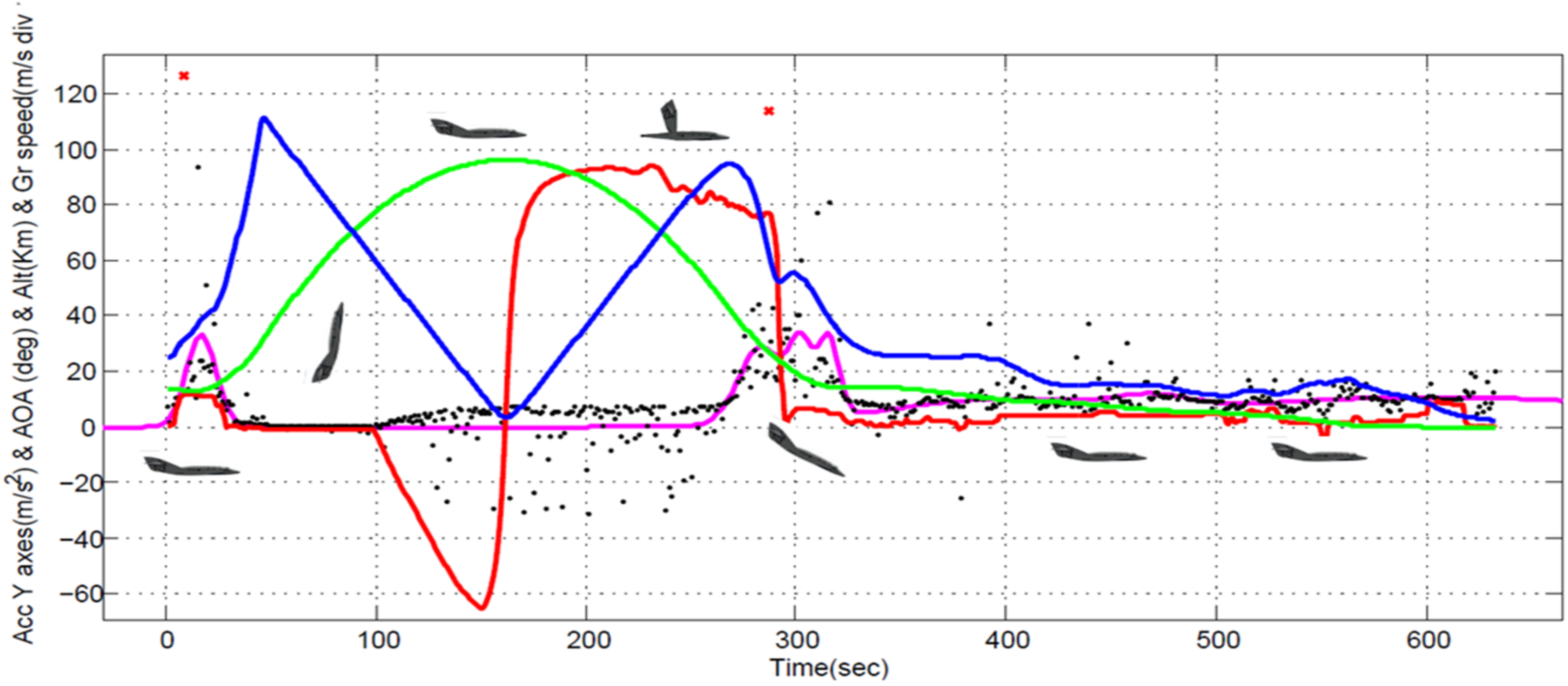
P_i = [1E-6 - 1E-3]
A_i depends on the event and the debris total energy
DP_i is the average population density on the ground
$T_{\%i}$ is the percentage of the mission time to fly the i-th leg

  - Evaluation of the acceptable population density upper limit (DP)

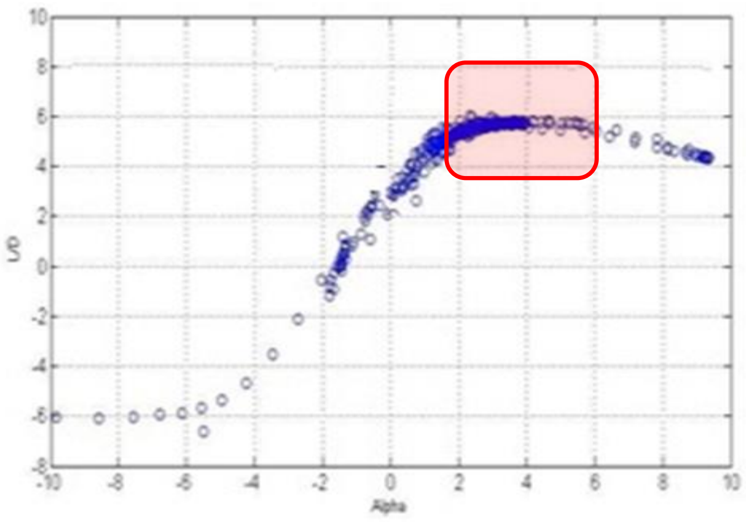
Methodology (4/4)

