Streamlining TGRS/IIP Modeling for Launch Range Safety using AGI Components

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Approved for Public Release
08-MDA-3854 (03 OCT 08)

Background

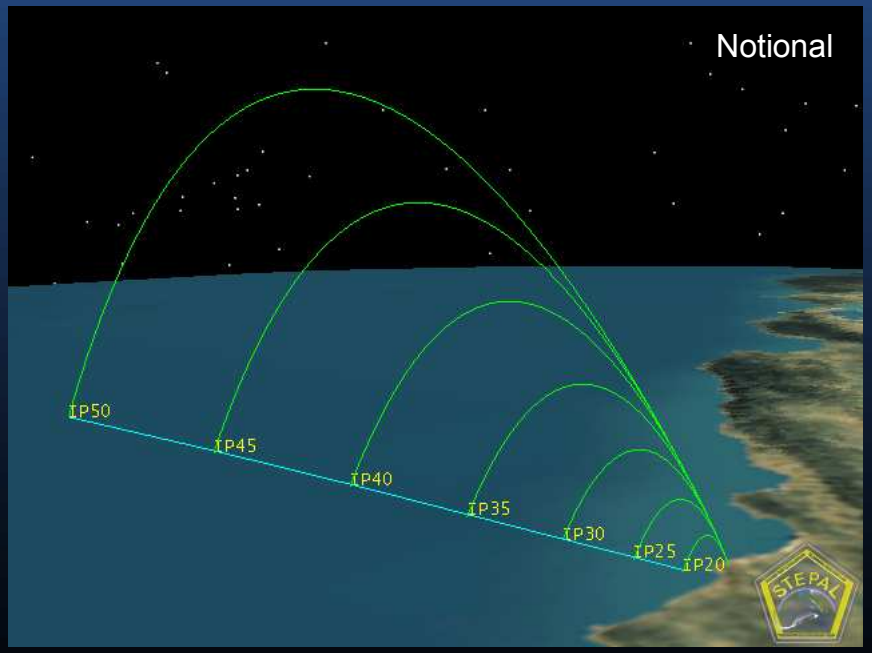
Tasking:

Predict Translated GPS Range System (TGRS) performance

Provide Instantaneous Impact Point (IIP) error analysis

Support Range Safety in the launch Go/No-Go decision process.

Expansion of original PDOP-based Go/No-Go decisions.