- Sub-obj. 2 – Second Part:
  - It is not necessary to be always compliant with the DP upper limit determined in the previous part; it is necessary to be compliant with the safety target
  - So, for a specific flight mission, for each i-th leg and for each catastrophic event, the corresponding risk was calculated
  - All contributions were summed up and the cumulative risk was compared to the safety target
  - This evaluation was repeated for each inherent reliability level [1E-6 – 1E-3] until the cumulative risk was below the safety target

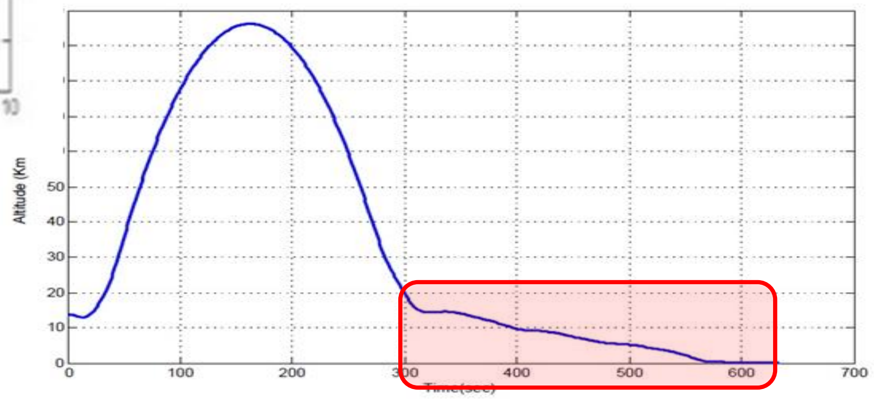
Results – Analysis of a flight profile



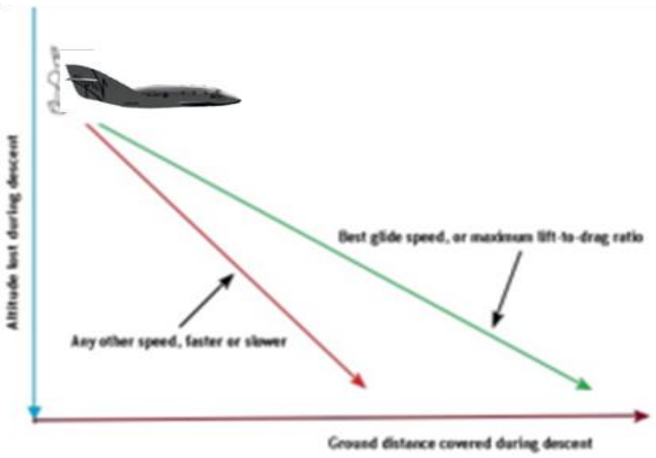
Results – Analysis of a flight profile



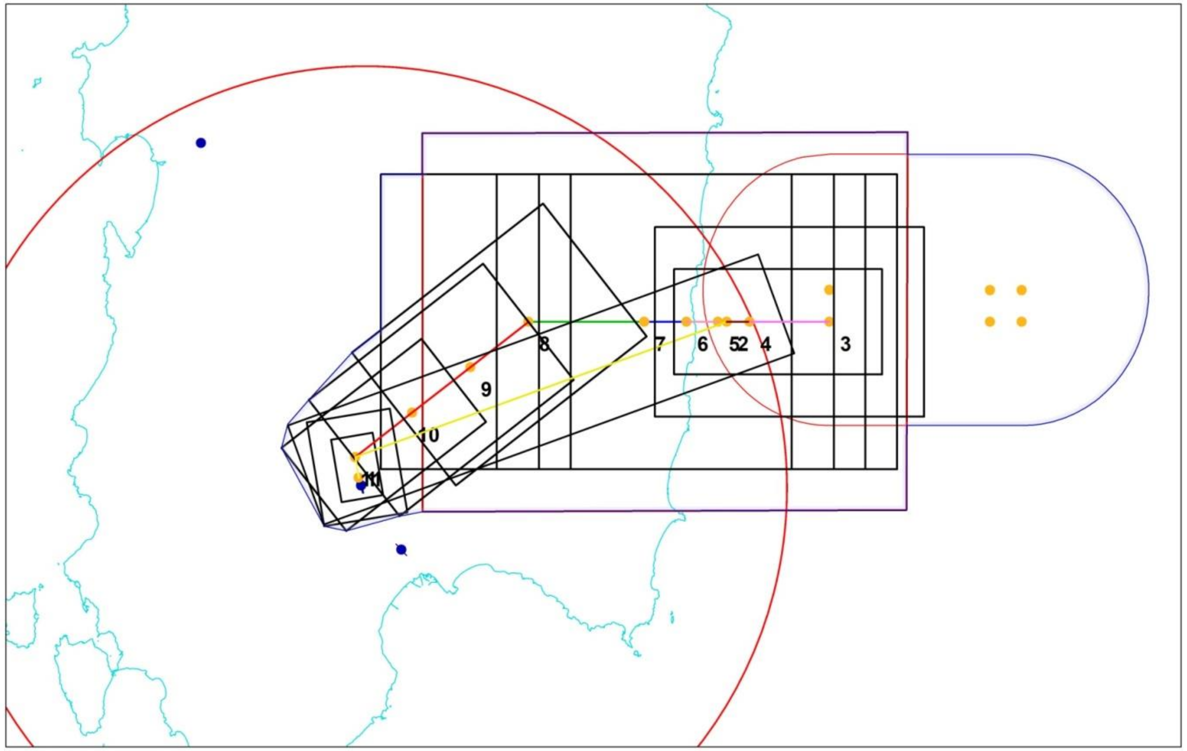
L/D - AoA



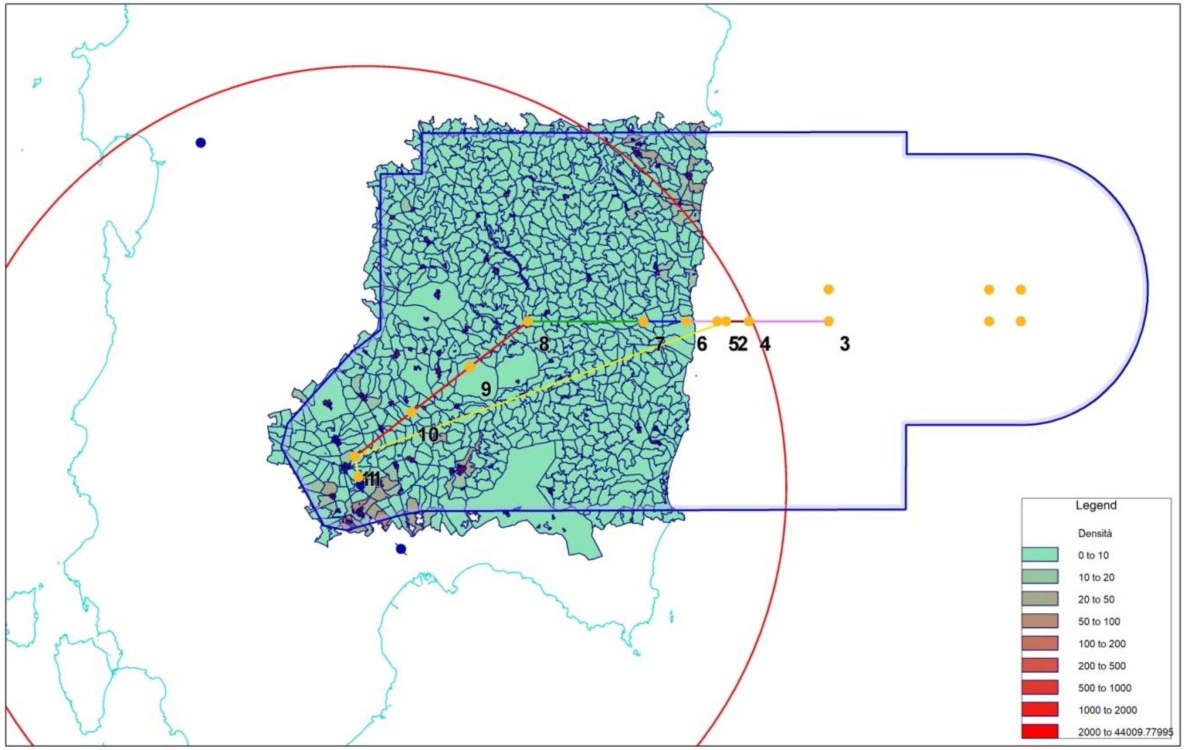