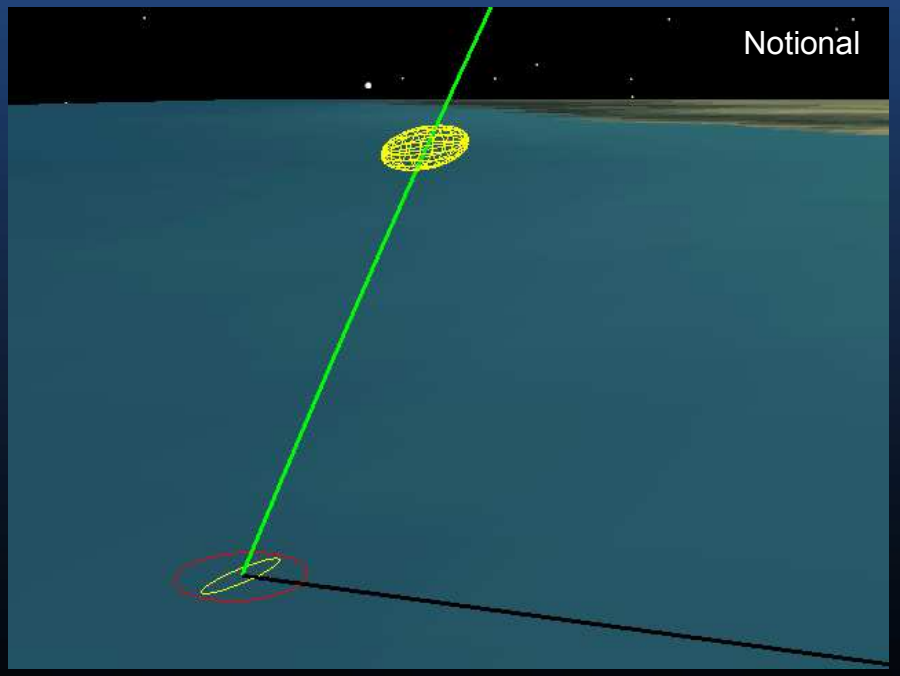


Requirements

Model GPS constellation and missile receiver and antenna characteristics

Simulate launches at one-minute intervals throughout 7-hour launch window

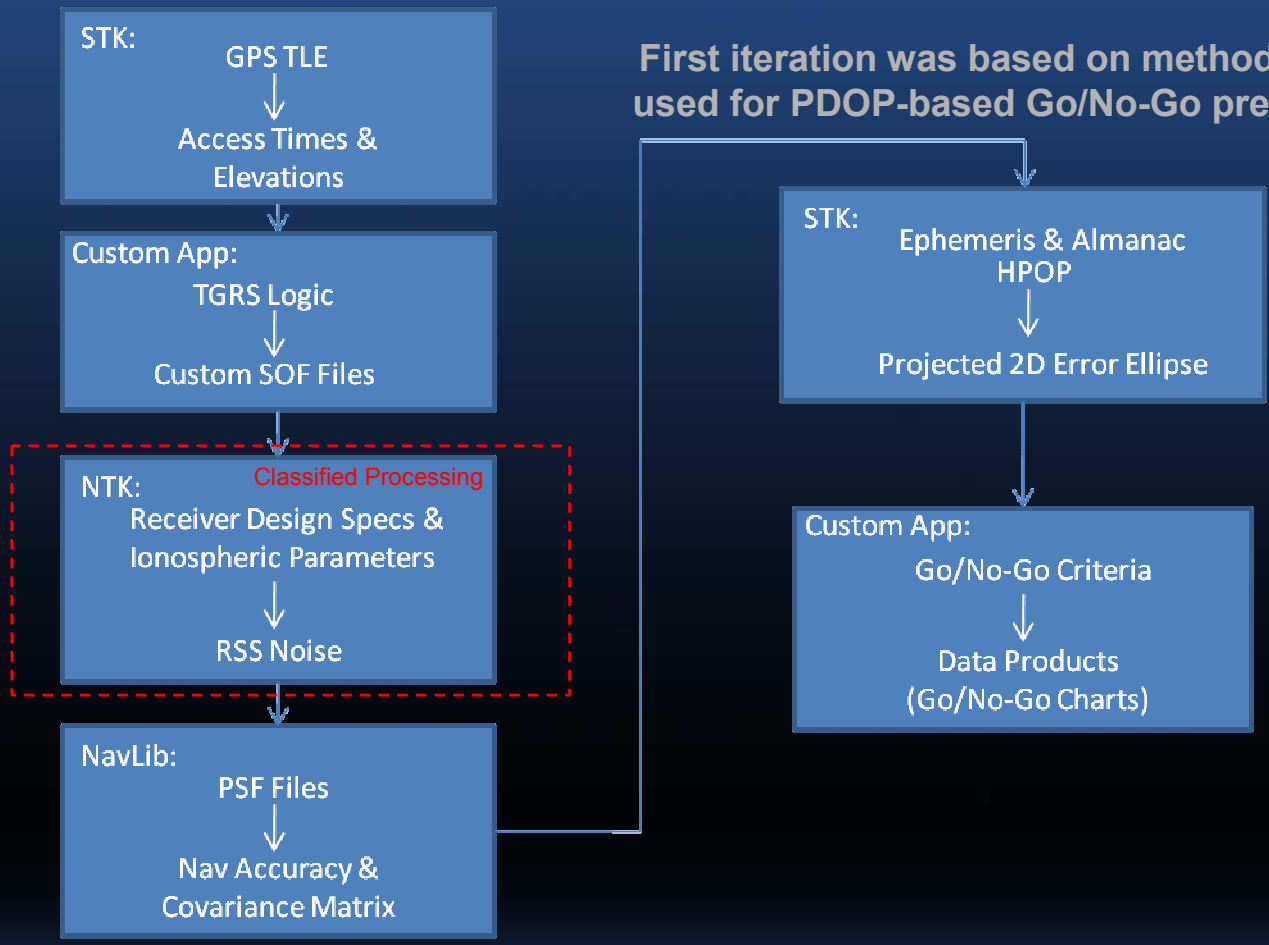
- Simulate boosted flight from launch through T+50 seconds at one-second intervals
- Predict TGRS performance determining system errors and error covariance matrices
- Propagate IIP error ellipse and determine projection at impact
- Compare projection at impact to Range Safety requirements
- Conduct analyses simulating satellite outages
- Analyze primary launch day and four backup days



Challenges

- Analyze over 3 million unique date time-satellite-configuration cases
- Tag, manage, interpret, and condense large volumes of data
- Provide useable products to launch team for Go/No-Go decisions
- Provide capability to produce time-sensitive analyses in the event of GPS constellation/system changes

Go/No-Go Process
First Iteration



Revamping the Process

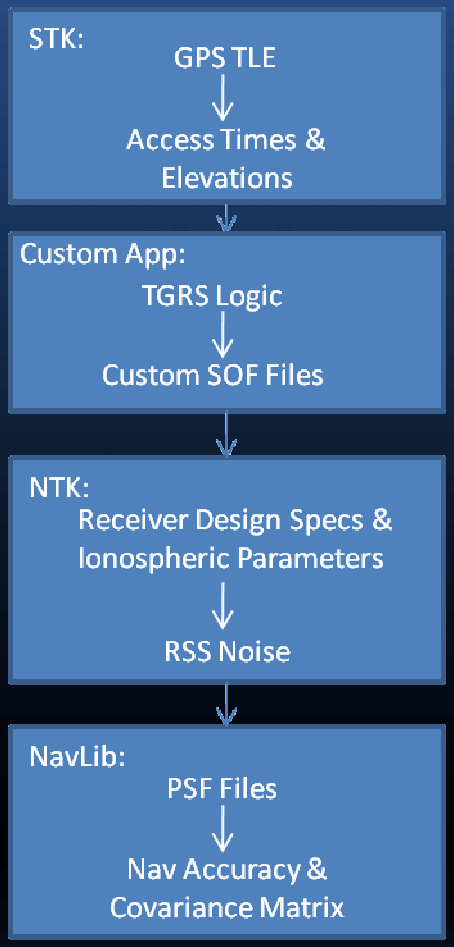
Drawbacks of first iteration

- **Cumbersome – requires generation/transfer of large numbers of intermediate files across multiple systems**
- **Slow – requires multiple computer run days to complete for single launch day (~ 7 hour window)**

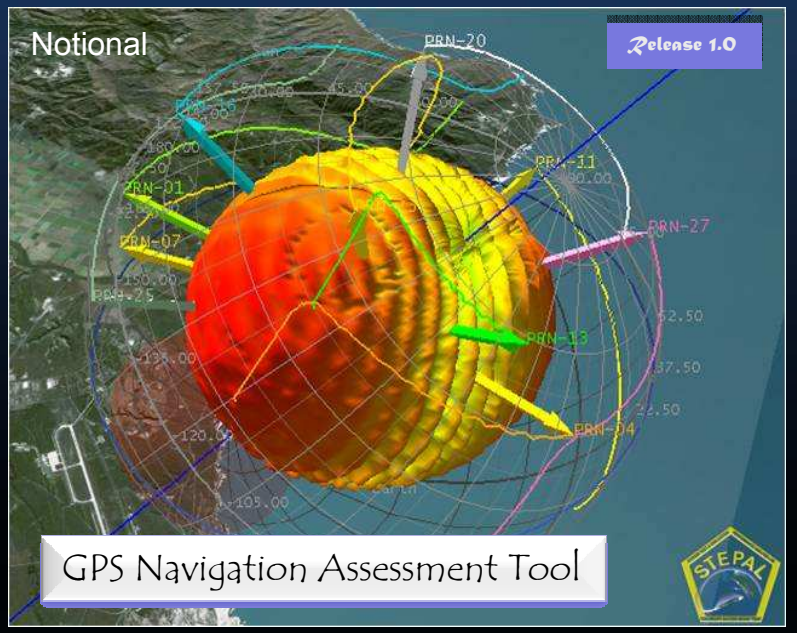
Opportunities provided by improvements to AGI Components

- **Four operations combined into one unified program requiring data from only a small number of NTK runs**
- **Fast – starting with r3 release of the AGI Components, computation speeds improved by a factor of 10 or more**