Altitude Profile



Results – Decimomannu AFB



Dati ISTAT 2001
scala 1:500.000



Dati ISTAT 2001
scala 1:500.000

DP_{tot} = 44,1 ab/km^2

Results – Decimomannu AFB

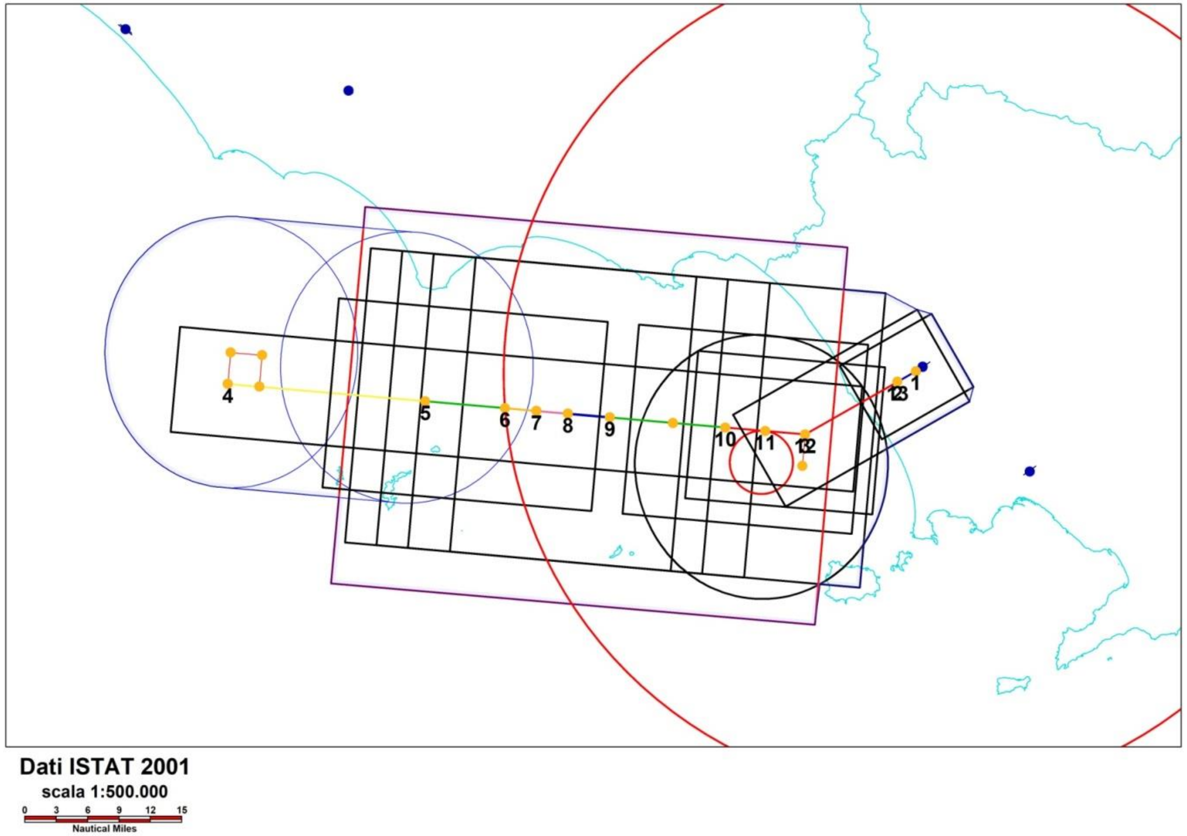
Dati ISTAT 2001
scala 1:500.000
0 3 6 9 12 15
Nautical Miles

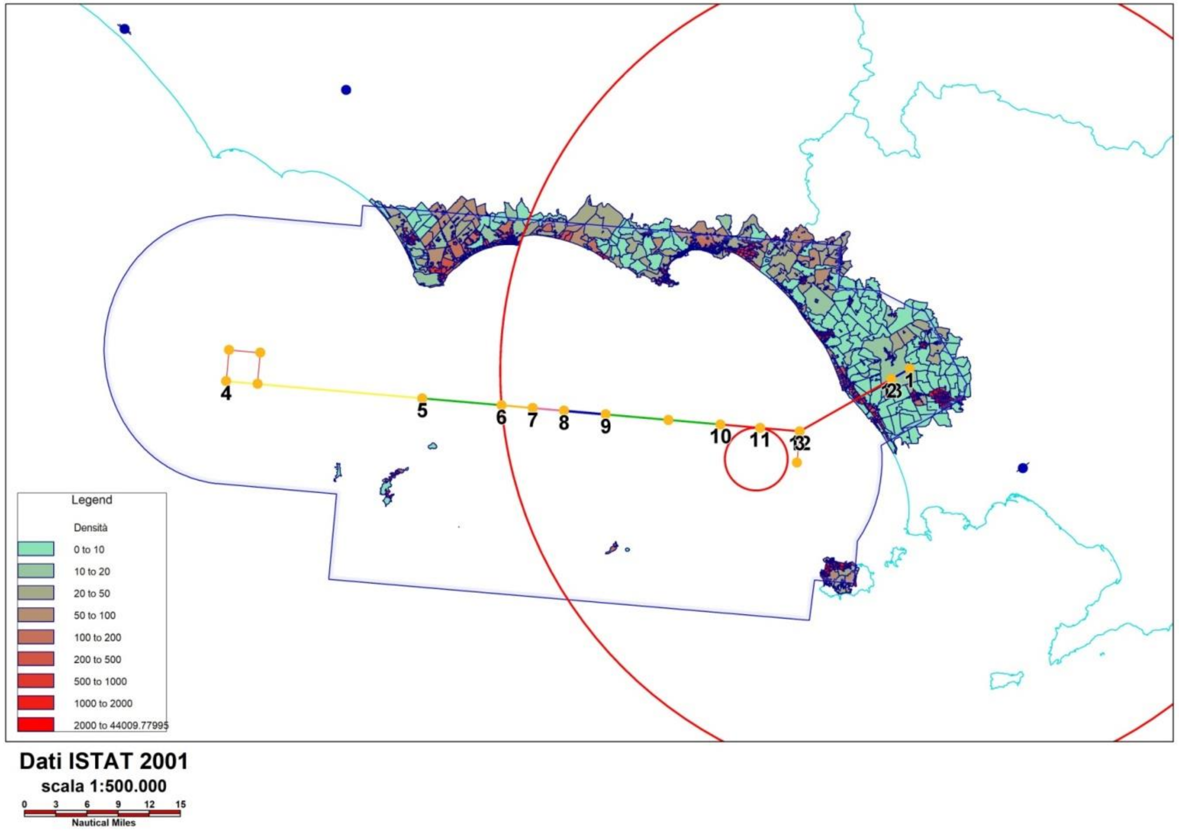
LVL DI RELIABILITY	DPmax [ab./km^2]
1E-6	112,0 – 374,0
1E-5	11,2 - 37,4
1E-4	1,1 - 3,8
1E-3	0,1 - 0,4

Security target: 1,9E-6 – 2,2E-6

LVL Reliability	Pcas,cum
1E-6	1,53E-7 - 4,42E-7
1E-5	1,53E-6 - 4,42E-6
1E-4	1,53E-5 - 4,42E-5
1E-3	1,53E-4 - 4,42E-4

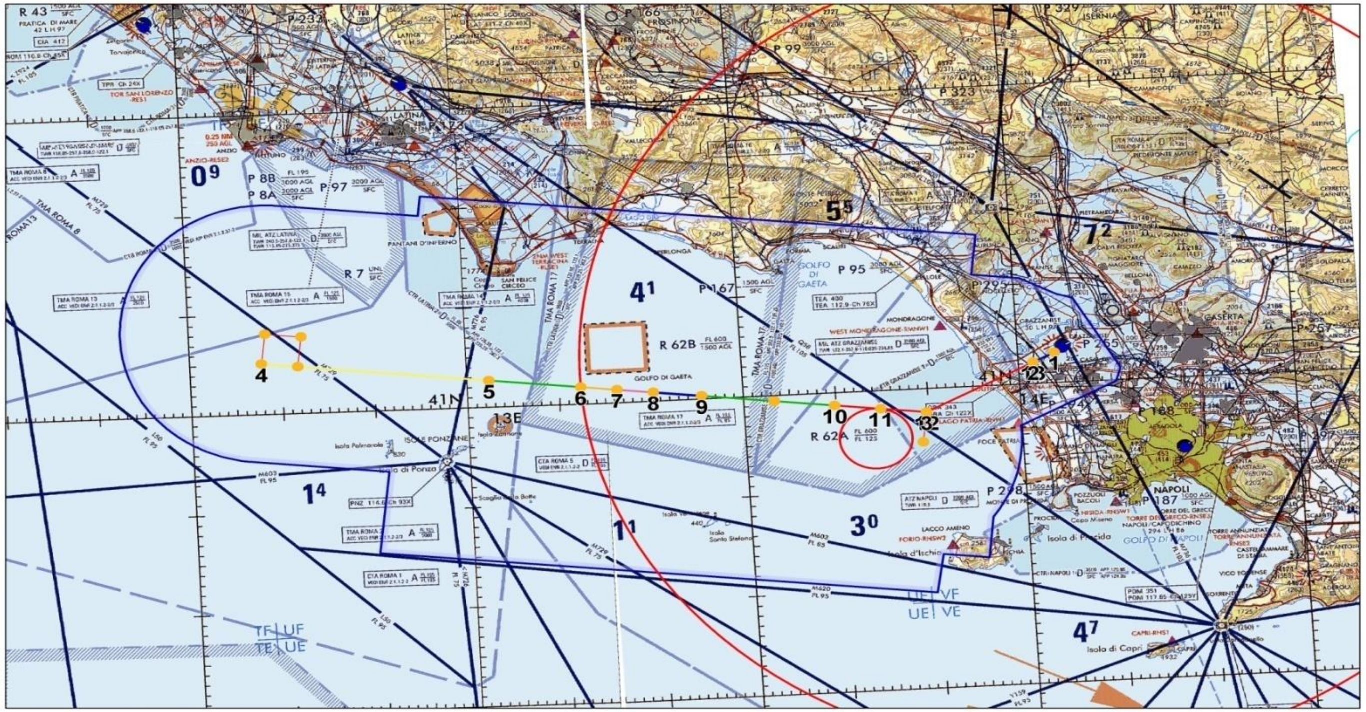
Results – Grazzanise AFB





DP_{tot} = 261,6 ab/km^2

Results – Grazzanise AFB



Dati ISTAT 2001
scala 1:500.000
0 3 6 9 12 15
Nautical Miles

LVL DI RELIABILITY	DPmax [ab./km^2]
1E-6	132,0 – 398,0
1E-5	13,2 - 39,8
1E-4	1,3 – 4,0
1E-3	0,1 - 0,4

Security target: 2,2E-6 – 2,3E-6

LVL Reliability	Pcas,cum
1E-6	1,70E-7 - 4,54E-7
1E-5	1,70E-6 - 4,54E-6
1E-4	1,70E-5 - 4,54E-5
1E-3	1,70E-4 - 4,54E-4

Conclusions

- On the basis of the information available and of the assumptions, the flight parameters determined in a simulated environment confirmed the known charcteristics of each specific flight phase
- Also, within the same limits and assumptions, the preliminary risk analysis demonstrated that a sub-orbital flight mission from/to the considered airbases is feasible, as long as the global inherent relibility is 1E-6 or better

Way-ahead

- This study should be improved by:
  - Obtaining information about the specific FMECA
  - Using more accurate catastrophic events and impact models
  - Performing other risk analyses, e.g. on «on-air third parties» (mid-air collision)
  - Additional analyses about other relavant aspects are to be included: infrastructures, logistics, facilities, etc.