Go/No-Go Process Second Iteration

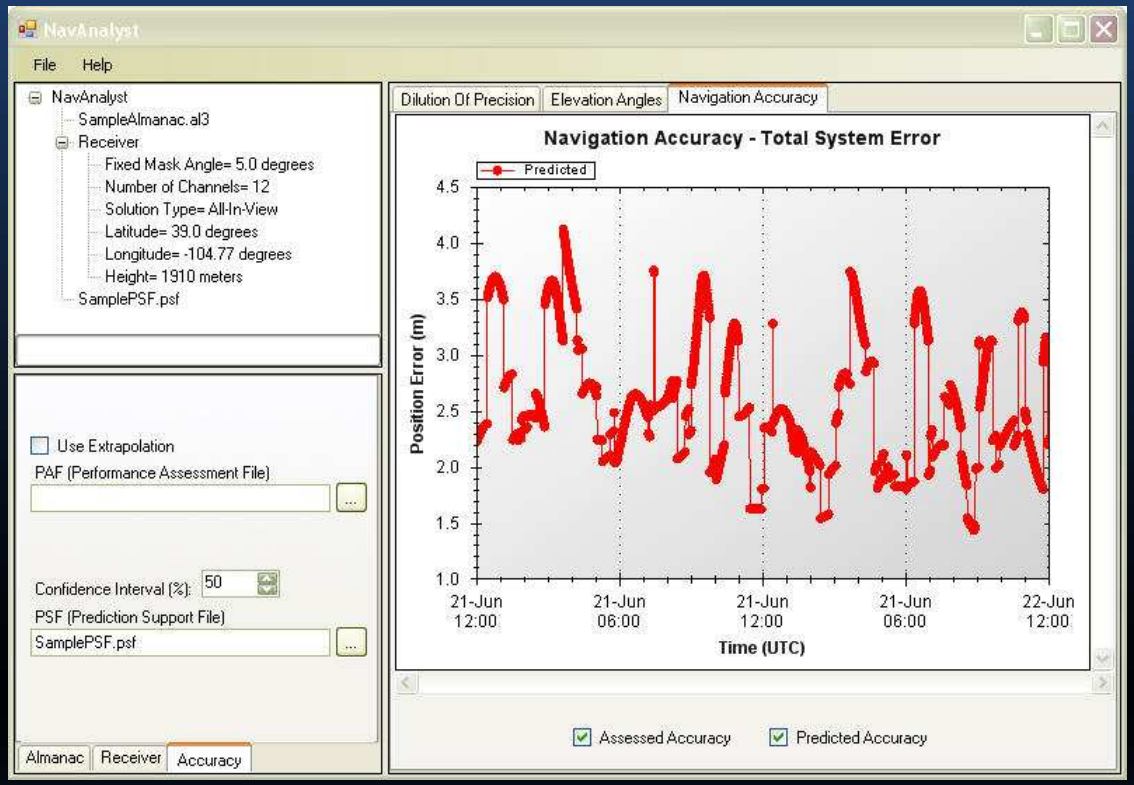


First four processes replaced by custom AGI Components application requiring only one NTK run per launch day



Design

Based on example code, NavAnalyst, included with AGI Components



Notional

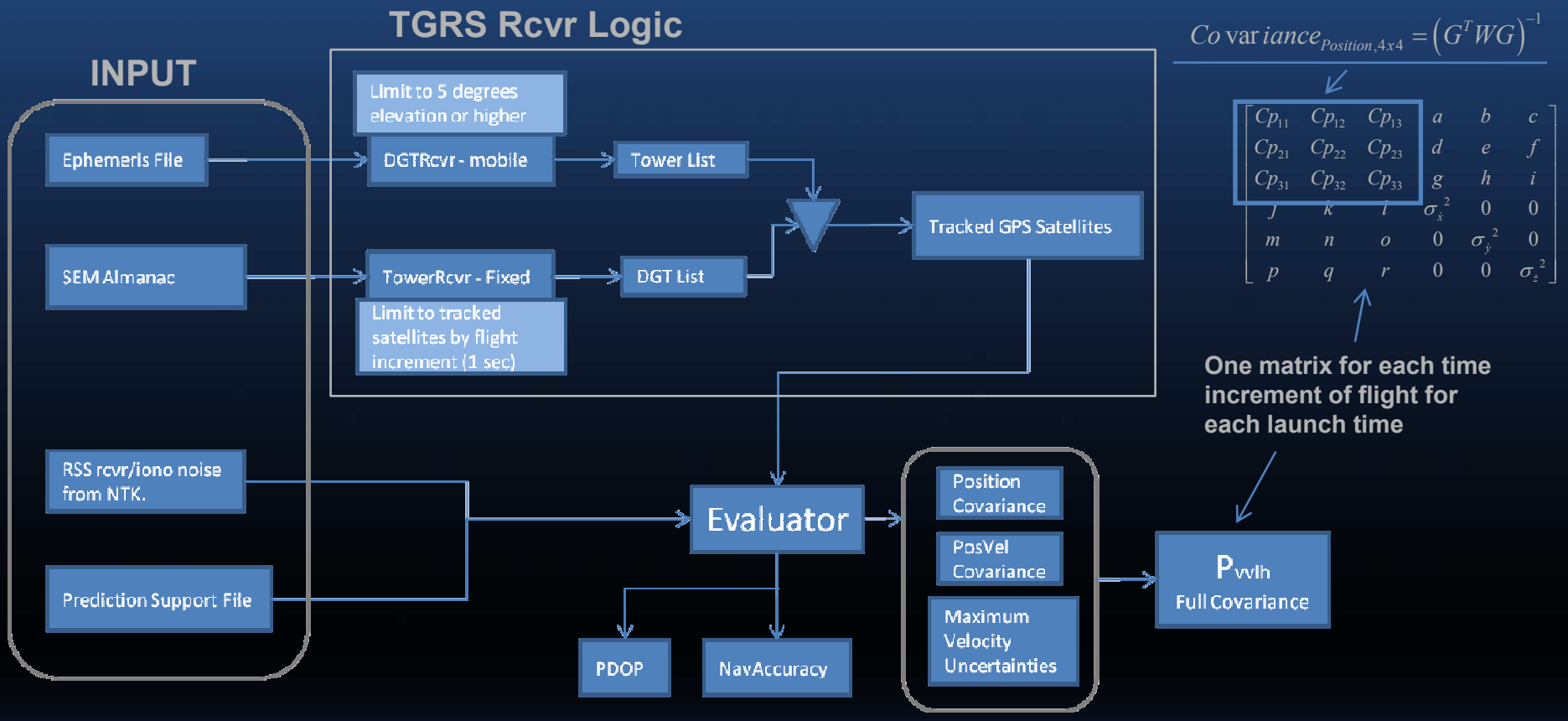
- NavAnalyst provides for a single fixed receiver and antenna platform
  - DOP
  - Elevation Angles
  - Assessed and Predicted Accuracy

Design

STEPAL expanded and reorganized to NavAnalyst include

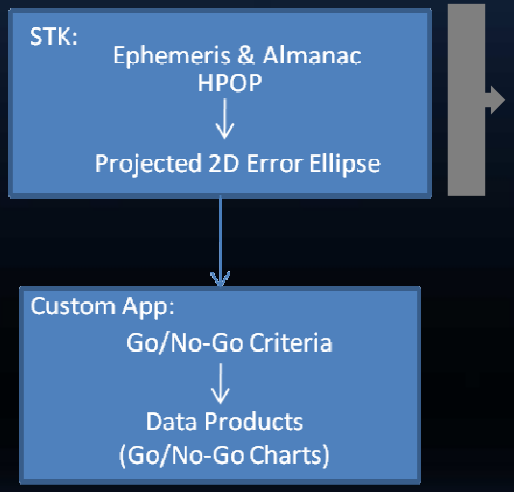
- Multiple receivers/platforms emulating TGRS operation
- Utilize input from limited number of NTK runs to generate data for a large number of launch times/days
- Utilize input from limited number of NTK runs to model dynamic receiver access during missile flight
- Output required data (PDOP, Covariance matrices, Predicted accuracy) in text format for further processing

Design


TGRS Rcvr Logic
INPUT
Ephemeris File
SEM Almanac
RSS rcvr/iono noise from NTK.
Prediction Support File
Limit to 5 degrees elevation or higher
DGTRcvr - mobile
Tower List
TowerRcvr - Fixed
DGT List
Limit to tracked satellites by flight increment (1 sec)
Tracked GPS Satellites
Evaluator
PDOP
NavAccuracy
Position Covariance
PosVel Covariance
Maximum Velocity Uncertainties
Pvvlh
Full Covariance
$Covariance_{Position,4x4} = (G^T W G)^{-1}$
$\begin{bmatrix} Cp_{11} & Cp_{12} & Cp_{13} & a & b & c \\ Cp_{21} & Cp_{22} & Cp_{23} & d & e & f \\ Cp_{31} & Cp_{32} & Cp_{33} & g & h & i \\ j & k & l & \sigma_{\dot{x}}^2 & 0 & 0 \\ m & n & o & 0 & \sigma_{\dot{y}}^2 & 0 \\ p & q & r & 0 & 0 & \sigma_{\dot{z}}^2 \end{bmatrix}$
One matrix for each time increment of flight for each launch time

Design

Replace need for multiple STK runs by using state transition matrices and improved covariance formulation



Impact Uncertainty Ellipse → Scaled semi-major axis length compared to range safety specs

$$P_{Topo}\left(t_{impact}\right) = K\left(t, t_{impact}\right) P_{VVLH}\left(t\right) K^{T}\left(t, t_{impact}\right)$$