Questions

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Back-up slides

Description of the object 1/5
White Knight Two

Aircraft specifications [edit]

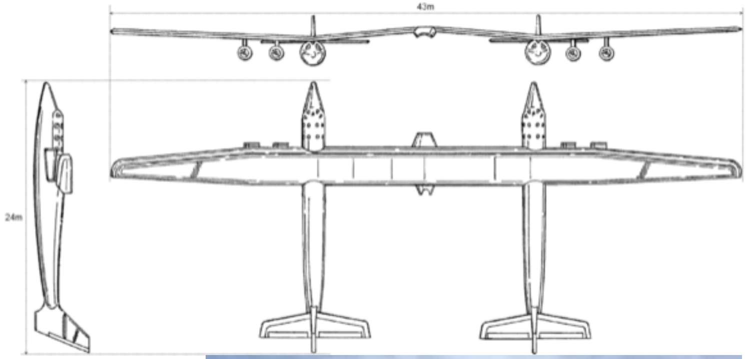
Data from Virgin Galactic Presentation 2007[22]

General characteristics

- **Crew:** 2 (flight crew) + spaceship launch crew
- **Capacity:** payload 17,000 kg (37,000 lb)[23] to 50,000 ft (15,000 m).; 200 kg satellite to LEO when carrying a LauncherOne orbital launch vehicle.[24]
- **Length:** 78 ft 9 in (24 m)
- **Wingspan:** 141 ft 1 in (43 m)
- **Powerplant:** 4 × Pratt & Whitney Canada PW308 turbofan engines, 6,900 lbf (30.69 kN) thrust each

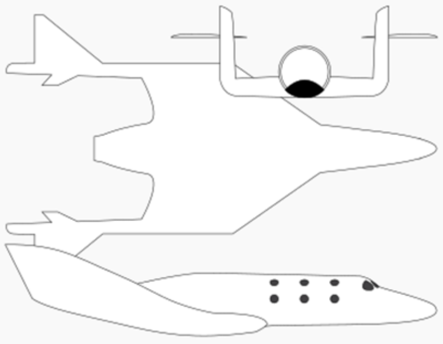
Performance

- **Service ceiling:** 70,000 ft (21,000 m) [23]



Description of the object 2/5
Space Ship Two

Dimensioni e pesi



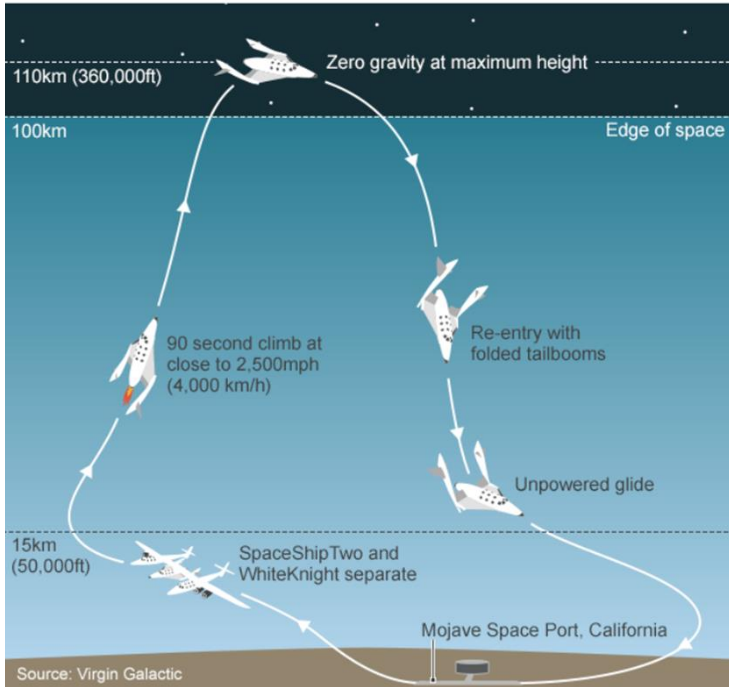
Tavole prospettiche

Lunghezza	18,29 m (60 ft)
Apertura alare	8,23 m (27 ft)
Diametro fusoliera	2,28 m (90 in)
Altezza	4,57 m (15 ft)
Passeggeri	6
Propulsione	
Motore	un motore a razzo ibrido RocketMotorTwo