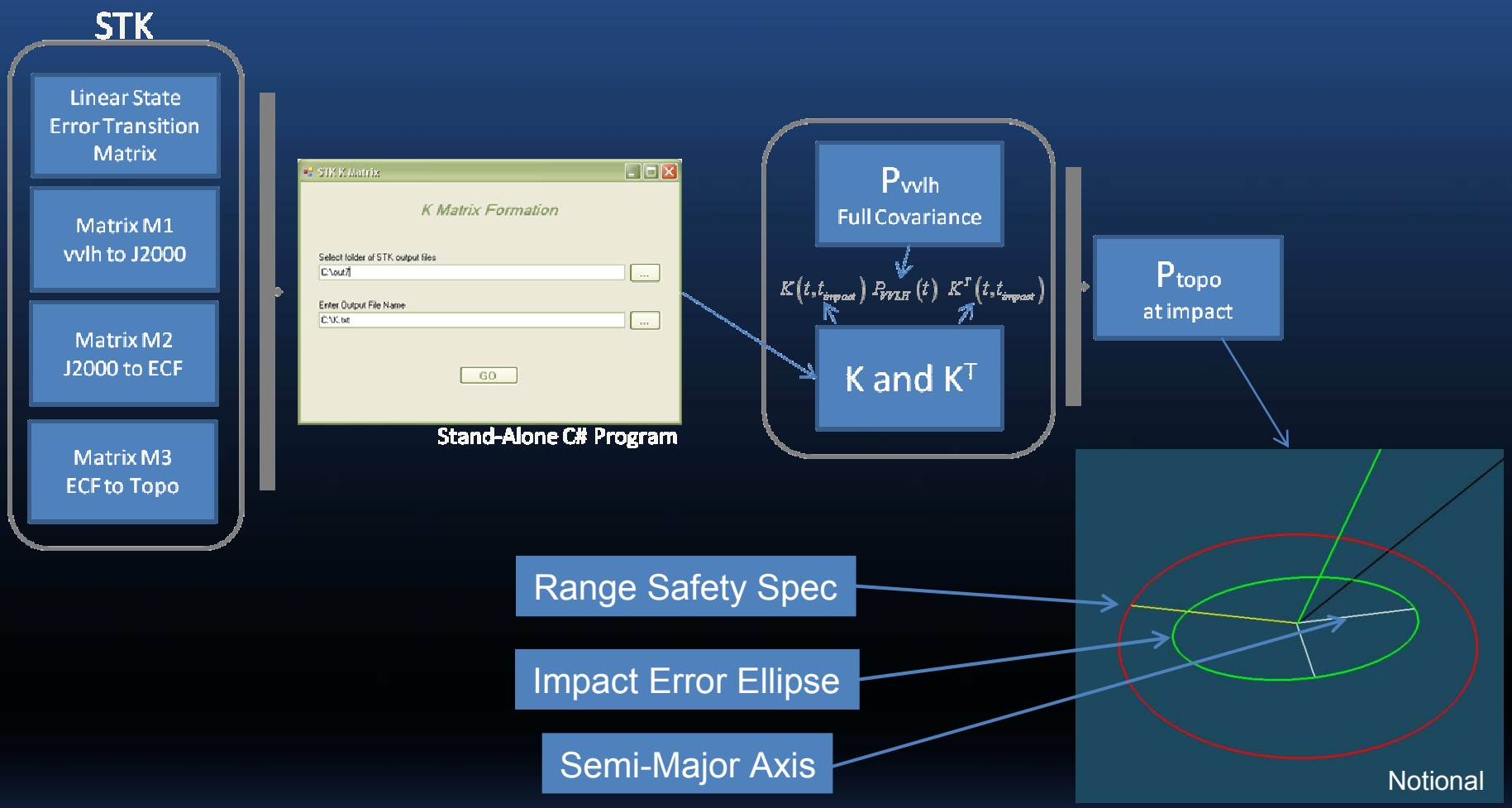
where

$$K\left(t, t_{impact}\right) = M_{ECF->Topo}\, M_{EME2000->ECF}\left(t_{impact}\right) \Phi_{\left(t, t_{impact}\right)}\, M_{VVLH->EME2000}\left(t\right)$$

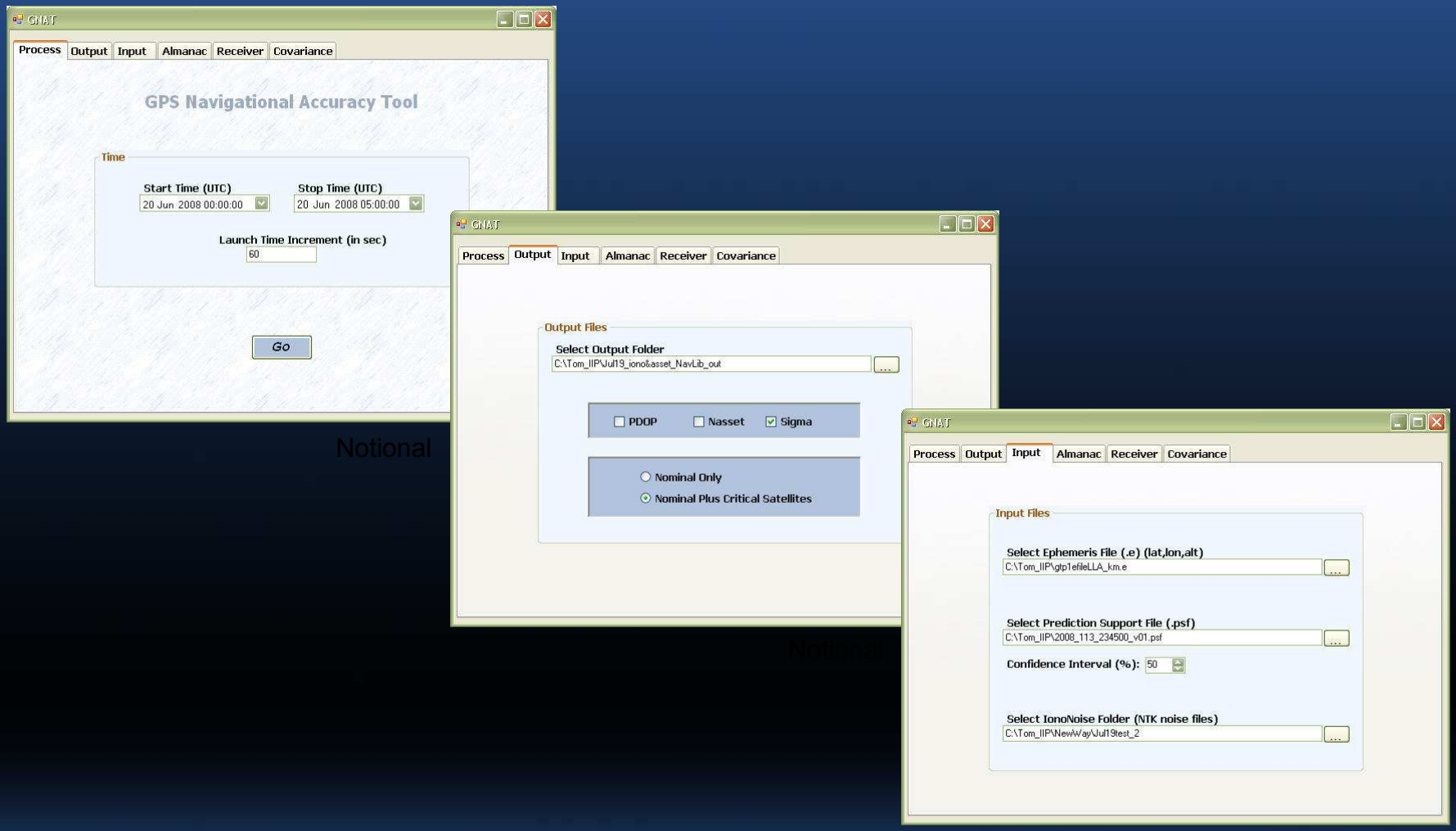
One matrix for each time increment of flight