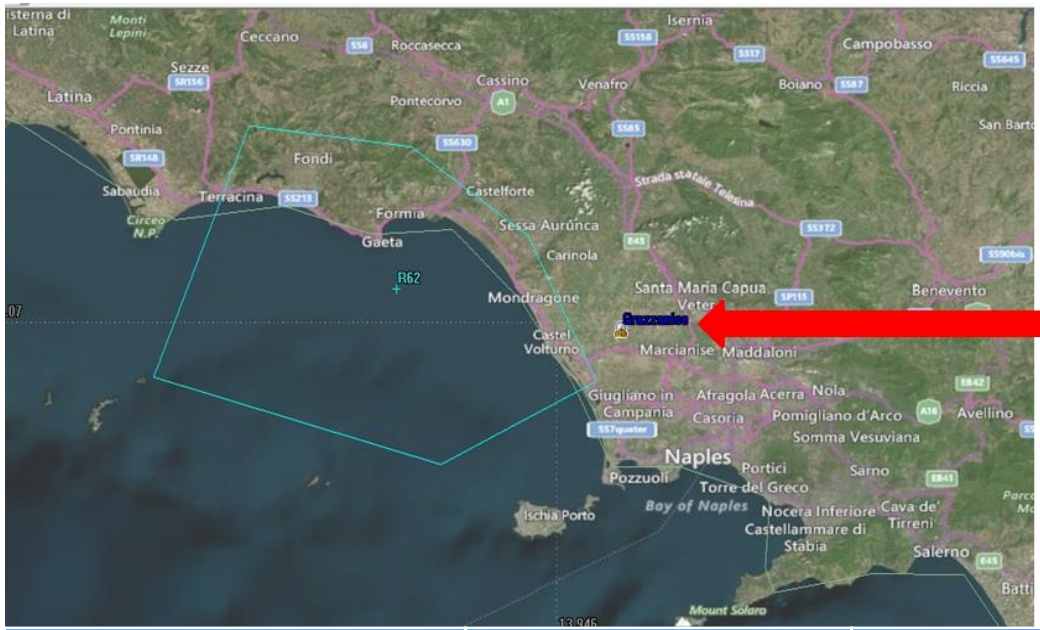
Description of the object 3/5
Space Ship Two

Flight Phases Description

- Take-off
- Transfer/Climb
- Release
- Boosted Ascent
- Coast
- Re-entry
- Pull-up
- Glide
- Landing

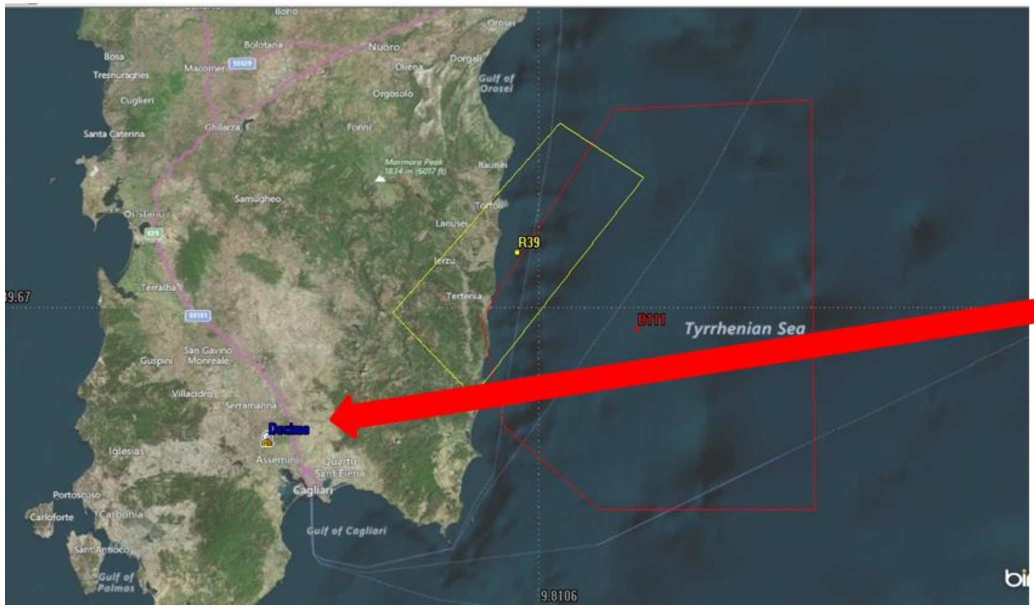


Description of the object 4/5
Grazzanise AFB



Airport	Rwy Lenght (m)	Rwy Width (m)	Rwy Altitude (m msl)
Grazzanise (CE)	2991	30	30

Description of the object 4/5
Decimomannu AFB



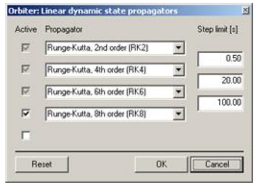
Airport	Rwy Lenght (m)	Rwy Width (m)	Rwy Altitude (m msl)
Decimomannu (CA)	3000	30	100

Methodology

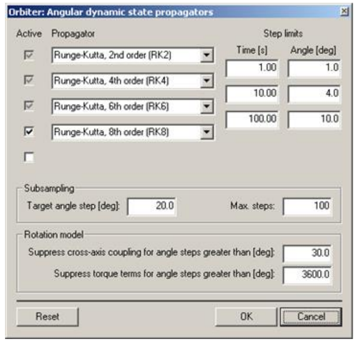
Gravity Model
Nonspherical gravitational field perturbations

Atmospheric Model
Jacchia model and NRLMSISE-00

Linear Propagation Model
Runge-Kutta and 8° order Simplectics integrators



Momentum Propagation Model
Euler method integration (by means of RK)

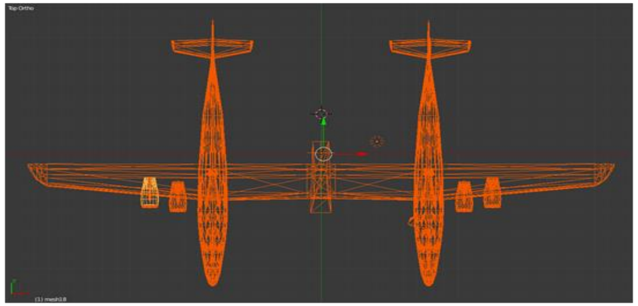


Perturbation Model
Nonspherical gravity sources
Solar radiation pressure
Gravity-gradient torque

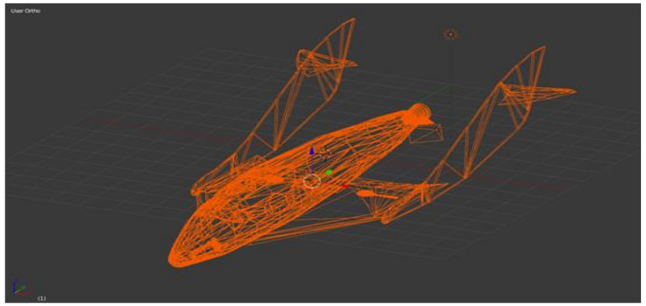
Methodology

Flight System Model

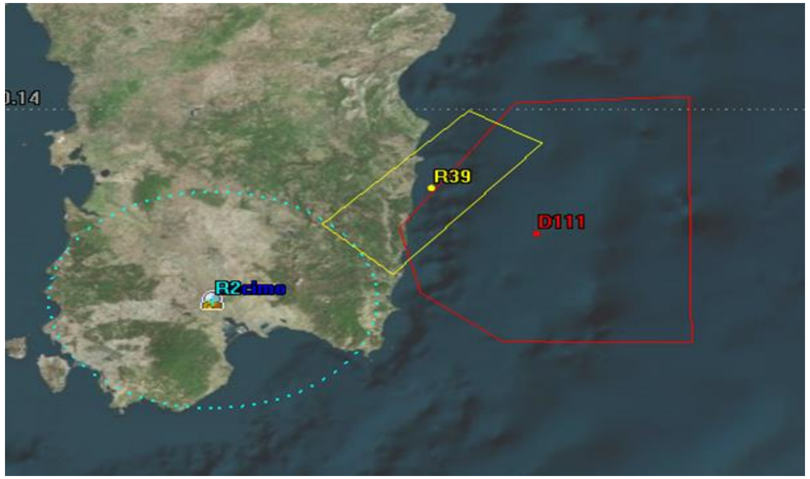
MESHNAME=white_knight2
EMPTY_MASS=8799 Kg
FUEL_MASS=9797 Kg
MAIN_THRUST=122771 KN
ISP=50000 m/sec (SPECIFIC IMPULSE)



MESHNAME=Space_ship_two
EMPTY_MASS=6273 Kg;6123 + 150 Kg for 2 people
FUEL_MASS=7030 Kg
MAIN_THRUST=270000 KN
ATTITUDE_THRUST=1400 KN
ISP=2650 m/sec (SPECIFIC IMPULSE)



Methodology



Methodology

Boundary conditions

Phase/Manouver	Condition
SS2 Release/Separation	15 km altitude
Boost	60 sec burn time 50 km burn-out altitude
Ascent	88° pitch attitude fino all'apogeo
Feathering (tail stowing)	90Km altitudine
Feathering (tail deployment)	24 Km altitude
Pull-out	40km - 28km altitude range

Results

- Case Study 1: Decimomannu

Definition of the flight parameters:

Airspeed:
WP0-WP1 → 150 KTAS
WP1-WP2-WP3 / WP7-WP8-WP9-WP10-WP11 → 250-350 KTAS
WP3-WP4 → 250-300 KTAS
WP5-WP6-WP7 → 500 – 2.200 KTAS
WP11-WP0 → 200 KTAS

Altitude:
WP1-WP2-WP3 → 10.000 ft
WP8-WP9-WP10-WP11 → 6.000 ft - 45.000 ft
WP4 → 45.000 ft
WP6 → 125.000 ft
Apogee → 330.000 ft
WP7 → 57.000 ft

Results

- Case Study 1: Decimomannu

Definition of the flight parameters:

Impact angles (loss):
WK2+SS2 → 5 deg – 15 deg
SS2 → 15 deg – 30 deg / 80 deg – 90 deg (only ballistic)

For other parameters, mean values from flight simulations were considered

Results

- Case Study 2: Grazzanise

Definition of the flight parameters :

Airspeed :
WP1-WP2 → 150 KTAS
WP2-WP3-WP5 / WP10-WP11-WP12-WP13 → 250-350 KTAS
WP5-WP6 → 250-300 KTAS
WP7-WP8-WP9 → 500 – 2.200 KTAS
WP13-WP1 → 200 KTAS

Altitude:
WP2-WP3-WP5 → 10.000 ft
WP10-WP11-WP12-WP13 → 6.000 ft - 45.000 ft
WP6 → 45.000 ft
WP8 → 125.000 ft
Apogee → 330.000 ft
WP9 → 57.000 ft

Results

- Case Study 2: Grazzanise

Definition of the flight parameters:

Impact angles (loss):
WK2+SS2 → 5 deg – 15 deg
SS2 → 15 deg – 30 deg / 80 deg – 90 deg (only ballistic)

For other parameters, mean values from flight simulations were considered