Linear State Error Transition Matrix
Eliminates need for repetitive STK runs

Design


STK
Linear State Error Transition Matrix
Matrix M1 vvlh to J2000
Matrix M2 J2000 to ECF
Matrix M3 ECF to Topo
STK K Matrix
K Matrix Formation
Select folder of STK output files
C:\out7\
Enter Output File Name
C:\K.txt
GO
Stand-Alone C# Program
Pvvlh
Full Covariance
$K(t,t_{impact})\ P_{VVLH}(t)\ K^T(t,t_{impact})$
K and K^T
Ptopo
at impact
Range Safety Spec
Impact Error Ellipse
Semi-Major Axis
Notional

GNAT Interface



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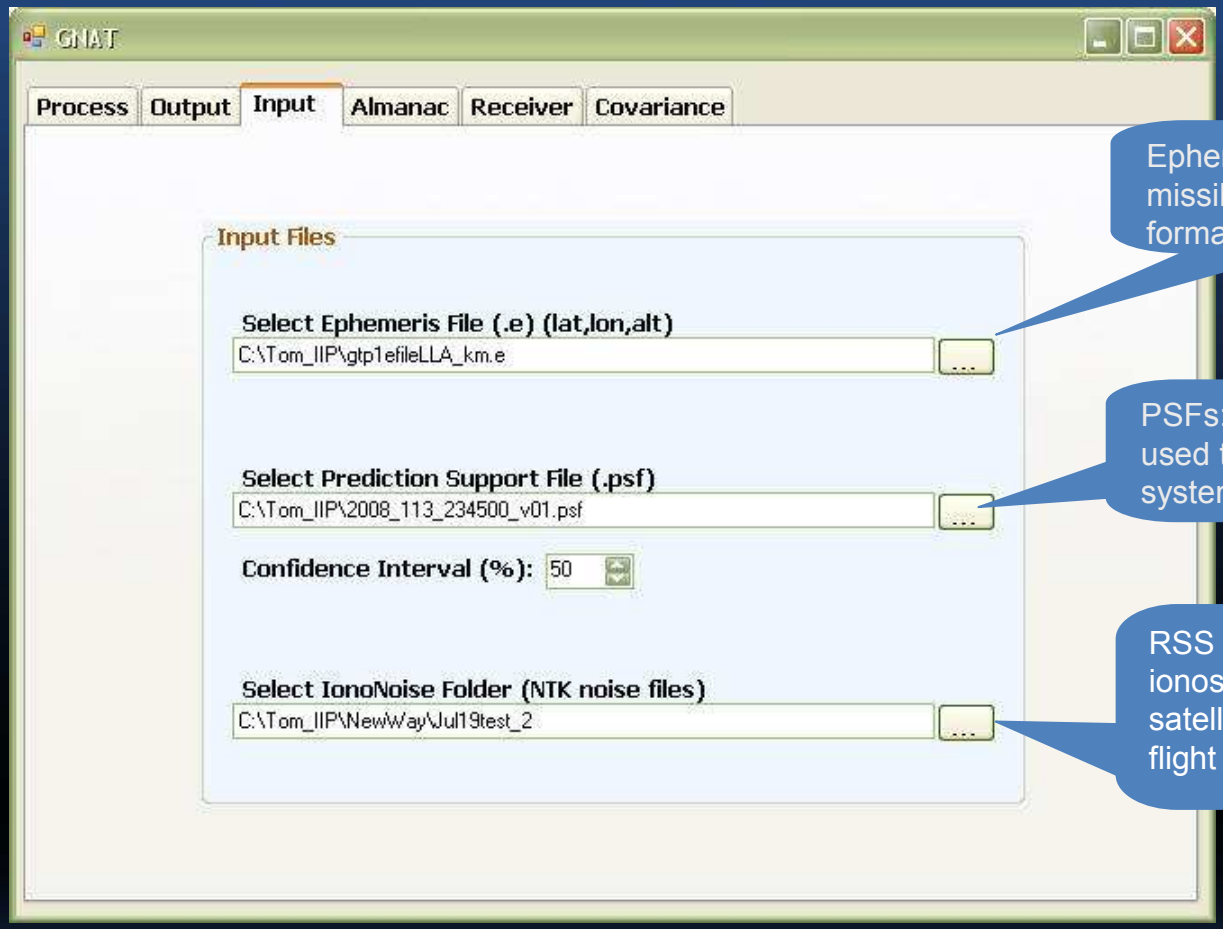


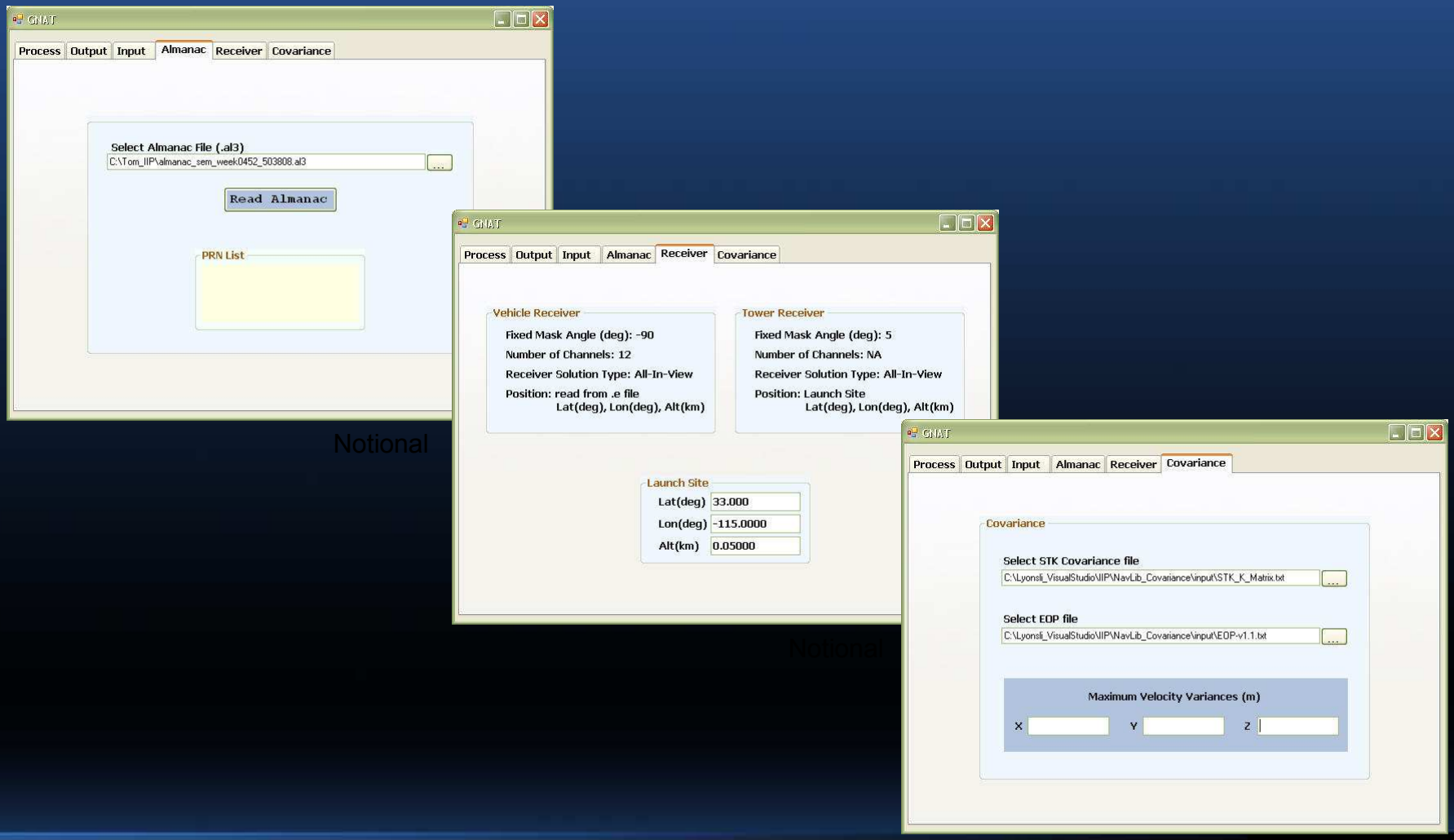
Ephemeris file for the missile in lat,lon,alt format

PSFs: provide data used to predict GPS system errors

RSS of rcvr noise & ionospheric noise by satellite by second of flight time

Notional

GNAT Interface



Notional

Notional

Final Processing and Products

Notional

Custom App:
Go/No-Go Criteria
↓
Data Products
(Go/No-Go Charts)

Each set of data includes –

Colored tables depicting Go/No-Go times

Tabular listing of times when IIP uncertainty > range specification for =>3 seconds

Launch day XX

Launch day 3

Launch day 2

Launch day 1

Go/No-Go Tables

16:xx	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19
	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
17:xx	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19
	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
18:xx	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19
	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59

Notional

Summary

AGI Components allowed for direct execution of specific subsets of STK and NTK functionality. This provided improved code generation and software control as well as an increase in processing speed.

Product delivery times have been reduced from weeks to days allowing for rapid response in the event of unforeseen changes in GPS constellation or performance.

AGI Assistance

STEPAL gratefully acknowledges continued assistance by AGI personnel, without which this task would have been impossible.

Ted Driver

Jim Woodburn

Sal Alfano

Frank Snyder